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José Alberto Benítez-Andrades · Paula García-Llamas · Ángela Taboada · Laura Estévez-Mauriz · Roberto Baelo *Editors*

# Global Challenges for a Sustainable Society

## EURECA-PRO The European University for Responsible Consumption and Production

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# Preface

The Second EURECA-PRO Conference on Responsible Consumption and Production provides an interdisciplinary forum for practitioners, academics, and scientific experts on the most recent advances to achieve UN Sustainable Development Goal 12 (SDG12), embracing the challenges posed by the European Green Deal. As such, the conference aims to represent a unique place to share experiences, scientific results, and visions for making the EU's economy sustainable by covering all sectors, especially transport, energy, agriculture, buildings, and industries. The conference also aims to constitute a benchmark for leading researchers in the SDG12 field to discuss current and future challenges, opportunities, and innovative solutions considering the technological, humanistic, economic, social, and environmental dimensions of responsible consumption and production.

Alliance consists of nine higher education institutions: Montanuniversität Leoben (Austria), Technische Universität Bergakademie Freiberg (Germany), Technical University of Crete (Greece), Universidad de León (Spain), Silesian University of Technology (Poland), University of Petrosani (Romania), University of Applied Sciences Mittweida (Germany), Hasselt University (Belgium), and University of Lorraine (France). EURECA-PRO integrates their joined forces to become the global educational core hub and interdisciplinary research and innovation leader in environmental and social framework development under the umbrella of SDG12, effectively contributing to the European Higher Education Transformation Agenda. Through the implementation of five Research Lighthouse Missions (LH) (LH1: 'Responsible Material Flows', LH2: 'Environment and Water', LH3: 'Sustainable Materials and Products', LH4: 'Clean Energy', and LH5: 'Process Automation and Industry 4.0'), EURECA-PRO is creating a research environment focused on actively developing solutions to SDG12 current global challenges.

In this book, readers will find excellence-based communications dealing with the following five topics: (i) Smart and Healthy Societies (LH2 and LH5), (ii) Recycling, Reuse, and Longer Lasting Products (LH1 and LH3), (iii) Clean Air, Freshwater, Healthy Soil, and Biodiversity (LH2), (iv) Cleaner Energy and Cutting-Edge Clean Technological Innovation (LH4) and (v) Industry 4.0. (LH5).

Thanks to the participants and the organising team for giving us this opportunity. The rest of us have no choice but to take advantage of it. On behalf of the organising committee, we hope you enjoy reading the content of the papers included in this book.

León, Spain

José Alberto Benítez-Andrades
Paula García-Llamas
Ángela Taboada
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Roberto Baelo

# Contents

# Plenary Sessions

# Plenary: Anti-Ephemeral Design for Responsible Production and Consumption of Mobility

Artur Grisanti Mausbach[1](✉), Cyriel Diels[1], Dale Harrow[1], and Maria Cecilia Loschiavo dos Santos[2]

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**Abstract.** This paper introduces the concept of Anti-Ephemeral Design through a discussion about automotive design responsibility on collaborating to the generation of consumption habits which have great impact on the environment. The paper examines the relationship between consumerism and the mythical images of the automobile. Findings from the Joyful Journeys (Mausbach in Fourteenth International Conference on Ecological Vehicles and Renewable Energies (EVER). pp. 1–9, 2019 [1]) and Ecofitting (Mausbachet al. in 2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER), pp. 1–9, 2020 [2]) projects are used to point out the need to look at tangible and intangible aspects of design to address both environmental, economic, socio-ethic and subjective aspects of sustainability. The paper proposes an alignment with new values, to design, produce and consume mobility sustainably.

**Keywords:** Automotive design · Sustainability · Consumption · Circular economy

## 1 Introduction

Anti-Ephemeral Design investigates alternative mobility processes and products aiming to support the transition to sustainability. While exploring the development of limited resources circular economy, looking at alternatives to expand the lifecycle of products, and examining designers and users' needs and aspirations, the project focuses on solutions which are at the same time responsible, joyful and meaningful at personal and social levels. This paper introduces the discussion about the relationship between the mythical image of the car and consumerism, presents alternatives to consumption and production though the Joyful Journeys [1] and Ecofitting [2] projects developed at the Intelligent Mobility Design Centre of the Royal College of Art, and questions in why, how and what form we can consume mobility responsibly.


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## 2 Car Design and Consumerism

According to Yuval Noah Harari [3], the twentieth century presented a battle between fascism, communism, and liberalism, ultimately won by the latter, but as "history took an unexpected turn", a crisis also hit the liberalism. While the economic crises of 2008, is cited as one of the reasons for the degeneration of liberalism, the climate crises and the sanitary crises highlighted that the aims and achievements of society were vain, and its values need to be reviewed. According to Umberto Eco [4] a crisis has extended to the concept of community, giving rise to "unbridled individualism", and "led to the collapse of ideologies"; then, without sharing values or being part of something, individuals are pushed to follow consumerism. One which Stuart Walker [5] signals as the kind of consumerism that turns everything obsolete, creating more frustration than satisfaction, and cultivating a society of selfishness, envy, and greed. According to Robert Crocker, "consumers are now 'trained' by advertising, marketing, and peer example, to adopt a linear perspective of the products they buy, as short-lived, packaged products and only of real value when they are brand new, or nearly so, a perspective that is neither natural or unchangeable, but one that can be altered" [6].

The design developed as part of the twentieth century economic systems is a reflection of their values and production systems. In the automotive industry, the pursuit for higher qualities of the products has been aligned to the mindset of societies which were less attentive to the consequences of their actions to others and the environment, according to Jackson [7], a "age of irresponsibility". Car design has served a system of consumption which depends on constant growth, massive amounts of resources for production and use, and responding to fashion cycles which ironically has rendered the contemporary car mostly irrelevant in meaning and emotional value. The ephemerality of car design raises questions about the designers' responsibility, which has been discussed by Papanek [8], Bonsiepe [9], Manzini [10] and others, but has not yet reached car design to support a cultural shift.

Cars have never been merely a tool. From its inception, it was both a utilitarian and a symbolic object, which quickly evolved its own imaginary context, represented by the myths of Speed, Freedom and Comfort [11]. The twentieth century Car design focused on attracting the consumer, expressing personality, and innovation. According to Gui Bonsiepe [9] "design has increasingly moved away from the idea of intelligent problem solving, and has approached ephemeral, fashionable, fast obsolete, formal-aesthetic game, glamouring the world of objects".

In the beginning of the twenty-first century the car is facing a moment of radical change. Electrification of powertrain, shared use, and autonomy are challenging the paradigms of the automotive industry and stimulating the replacement of the current fleet by new vehicles. While this might create a demand for new cars, it does not consider if people are prepared to replace their vehicles, financially or emotionally. How to deal with the current world fleet of 1.4 billion [12] cars has not been addressed by automotive design, which is focusing on creating the novelty. Ephemerality of products need to be discussed in relation to the possible design strategies. Both the embodied carbon and their meaning, cultural and personal sensitivities are significant parts of a product. Proposals of circular economy must start from existent objects, and its already embodied carbon footprint. Moreover, the transition also interferes with the way people consume, use, and experience cars, and more widely, mobility.

Indeed, deeper transformations are needed to deal with the environmental, societal and climate crisis that humanity is facing now. Particularly, to improve the model of interaction between the industry and the natural environment in the direction of sustainability, our social, ethical, aesthetic, and economic paradigms need to shift, and both our subjective and objective experiences need to be addressed. Stuart Walker [5] proposes to extend the foundation of sustainability to a Quadruple Bottom Line, pointing out that creative design endeavors should be informed by their Practical Meaning, Social Meaning, Personal Meaning and Economic Means. Therefore, when looking at the transition of the automobile and its consumption, we should also investigate the subjective aspects of design. To be able to transform we need also to evolve our viewpoints and be open to change our assumptions in many areas. The following sections projects from the Royal College of Art present projects which explore the cultural shift necessary to achieve more responsible production and consumption of mobility.

## 3 Sharing Joyful Journeys

The Joyful Journeys project was developed at the Royal Centre with the Loughborough School of Design, to investigate how meaningful mobility experiences are created. The project used design research methods such as journey shadowing and interviews to identify experiences and values inside the current context of mobility. One of the journey shadowing subjects stared an older woman who gives people lifts in a rural location in the UK. The recording was transformed in a short movie, including additional animations, showed in the 2018 London Design Festival, and is available on YouTube [13] (see Fig. 1).

In the piece, it is noticeable that the experience of a journeys has values beyond the functional aspect of mobility. The lady points out her love for driving, also as something that she can still do, and that she likes to give lifts to people as a community bound. Moreover, the Joyful Journey was created to provoke a debate about the main market target of current MaaS (Mobility as a Service) on young city dwellers, and to remember that it is possible to share mobility outside of a monetized structure. The idea of sharing can immediately reduce the impact of a particular commute while including more people in an existing vehicle journey. Reducing the ecological footprint of mobility should not depend solely on the implementation of new technologies or services. There are four levels of designers' intervention to transition to sustainability, according to Vezzoli and Manzini [14]. The fourth level is the proposal of new scenarios corresponding to more sustainable ways of living: developing at a cultural level; promoting new standards of quality; changing the structure in response to demand.

## 4 Ecofitting Circular Economy

The Third level of intervention according to Vezzoli and Manzini [14] is the creation of a new and sustainable mix of products and services: offering a different and more sustainable way to achieve the benefits a product can give, through a new mix of products and


**Fig. 1** Still from the Joyful Journeys video (REF)

services—must be committed to cultural change and new consumer behaviour. Circular economy proposals can be included in this group. For the success of circular economy, an important is the integration of the consumer, or user, in the system, expanding the activity as an integral part of community and creating cultural change. Therefore, design it is at the core of circular economy.

The Ecofitting project was developed at the Royal College of Art Intelligent Mobility Design Centre with the support of CENTS (Circular Economy Network + In Transportation Systems) from February 2020 to January 2021 [15]. Ecofitting is a sustainable solution for the large UK fleet of internal combustion engine cars that is rendered non-compliant with initiatives like the Ultra-Low Emission Zones. Focused on sustainability and conceived as circular economy strategy (see Fig. 2), Ecofitting goes beyond just electrification, opening an opportunity for new approaches to automotive design, and to cater for generational shifts in desirability. The project proposes the retrofitting to electric of cars mainly from 1980 to 2000s, which also incorporate alternative aesthetics and materials.

The project findings indicate that there are promising opportunities for developing automotive design differently. Car design has developed an aesthetic of perfection, which is represented by the sleekness of surfaces, thinness of the joint between panels of metal or plastic, the shininess of the chromes, sharpness of edges, or even the noise of closing doors which is not aligned with the taste of new generations and is too costly to maintain and unsustainable [15]. It also points out that Ecofitting is an effective sustainable solution which respects emotional and cultural values of cars, promotes long-term ownership, and can change how cars will be designed in the future.

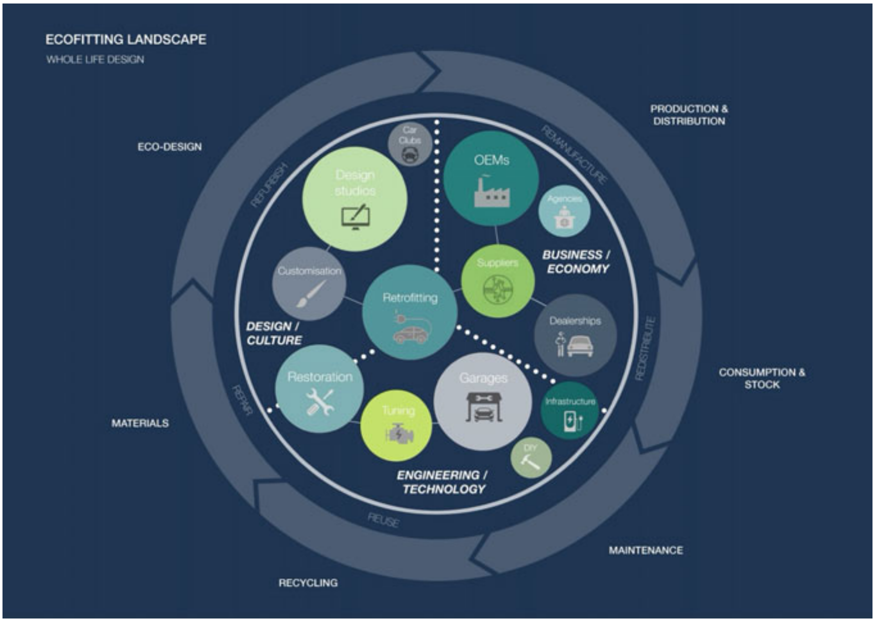


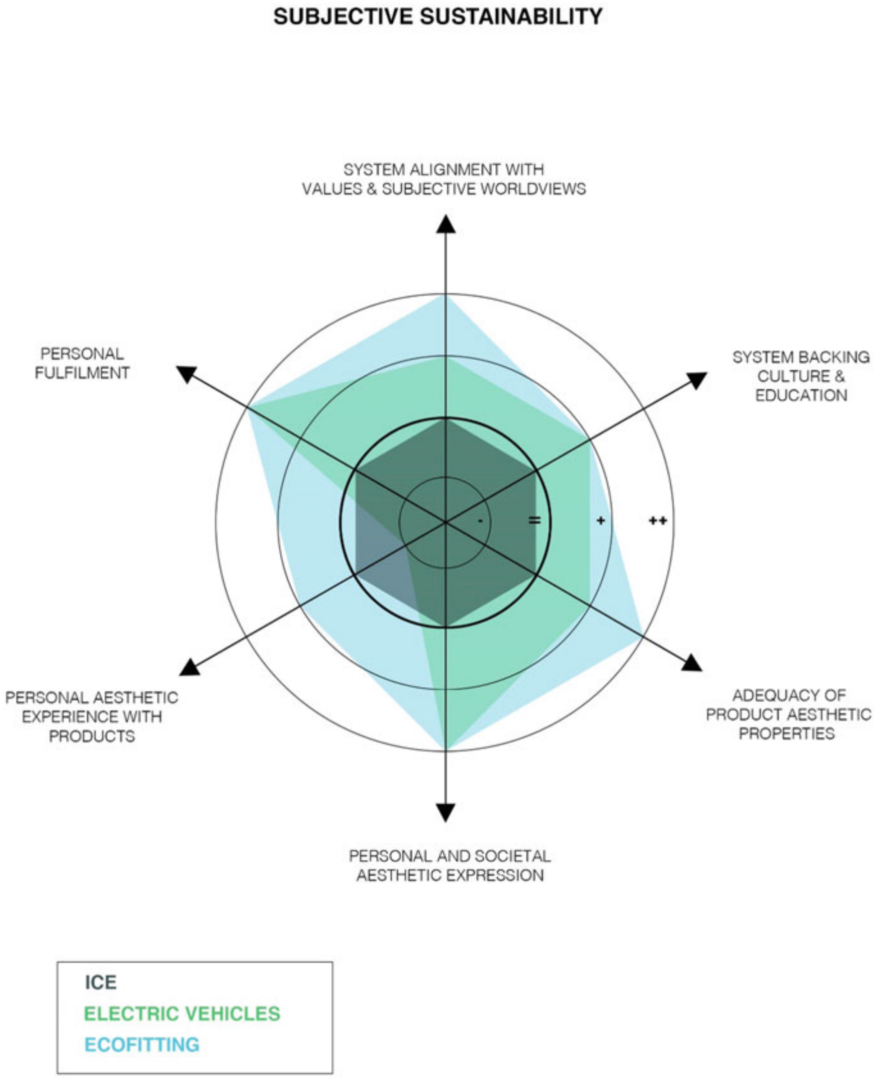

**Fig. 2** Ecofitting Circular Economy landscape [2]. The concept of circular economy creates opportunity for new SME to participate on activities of retrofitting vehicles aiming to extend their lifecyle and reduce their environmental impact. Automotive design practice will be like architecture design practice, bringing professionals and users closer, and cars understood as long lasting platforms, like architecture

The circular economy solution and concept products developed at the Ecofitting project were analyzed applying the Sustainable Design Orienting developed to consider a quadruple bottom line for sustainability [16] (see Table 1). The tool which was originally developed by the Polytechnic of Milan [17] and included Environmental, Economic and Socio-Ethic Sustainability issues. It has now been updated with the inclusion of Subjective Sustainability issues. Benefits of Ecofitting are related to long-term ownership, waste and resource reduction, local production and wider distribution of opportunities, promotion of local culture, nurturing communities and responsible consumption, promotion of an aesthetic of sustainability, valorization of personal identity and deeper values. The research highlighted the importance of creating design development tools considering both the tangible and intangible aspects of design.

## 5 Conclusion

The transition to sustainable mobility is urgently needed to fight climate change, and at the same time it can produce great environmental impact. According to Ekins [18] the Impact on the environment is a product of People, times Consumption, times Technology (I = PCT). It is necessary to re-think production and consumption, and design becomes a strategic tool. It has an important role as an applied art that draws upon our

**Table 1** Subjective Sustainability comparative analysis using the SDO tool




The performance of Ecofitting was compared to mainstream industry's electric cars and internal combustion cars (ICE)
The values on the vectors come from a checklist [16]

imagination envisioning alternative perspectives, if informed by philosophical, ethical and environmental considerations, it can make a constructive contribution to the nature, extend and pace of positive change [5]. This transition should change the relationship between consumers and product to one of care. According to Crocker [6] "the object once possessed effectively 'talks back' to its owner, requiring time, place, maintenance and attention: this is a material, psychological and social relationship, and not just a momentary transaction.” The relationship of “care” also establishes a connection to the materiality of the objects.

The Anti-Ephemeral Design research explores the idea of a meaningful engagement with objects as part of a circular economy, particularly focusing on dealing with the carbon footprint compromised by aesthetical, normative or technological obsolescence in the existent car fleet. Anti-Ephemeral Design aims at extending the lifecycles, adapting products, working with alternative materials and processes, including people through open source and economic opportunities, therefore, proposing a cultural and societal shift.

The Joyful Journeys and Ecofitting projects (see Fig. 3) pointed out the need to look beyond the creation of new products: changing the way we use and extending the lifecycle of products can offer alternatives for reducing the impacts of mobility in the environment. To achieve that there is a need for a cultural paradigm shift, we must think from the point of view of sustainability. We cannot judge sustainable solutions with a mindset of a non-sustainable society, economy or culture. As advocate by Papanek “designers have help to wield power to change, modify, eliminate, or evolve totally new patterns” [8]. It is necessary that design moves from being part of the problem to being part of the solution. Otherwise, the new paradigms of sustainable mobility Autonomous, Electric, and Shared will become the new myths. While designing sustainable mobility, we must consider environmental, economic, socio-ethic and subjective issues, and aim for joyful, meaningful and responsible mobility.

**Fig. 3** Ecofitting Upcycled Golf: the design is used to challenge aesthetic conventions and provoke a debate about consumption habits [15]

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# Plenary: Implementing Constructed Wetlands for Sustainable Water Management in a Circular Economy: Examples and Case Studies

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**Abstract.** We realize today that the unsustainable way that our societies grow, consume, and waste natural resources. While resources such as water, fossil fuel, and nutrients are becoming scarce, climate change is progressing. Sustainable development implies the need to identify tools to properly manage our water resources.

## 1 Summary

We realize today that the unsustainable way that our societies grow, consume, and waste natural resources. While resources such as water, fossil fuel, and nutrients are becoming scarce, climate change is progressing. Sustainable development implies the need to identify tools to properly manage our water resources. However, the challenge is to understand the interconnections and synergies between technical and non-technical/social/management and economic aspects. Circular economy appears today as an alternative economic model that can guarantee the economic growth while minimizing– or ideally eliminating—the climate change impacts. It dictates that new solutions are required to deal with waste; in fact, in a circular economy, waste is no longer viewed as 'waste' rather than as a valuable input/material to another process. This new approach also demands new solutions and processes that will not generate an environmental impact themselves while targeting at solving an environmental issue and/or minimizing a different environmental impact [1].

Although the circular economy model is already studied and proposed by many governments and international organizations, water resources management and especially wastewater management has not received the similar attention in the context of circularity as is the case of, e.g., solid waste. The relevant discussion has only begun in recent years with proposals aimed at reducing consumption, reusing and recycling of water and wastewater and recovery of materials and nutrients. In general, we can say that liquid waste (human waste, rainwater, runoff) remains the largest untapped waste category, but it is a pillar of circular economy as defined by the European Commission.

Water reuse has been practiced world-wide under varying regional/local conditions for decades and is recognized as a vital part of integrated water resources management


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in many countries. Meanwhile, recent developments in the concepts of climate change adaptation, sustainability and circular economy, as highlighted in the EU Green Deal, and the UN Sustainable Development Goals for clean water and sanitation, are providing a renewed interest and awareness on water reuse, and in some cases increased funding opportunities. On the other hand, these recent initiatives may neglect continuing attention to traditionally recognized challenges, such as public acceptance, economic feasibility, and planning and implementation for the protection of public health under specific local conditions.

At the moment, wastewater recycling initiatives have emerged mainly in countries facing the problem of reduced water availability mostly due to the effects of climate change and the increasing cost for drinking water production. The European Union published just in 2020 a new regulation on water reuse with limited application in agriculture. There is therefore a lack of a comprehensive plan for the sustainable and efficient use of wastewater.

In this context, Nature-based solutions (NBS) are more and more widely recognized as important tools in climate action, in addressing societal challenges, protecting, and restoring ecosystems and supporting biodiversity conservation [2]. NBS represent an attractive and useful toolbox for sustainable strategies that can play a key role in the implementation of the European Green Deal. The European Commission sees NBS as part of the EU Climate Pact and even promotes nature-based learning initiatives. This is why the use of NBS such as the green technology of Constructed Wetlands (CW) is gaining increasing global attention and popularity over the last years. This technology in particular, has typically few mechanical parts, limited maintenance and operation needs, limited or even no need for specialized staff, minimized use of non-renewable materials (concrete, steel etc.), design flexibility and replicability, minimum greenhouse gas emissions, minimum or even zero energy consumption, and produces no harmful by-products. NBS can provide solutions that contribute towards a more circular management of water and wastewater.

NBS change the processes used to treat wastewater to reduce the pollutants load by applying ecological engineering techniques with reduced carbon footprint and minimized use of materials. Moreover, and most important, NBS can provide the option to further valorize the treated effluents for beneficial reuse, e.g., for irrigation of crops or recycling in an industrial process, closing this way the loop of water as a natural resource in the economic model and promoting circularity aspects and practices (Fig. 1).

This plenary talk will document this approach through a series of case studies that demonstrate the feasibility, scalability and opportunities provided by CW technology for circular wastewater management and reuse of different wastewater sources. These examples will help reflecting how water reuse projects may fit into the context of sustainability and circular economy and be promoted not only in the rural context but also in the urban environmental and the industrial sector. The case examples highlighted in the plenary talk will be from Europe, South America, Asia, Middle East and Africa [3, 4].

Identifying sustainable management ways for wastewater effluents is a key factor towards expanding and implementing the circular economy principles. New, green technologies are needed to enhance the sustainable character of wastewater management,

**Fig. 1** Left: a constructed wetland system in the Czech Republic for wastewater treatment and reuse. Right: a constructed wetland system in Oman for oily water treatment reuse

especially in the industrial sectors, but also new initiatives to close the materials cycle and promote water reuse and recycling. Nature-based solutions such as the green technology of Constructed Wetlands can provide these desired characteristics. The case studies presented here from different wastewater sources and different climatic conditions demonstrate that the dual goals set of implementing sustainable technologies and circular practices is technically and economically feasible at various scales. The use of Constructed Wetlands for wastewater allows the recycling of the treated effluent in the industrial process reducing this way the freshwater consumption. It also enables the reuse and exploitation in irrigation to produce valuable crops. These examples of wastewater management indicate the potential to close the loop of water and promote circularity aspects and practices in the water sector.

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# Panel Discussions

# Panel Discussion: Smart and Healthy Societies

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**Abstract.** Smart and healthy societies are among the research areas where it is important to make progress in order to achieve the targets set by SDG 12 within the framework of the EURECA-PRO alliance [1]. For this reason, a panel discussion was held during the 2nd EURECA-PRO Conference on Responsible Consumption and Production". This panel was attended by two expert researchers with complementary profiles that allowed a dynamic discussion on this topic: Manuel Franco, from the University of Alcal´a (Spain) and Barbara Wedler, from the University of Mittweida (Germany). The experts answered four questions related to smart and healthy societies and how they can help to achieve several of the objectives of the European Green Deal: (i) what are the challenges of smart and healthy societies on the way to achieving climate neutrality by 2050; (ii) what new opportunities will sustainable production bring in the field of smart and healthy societies; (iii) how can we promote sustainable production in the field of smart and healthy societies; (iv) how can we promote sustainable production in the field of smart and healthy societies; and (v) how can we promote sustainable production in the field of smart and healthy societies? [2].

**Keywords:** Smart societies · Healthy societies · SDG12 · EURECA-PRO · European green deal · Responsible consumption and production

## 1 Introduction

The European Green Pact is the answer to climate and environmental change and the social challenges they bring. Achieving such a change is not easy, which is why it requires the mobilisation and support of citizens and governments in all European countries. To promote the efficient use of resources by moving towards a clean and circular economy, a roadmap has been incorporated with a series of actions proposed by the EU:


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- Become climate neutral by 2050.
- Protect human life, fauna and flora by reducing pollution.
- Helping companies to become world leaders in clean products and technologies. European industry currently uses only 12% recycled materials.
- Help ensure a just and inclusive transition.

Several lines of research can help to achieve these objectives from different perspectives. For this reason, the EURECA-PRO ('European University on Responsible Consumption and Production') Alliance has generated five lines of research called Light Houses (LH1: 'Responsible Material Flows', LH2: 'Environment and Water', LH3: 'Sustainable Materials and Products', LH4: 'Clean Energy', and LH5: 'Process Automation and Industry 4.0'). In this sense, smart and healthy societies are part of LH2 and LH5.

Smart cities and societies have as their primary objective to implement different technological innovations that help improve the population's quality of life [3]. This objective is complemented by improving the environmental impact of people's lifestyles. This is achieved by implementing new policies and improving the management of, for example, public transport in cities, among many other actions. This will help improve sustainability and achieve the climate neutrality desired in the European Union and is a priority today.

On the other hand, from the perspective of healthy societies, the objectives of making people healthier and healthier have as a direct consequence sustainable food systems, boosting the economy and caring for nature [4]. An example of this is the European agricultural and food system, which is a global benchmark in terms of security, as well as security of supply, nutrition and quality. If this message and approach can be conveyed to the whole world, a global standard of sustainability can be created. Through these changes, several of the objectives of the European Green Pact will be achieved.

In view of the above, the main objective of this panel discussion is to answer the following four questions in the field of smart and healthy societies from experts:

1. Which are the main challenges to address in the field of smart and healthy societies? And which are the key actions to be adopted to move towards EU climate neutrality and a more sustainable prosperity in this field?
2. Which new opportunities regarding sustainable production the European Green Deal will bring about in the field of smart and healthy societies?
3. How can we encourage responsible consumption and boost the nexus between the systems of production and consumption to reach the European Green Deal in the field of smart andonlthy societies?
4. How can we increase/raise awareness of young EU citizens about the need of boosting responsible consumption and production in Higher Education Institutions like Universities?.

Section 2 of this paper then summarises the views of Manuel Franco and Barbara Wedler with regard to the proposed questions and, in Sect. 3 sets out some final conclusions in this regard.

## 2 Panellist Discussion

### 2.1 Manuel Franco

To answer the first questions, *which are the main challenges to address in the field of smart and healthy societies? And which are the key actions to be adopted to move towards EU climate neutrality and a more sustainable prosperity in this field?*, it is first very important to highlight that urban population in Europe is around 80% of the total population, as it is in Spain. Other regions in the world, Latin America, for example, has had one of the most rapid increases in urbanization, seeing its proportion urban population double from 1950 to 2020. While Africa and Asia have lower urbanization rates, urbanization has increased rapidly in these regions in recent years, and it is expected that later this century these regions will be home to most of the world's urban population.

The key actions to be adopted in EU cities to move towards EU climate neutrality and a more sustainable prosperity are at least three for and Urban Health perspective.

- Developing sustainable food systems, moving toward plant-based diets, and reducing meat consumption.
- Developing and promoting active (walking, biking) and public transportation that can drastically reduce greenhouse gas emissions while improving health.
- Speeding communication and translation of significant science regarding these topics.

Once identified these key points the main challenge is; how do we do it? How can we make it happen? Intersectional cooperation and collaboration will be fundamental.

Regarding the second question, *Which new opportunities regarding sustainable production the European Green Deal will bring about in the field of smart and healthy societies?*, the European Green Deal offers a great opportunity in the topic of healthy and sustainable food systems in EU cities. Developing sustainable food systems moving toward plant-based diets, more just food chain workers and reducing meat consumption.

As a relevant example, the EU funded project School food for change (SF4C) includes eight relevant objectives regarding healthy and sustainable food systems and the European Green Deal:

1. 40% organic food to be offered in EU school menus
2. 25% of primary food products to be offered in EU school menus from regional sources (¡ 200 km)
3. 25% Green House Gas emissions reduction through more plant-based food content, food waste reduction and low-carbon food chain (from farm to fork EU strategy)
4. 15% of schools offering free of charge breakfasts or healthy snacks (organic, potentially regional fruits/food/drinks) for all, in particular to support disadvantaged groups
5. 15% of SF4C tenders including food education related criteria (e.g. awareness raising for children or kitchen staff)
6. 15% increase of n° of kitchens preparing less than 5000 meals/day (to support better market access to smaller producers, reduce industrialized food dependency; increase job creation; promote "kitchen food hubs")

7. 12% of food procured from small farmers (below 10 ha) and/or social food producing cooperatives or/and engagement with at least 3 SMEs in food procurement
8. 50% of coffee, tea and exotic fruits (where they are exotic!) from fair trade sources (to support small farmers, vulnerable groups, gender, international cooperation).

In relation to the third question, *How can we encourage responsible consumption and boost the nexus between the systems of production and consumption to reach the European Green Deal in the field of smart and healthy societies?* as researchers are part of the stakeholders in responsible production and consumption, we need to help and participate in the communication and dissemination of research projects and results. For example, myself I collaborate with national and international newspapers, radios currently have a newspaper column on urban health.

We most also acknowledge that civil society engagement is fundamental to encourage responsible consumption and production. To make happen the most relevant social changes related to responsible production and consumption civil society engagement through associations and third sector will be fundamental.

Finally, in relation to the last question, *How can we increase/raise awareness of young EU citizens about the need of boosting responsible consumption and production in Higher Education Institutions like Universities?*, teaching programs at the Universities including a responsible consumption and production lens is needed, but research and participation in practical work is very the only way to assure that students engage with the meaning of SDGs.

## 2.2 Barbara Wedler

The world as we know it is over. Many people in Central Europe grew up in peace, could educate themselves freely, lived with enough food and used energy at all times. As it turned out, these things that were taken for granted are not a matter of course. Now, we are more aware of this as individuals and as a society.

We now live more consciously and deal with everything more carefully as a gain in this otherwise dramatic development.

The most important challenge to address in the field of smart and healthy societies is to enable and to promote positive change in behaviour. There is already a great deal of encouragement among the population about issues relating to the environment, the climate and animal protection. The challenge is to implement positive intentions in everyday life. The circumstances, such as financial hardship, useless advertising, misleading offers, everyday habits, a bad infrastructure, etc. go in exactly the opposite direction. The orientation towards profit maximization ignores the real needs of the people. It is also necessary to apply alternative economic models that exploit neither people nor the planet. As a goal and at the same time a result of the before mentioned challenges: climate change must be reduced. It takes intersectoral cooperation and thinking in systems. There is a positive vision like the "Economy of Well-Being" to bring stakeholders and policymakers together. The World Wide Fund For Nature says "A 'well-being economy' starts from the idea that public interests should determine economics and not the other way around. Rather than pursuing economic growth through narrowly defined indicators such as GDP, a well-being economy monitors and values what truly matters: our health, nature, education, and communities”[1].

Basically, people should not forget, despite all the options regarding sustainable production, the European Green Deal will bring about in the field of smart and healthy societies, that social interaction is an essential dimension of health. At the same time, the high degree of mechanization allows more people to work in humanitarian areas. Moreover, the health sector have technologies that relieve nurses, teachers, etc., of a lot of time-consuming work. For example, a professor from the University of Applied Sciences Mittweida disassembles old televisions and radios. He keeps the old components inside but also fits in modern technology. Therefore, old programs can be played and old technology can be worked at the same time. The aim of using old media technology is to stimulate the mental performance of older people with dementia through media support and to maintain it for as long as possible. The use of technical possibilities offers the chance to approach the special experiences and needs of people. At the same time, pressure from staff (e.g. nurses) can be taken off. The possibility of living in the past through these media, with images and sounds, is familiar and comforting.

What we can see from this example: good cooperation between engineers, nursing staff, older people, etc., is needs-and demand-oriented. People for people can be great model for the future.

The goal is that production will be oriented more towards what people really need: care sharing instead of large-scale production; expansion and securing of public transport; production of ”culture” as an educational asset; promote regional agricultural products and reduce overproduction of food.

Encouraging responsible consumption and boosting the nexus between the systems of production and consumption to reach the European Green Deal in the field of smart and healthy societies need our own action, which should always serve as a role model Knowledge of the interactions plays an important role. Of course, politicians must also be aware of their responsibility to all people. Necessary are:

- An integrated approach across all policy areas
- A common purpose
- Networked actions by all relevant actors, for example: The promotion of regional, biologically unpolluted agricultural products. This requires the subsidization of an appropriate for the species and chemically unpolluted agriculture. As a result, the sales opportunities for regional products must be increased and promoted. The transport routes should also be optimized and imports should be checked.
- A comprehensive, target group-oriented processing of information, for example: promotion of health and climate protection as a regular part of school lessons.
- The “healthy” society should already be a product of the Green Deal, for example: The University of Applied Sciences Mittweida has been in place since 2017 the health management. In addition, exists a concept for climate protection. All areas merge into each other and show how carbon dioxide emissions can be reduced in the company and how health can be strengthened.

[1] https://www.wwf.eu/what_we_do/eu_affairs_governance/towars_an_eu_wellbeing_economy/.

- Improvement of structures and participation opportunities in schools, communities, cities etc.

In these processes, universities also have a role model effect. The University of Applied Sciences Mittweida feels connected to the European Green Deal, the federate state strategy of the Free State of Saxony and the Ottawa Charter of the World Health Organization (WHO). So, what does it mean in praxis? The connection between the EU targets for reducing carbon dioxide emissions and keeping employees healthy can be found in 6 overarching fields of action.

For example, the university aims to activate mobility via bicycles. The so-called "Campus Flitzer" are freely available to avoid using car on campus. Students refurbished the bikes, which are over 30 years old. This is an example of using human resources, outdated equipment and strengthening active mobility.

Two years ago, the university also made further adjustments in relation to climate change. It has supported converting green areas into biodiverse flowering meadows and meadow orchards. Now they offer various insects a space to live. Education in the sense of knowledge transfer and participation means inspiring students and taking as many people as possible along the way. However, communication beyond the boundaries of the university and networked actions are also important to inspire enthusiasm for the Green Deal.

## 3 Conclusions

Summarising the expert's answers to the four questions posed in this panel, we can say that the objectives to be achieved by solving the problems related to smart and healthy societies, in an indirect way, can help to solve the problems within the EU SDG 12 on responsible production and consumption, as well as sustainability. There are different challenges that, through the achievement of smart and healthier societies, will ultimately have a positive impact on climate neutrality. To this end, it is necessary to educate the population through various training and educational actions that help to promote responsible production and consumption within this topic.

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# Panel Discussion: Circular Economy

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**Abstract.** This paper summarizes the contribution from the panel discussion about Circular Economy at the 2012 EURECA-PRO Responsible Production and Consumption Conference, held in the Universidad de León, Spain in October 2022.

**Keywords:** Circular economy · Design · Values

## 1 Introduction

Circular economy (CE) in a nutshell is the process of discovering and using waste as a resource. The traditional approach of society in using materials is the "take-make-use-dispose" approach, which in the light of current environmental pressures and our finite planet is not something which leads us to be a healthy society and thus should not be pursued any longer. There are different types of approaches within the circular economy, namely reduce, reuse, repair, remanufacture and recycle, according to given needs. However, there are certain challenges and limits to the circular economy, reaching amongst others from socio-economic developments such as population growth and developing economies which is connected to growing material demand, over to material requirements such as qualities for high-tech products or availability of secondary materials to systemic and economic implications such as stable policies that allow for stable business models within the CE. The European Union has launched the CE Action Plan in March 2020. It is meant to be one of the building blocks to achieve the Green Deal and focuses on initiatives along the entire life cycle of products in key industries such as for example batteries, plastics, textiles, food and construction. The main targets that are meant to be tackled are product design, CE processes, encouraging sustainable consumption as well as waste prevention. It represents not only a document along which measures can be implemented but is a call to action for European society and industry. Despite such comprehensive documents and actions, it seems CE is a much more complex and far-reaching topic and successful implementation tricky. The panel discussion mirrored that the question of integrating all the materials that are already in


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circulation is not treated sufficiently. It is one thing to start designing things for recycling now, developing a comprehensive circular life for a new product, but the other aspect is that there are extensive amounts of materials that haven't undergone a process of being redesigned for a second life. In this respect the relation of conventional cars vs. the amount of electric cars was mentioned. Are we going to throw away all regular cars and produce new electric ones from primary materials? This question was then closely linked to the question of how to control waste streams efficiently. First this is true for collection systems because only what is collected can be recycled and second if it is not known where some products disappear to it is hard to design stable CE streams and stable business models from them. It was clearly ascribed to policy to take responsibility to ensure successful reclamation as well as successful and increased utilization of these secondary materials in new products.

## 2 Panellist Discussion

### 2.1 Artur Grisanti Mausbach

**Circular Economy**

The European Green Deal aims to EU climate neutrality by 2050, setting ambitious goals for environmental, health and social standards. The European Green Deal is the EU's new growth strategy, aiming to transform the EU into a fairer and more prosperous society, with a modern, resource-efficient and competitive economy, with no net emissions of greenhouse gases by mid-century [1]. The Commission is supporting the move to a more circular economy, which can help to secure Europe's economy while reducing the dependence on imports. The Commission notices that "however, achieving a climate neutral and circular economy requires the full mobilisation of industry"[2]. The challenge is even bigger when we look at the world of objects and business which exists already and were not made to be circular.

The adoption of a circular economy model, instead of a linear model is a significant aspect of the systemic change aiming sustainability. It aims for wider benefits to society, business and environment which require changes on attitudes of consumers, improving communication and sharing information on supply-chains, doing business in unusual ways, understanding the new position of stakeholders, and others which without the very change in products and design would be ineffective. The integration of the consumer, or user, in the system, is a key aspect of the circular economy model, since he is an active actor of the cycle, and an integral part of the community creating cultural transformation. This kind of change would impact the economic model and might not produce the same amount of profit, but can produce other matters of economic gain, such as inclusion and sharing.

**Opportunities to SMEs and Start-ups**

The Ecofitting project [3] developed at the Royal College of Art Intelligent Mobility Design Centre demonstrates in the case of car retrofitting, how many systems of productions need re-thinking and repositioning to include circularity. For business it can also mean opportunities. Ecofitting presented the design of a platform to connect consumer to business in a circular economy (see Fig. 1).

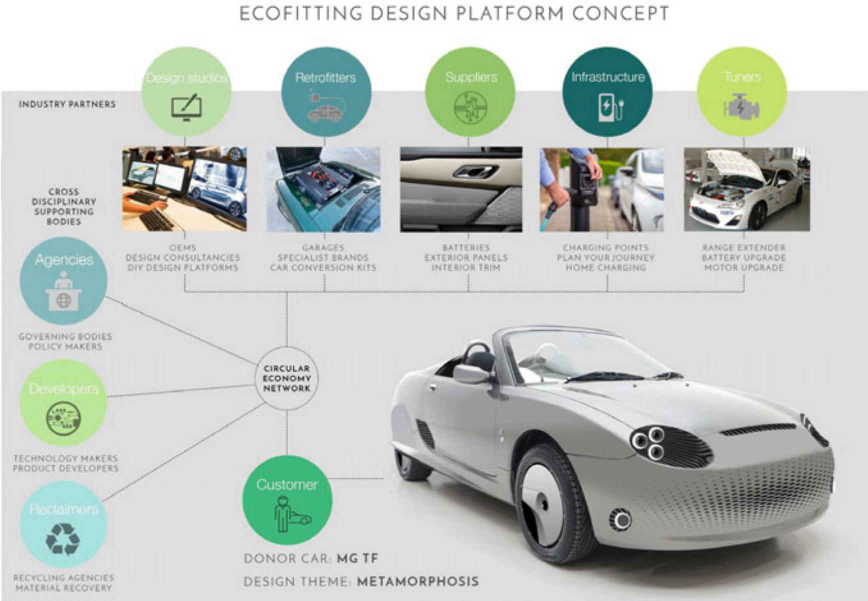


**Fig. 1** Ecofitting design platform diagram [4]

The support to SME and start-ups is the key, also because they are the home of the disruptors, and to change from one system to another we will need to disrupt. The disruption will be characterized by new economy and production structures and a shift in consumer behaviour. This also means changing what is designer, how is design, and when to design. We have to support adaptations and be open to alternative technologies. Remembering that not always we need to replace technologies, but we need to change how much we use them.

**A Change in Values**

We need to change the focus of society. An economic and societal change cannot happen without a change in values. We cannot constantly promote consumption and competition and call it responsibility. Walker [5] adds that the "consumer society encourages all these social ills through the constant supply of novelty and status-oriented goods combined with marketing techniques that incite socio-positional competitiveness". It's not enough to have circularity. We need to slow down the circle…

We depend too much on objects and material and financial resources to find our happiness, which ironically isn't there. We have to refocus to human to human and to nature relationships to find meaningful, respectful and joyful experiences. The shift to circularity, to responsible consumption and production, to equality, to inclusion and to sustainability, can only happen if we change *hearts and minds*. Universities and schools are a where we develop intellectually and spiritually, and therefore these are the places to start the change.

## 2.2 Beatriz Jiménez Parra

**Question 1**

In order to achieve the ambitious target, set in the Green Deal related to the reduction of carbon emissions by 55% by 2030 compared to 1990 levels, our society have to deal with a number of key challenges.

In my opinion, one of the most important one is fostering a real and effective transition process from a linear model to a completely circular pattern. According to European Commission (2020), only 12% of secondary materials and resources being brought back into de economy. This involves encouraging a climate of cooperation, commitment and co-creation among all stakeholders. For example, enterprises should rethink their business models, adapting them to circularity and, investing in R&D, which implies to own money, time and other kind or resources. Consumers should change their "use and throw away" philosophy of consumption, choosing the most environmentally friendly options such as recycled, remanufactured and/or repaired products, which means that these alternatives have to be provided by enterprises. Finally, policymakers should develop more measures to tackle firms´practices such as products´ planned obsolescence or greenwashing.

Other important issue that is shaping up as a challenge is waste management. It must be acknowledged that small steps have been taken in this regard and progress has been made in this direction. However, there is still a pending issue since there exist some waste material that, due to their characteristics, source of origin, quantity, volume, etc., is more difficult to recover, manage or dispose of (waste from construction sector, hazardous material from WEEE, etc.).

The aforementioned challenges require the implementation of some key actions such as (1) co-creation/cooperation working groups among stakeholders (firms, consumers, citizens, policymakers, environmentalism associations, NGOs, etc.); (2) reinforcing the legal framework; (3) developing and implementing awareness actions aimed at key stakeholders; and (4) providing financial incentives to companies and consumers to encourage them to adopt more responsible production and consumption patterns.

**Question 2**

In general, moving towards a more circular economy, and in particular with regard to responsible production, implies some important benefits [6–15]. To name a few:

(1) Reducing the pressure on the environment by eliminating waste and pollution (reducing or eliminating packaging, water use, etc.) and regenerating nature supporting natural processes and leaving more room for nature to thrive.
(2) Improving the security of the supply of raw materials by keeping materials in use, either as a product or, when that can no longer be used, as components or raw materials through remanufacturing, recycling, refurbishing, etc.
(3) Increasing the competitiveness and stimulating innovation, for example, embracing new technologies such as extended reality, blockchain or internet of things, and designing more durable and innovative products that will increase the quality of life and save consumers money in the long term.

(4) Boosting the economic growth and creating new jobs o increasing the demand of the existing ones (experts in waste management and valorization, bid data, new materials, and new (renewable) energy sources, among others).
(5) Provinding more durable and innovative products that will increase the quality of life and save consumers money in the long term.

**Question 3**

In order to encourage responsible consumption, it is essential to provide consumers with a set of tools to enable them to make environmentally conscious choices. This means providing them with complete and relevant information on the characteristics (recycled, repaired, remanufactured, etc.) of the products, developing a standard product labelling system, dealing with the planned obsolescence and, improving product guarantees, among others actions. These are some of the issues on which the European Parliament (2020) has already been working in recent years, but more progress needs to be made on this regard.

Similarly, it is important to promote product service systems (PSS) and collaborative consumption patterns. This implies that, where economically feasible and possible, it should be replaced product ownership with product use. These consumption patterns arrangement lower the financial threshold that customers must meet to acquire expensive equipment, increases customer access to the company, and eliminates consumer burden of end-of-life disposal and recycling [5]. This PSS also presents an opportunity for companies to design the product for disassembly, single part replacement, recycling, remanufacturing, etc., which is commonly named “design for X”. It means that enterprises can play an important role to reinforce the link between responsible and consumption and production obtaining some benefits/advantages while allowing consumers to save money and make a more responsible choice.

I believe that cooperation among the different parties involved (enterprises, consumers, citizens, policymakers, etc.) is essential to boost the nexus between the systems of production and consumption to reach the European Green Deal in the field of Circular Economy. It means to create a culture of inclusion that enables co-creation. Some actions aims to get this objective might include the establishment of alliances among different stakeholders, such as the EURECA-PRO alliance (https://www.eurecapro.eu/) or the “New European Bahaus” (https://new-european-bauhaus.europa.eu/index_en).

**Question 4**

Higher Education Institutions, especially Universities, can contribute to increase awareness of young EU citizens about the need of boosting responsible consumption and production. Actions in this area should focus on two pillars: (1) providing students with knowledge on these topics and (2) involving students in the process of changing by helping them to know how they can contribute to this transition process.

Some examples of actions that Universities can carry out to achieve these objectives, could be:

(1) The inclusion of subjects/modules directly related to sustainable consumption and production in their study programs at several levels (bachelor, master and PhD).
(2) The cooperation agreements between Universities and enterprises or other private and public institutions so that students can be more aware of what it needs to be done and how they can contribute to achieve it, both in their current role as consumers and as future professionals.
(3) The development of activities and participation in events on topics related to responsible consumption and production issues (design for "X", zero waste, planned obsolescence, etc.).

## 3 Conclusions

A central point of the discussion turned out to be the principle of economic growth and what it entails in terms of production and consumption. It was mentioned that companies should focus much more on qualitative than quantitative growth and that the growth of the circle needs to be slowed. The consumer was also ascribed responsibility in their behavior, however, it was made clear that the way current business functions and the marketing mechanisms that are being leveraged are making it difficult for consumers to act responsibly. New generations of phones, cars, clothes coming out every few months evoke a feeling of need in consumers and this is even aimed for. Mostly new things are bought not because they lose their technological function but because they lose their aesthetic function, which means new things are bought for their looks.

In conclusion, it was agreed that as society we have failed to address the pressing issues regarding CE sufficiently and in an efficient way. Despite European efforts this remains a big global challenge. The common tenor echoed that not a single stakeholder group is responsible for the entire cycle but many groups are responsible for different sections of it. These groups need to work in an integrated way and develop solutions together and quickly. Success can only be gained from multi-perspective approaches. All learnings and the consciousness for responsible system design with regards to CE needs to be included in all education so that future decision makers have this engrained in them as basic principle in all they do. The topic needs to be jointly reflected and much more brought to the center of attention of everybody.

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# Panel Discussion: Environment and Energy

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**Abstract.** Environment and Energy are among the research areas where it is important to make progress in order to achieve the targets set by SDG 12 within the framework of the EURECA-PRO alliance. For this reason, a panel discussion, facilitated by Prof. Evan Diamadopoulos, was held during the 2nd EURECA-PRO Conference on Responsible Consumption and Production. The panel consisted of two expert researchers with complementary profiles that allowed a dynamic discussion on this topic: Jimeno Fonseca, from AXPO GRID (Switzerland) and Carsten Drebenstedt, from the Technical University Freiberg (Germany). The experts answered questions related to environment and energy and how they can help to achieve several of the objectives of the European Green Deal.

**Keywords:** Environment · Energy · Sustainability · SDG12

## 1 Introduction

The global environmental problems do not necessarily come from the wrong application of technology, but quite often they are directly related to modern societal expectations: Urbanization, land use, transportation patterns, intense food production (particularly meat production), waste production and disposal, high energy demand based on energy generation from fossil fuels. Therefore, new innovative approaches on global scale are required which encompass sustainability practices, integration of primary and secondary resource material flows and efficient resource use in the frame of Circular Economy. However, technological advances by themselves are not enough: Societal changes are required primarily through the development of an inclusive, borderless and integrated European Education System (Education in the broader sense of the word) as the key to reaching competent and conscientious citizens who can contribute to this grand European societal challenge.

The EU has set very ambitious goals for mitigating climate change: Targeting Carbon Neutrality by the year 2050, carbon emissions should be reduced by 55% in 2030 with respect to the 1990 levels. However, is such a plan plausible, given that, according to Eurostat, 70% of energy needs in 2020 in EU27 were covered by hydrocarbons and coal? This European Green Deal is also a commitment that the EU will be moving towards that direction at a higher rate than any other country or region, while most of EU clean energy infrastructure must be installed in the next two decades.


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It is understandable that Carbon Neutrality or even reduced carbon emissions cannot be achieved in a short period of time, a transition period is needed, in which natural gas is supposed to play a significant role. However, a tremendous increase in the price of natural gas either because of the high demand for it and, of course, the war in Ukraine has been experienced. On the other hand, if the European Union moves towards renewable energy sources, a great deal of mineral resources are needed: raw materials and steel for wind generators, and rare earth and other elements for electronics, batteries and photovoltaic systems, none of which are produced in Europe in sufficient quantities. The EU will have to balance out the need for clean energy, sustainable prosperity with high environmental and social standards, and the fact that Europe depends on other countries and economies with different or even hostile geopolitical priorities.

In order for the EU to be transformed into a resource-efficient, yet competitive economy, the supply of critical elements has to be guaranteed. However, the EU lags in the production of lithium, rare earths, and essential industrial metal elements to the extent that it faces a significant risk of a supply gap jeopardising the plan for clean energy projects and infrastructure. In order to meet its clean energy goals by 2050, the EU will require 35 times more lithium and 7 to 26 times the amount of rare earth metals compared with today's figures. In addition, the energy transition towards Carbon Neutrality will set increased requirements on annual supplies of zinc by 10–15%, aluminium by 30%, copper by 35%, silicon by 45%, nickel by 100%, and cobalt by 330%.

In relation to the Energy Green Deal, Europe faces four essential questions:

1. Can Europe rely on increased imports of critical elements in order to secure the increased demands of them? China, being the leading supplier of refined metals, will make Europe highly dependent on her.
2. Can Europe increase mining production and refining capacity which will lead to a reliable stream of essential metals into Europe? Considering that mining, processing, and refining are energy-intensive (and at times that energy prices are skyrocketing), environmental concerns are high, and production capacity is limited, this scenario cannot provide the required quantities of critical energy elements fast enough to reach the goals set in the European Energy Green Deal.
3. Can recycling of essential energy elements play an essential role in Europe's demand for them given that for some basic metals (for example, aluminium, copper, and zinc) recycling already provides half of Europe's supply? Europe will have to facilitate a new recycling industry for solar photovoltaic panels, as well as electric vehicle batteries, both reaching end-of-life conditions after 2035. Recycling could give Europe a significant supply source, yet new recovery technologies and recycling infrastructure should be developed.
4. Even if Europe guarantees the required supply of metals and other critical elements, what kind of infrastructure must be developed during the transition period in addition to new mines, processing, and refining facilities, as well as recycling industries? New electricity grid networks have to be designed and commissioned. Water reservoirs at different elevations that would act as energy storage have to be constructed. Development of hydrogen production facilities (after testing appropriate hydrogen generation technologies) and hydrogen distribution networks must be implemented.

Computer Artificial Intelligence techniques, Data Analytics, and Digital Twin technologies in the energy sector should provide guidance towards this direction. And finally, administrative complexity in relation to the resource efficiency and carbon neutrality must be minimized.

## 2 Panellist Discussion

### 2.1 Jimeno Fonseca

The role of technology in the energy transition goes pretty much hand in hand with socio-economical change. Technology makes processes more efficient and bring us together. On the other hand, the implementation of any technology depends on socioeconomic factors, such as capital, land, labor, and acceptance. Would technology alone help us to reach the goals of the energy transition, such as carbon neutrality or adaptation and mitigation for climate change?

This question is rather difficult to answer, but it reminds me of 2016, where the book "Energy Efficiency Strategies for Urban Communities" [1] portrayed four alternatives for cities to reach carbon-neutrality in Switzerland. These included energy efficiency, infrastructure retrofits, clean energy and land-use re-/allocation. While the first three relate to technology, the last is a socioeconomical decision of high impact. According to the book, land-use can already constrain 30% of the future demand and production of energy in cities, other factors such as technology remain the same. After all, land constrains services, which constrain transportation, water, food, and energy too. Despite its potential, such a socioeconomic strategy, if considered, is pretty much far from easy.

Another socioeconomic strategy to reduce the strains on energy systems and fossil fuel consumption widely studied is behavioral change. The truth is that from all possible nudges meant by energy saving campaigns, price signals have demonstrated to be the only strategy due to make an impact at scale. I decided to make a small test during the Eureca-Pro Conference of October 2022. There, 90% of the participants were already drastically saving energy at home as a result of the high energy costs in Spain. The percentage was just 10% one year ago, despite the multitude of ongoing campaigns about energy, climate change and decarbonization. While effective, the problem with socioeconomical strategies such as demand management, is that they are inflationary and may even lead in most cases to social unrest, as seen in France last year.

Since socio-economical strategies prove rather difficult to be applied or sustained, and most of all, work towards setting up restrictions instead of opportunities, I prefer to rather look at the vast number of opportunities that innovation in digital technologies can lead us to the future of the energy system. It is not rare to find companies in the energy supply business such as Axpo [2] to heavily invest in technology as the means for increasing the efficiency and sustainability of their business. Such technologies can be divided into three categories: Hardware, Software and Processes. What I like of all these three categories is that small improvements can be measured, replicated and be understood at scale.

In terms of Hardware, we decided at Axpo to modernize our grid by doubling the voltage of our power lines some time ago. This brings today the possibility to cut to a fourth the transmission losses of our network, while getting us ready to attend a growing demand of energy. What made such an increment on efficiency sustainable is today a small, yet powerful Innovation called the iTAK System (Insulated Suspension Chains) of Axpo [3]. In the past, we had to remove masts to locate new power lines to increase transmission capacity. Thanks to this chain, we can now do it at a fraction of the cost while reutilizing our masts.

In terms of Software and technological processes, companies in the energy sector advance their capabilities to better generate, manage and extract value of their data. The advent of technologies such as Cloud Technology, Data Analytics and Building Information Modelling make this possible. Cloud Technology hast been adopted to a great extent to better inform customers, suppliers as well as every employee. Integrated Asset Management platforms such as Insights [4], for example, serve as the "google" of digital assets, making possible to connect all wealth of information to a single location. Bringing thousands of terabytes of information to a single clear spot is key for improving the operational efficiency of big energy companies and making a service of the highest quality possible. On the other hand, Building Information Modeling, or the BIM-Method [5] at Axpo is transforming the whole way how energy infrastructure is planned and built. On the principle of "Build first digital, then physical" engineers in energy companies are improving the efficiency of their entire planning and construction process with the use of information models instead of 2D printouts. The BIM-method and its digital tools improves transparency, facilitates decision and helps to early identify and mitigate failures, which in return leads to better safety, material and time savings.

Digital technologies represent a clear opportunity to improve the efficiency of energy infrastructure not only during planning and construction. During the operation stage of infrastructure, a gain in efficiency results in better production capabilities, less costs, a more sustainable business, and when done right, a positive impact on the environment. A clear example of improvements for energy companies is the advent of automated inspections of their assets with Unmanned Aerial Vehicles (UAV) or drones [6]. Damages to power lines are critical for every society. Until recently, preventive inspections were carried out by climbing on poles or with helicopters in remote and sometimes dangerous locations. The process was time consuming, costly, and required a built up of permits. Companies such as Axpo bring today these digital technologies such as UAV and software for image recognition successfully to the field. Together, they allow to semi-automatically inspect and identify damages of infrastructure in record time. The results of "From Mast to Monitor" are astonishing and have made the whole inspection process double accurate and faster.

To conclude, digital technologies play an important role in improving the efficiency and sustainability of energy companies. Examples of Hardware, Software and technological Process are becoming widespread. Key technologies in this realm such as Cloud computing, Data Analytics, Building Information Modeling, and Unmanned Aerial Vehicles are becoming an intrinsic part of the operations of the energy sector. While socio-economic factors such as land-use reallocation and behavioral change do represent an important aspect of the energy transition, they lie beyond the tangible, and feasible scalation of strategies that we need to build a sustainable future.

## 3 Conclusions

As Europe, are we ready to move towards a Carbon Neutral environment without jeopardizing the high economic, social, and welfare standards we experience here in Europe? Can we achieve this strictly by technological change or it is important to raise citizen awareness towards responsible consumption patterns, sustainable transportation, and nature-based solutions? How can we cooperate with other countries and regions worldwide in order to be effective on global scale? Of course, all these questions are difficult to be answered, but the time to work on them has reached us all.

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# Papers

# The Role of Public Policies and Sustainable Tourism to Face the Demographic Challenge and Sustainable Production

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**Abstract.** In the current context, the situation of the Spanish rural environment, its depopulation, as well as the alternatives that must be addressed from the public administration to address this problem, possesses within the agenda of the State to find a way to revitalize the countryside, in particular to light of the most recent world events that have occurred since 2020, which have evidenced that the food strength of the country goes hand in hand with the generation of strategies that to serve the increasingly depopulated rural environment. We intend to make a brief illustration of this phenomenon, making a global analysis of the situation to then focus on the province of León, analyzing the causes of the depopulation of its rural environment, the negative vegetative growth that has been experienced in recent decades and that still impacts the region today, the consequences that this situation has brought to the countryside, as well as the strategies, public actions and policies developed at the administrative level to address this a problem that is spreading more and more throughout the various Spanish Autonomous Communities. With this panorama in mind, we will review the trends related to sustainable tourism, the viability of implement a sustainable tourism strategy aimed at demographic revitalization for the Province of León, the responsible use of its resources natural resources, as well as the guarantee of their survival, within a component of public policy for the sustainable growth of environments.

**Keywords:** Sectoral economy · Social change and development · Evolution of societies · Legal system and protection

## 1 Introduction

The Spanish rural scenario has been strongly affected by various phenomena that have led to its depopulation, consolidating what is now commonly known as "empty Spain" [1]. Among them we have the abandonment of agricultural work, its reduction by modernization [2], the attraction of the city towards the inhabitants of the countryside derived from industrialization and the growth of new urban centers [3], the decrease of social, labor, educational and cultural opportunities in less productive environments [4], as well as the progressive devaluation of the rural world derived from the perception of the rural


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way of life as a space of cultural backwardness and lacking value [5, 6]. At the same time, the poor communications network that the country has been dragging for some time [7], makes the rural space even more distant both physically and temporally from the current Spanish reality, which ultimately has led to an aging of the rural population [8], and loss of employment [9].

Since the 1960s, various strategies have been designed to guarantee the sustainability and survival of the rural world, as was the case of the vacation programs in farmhouses [7]. On the other hand, tourism has become an axis of economic development in the country, with the objective of generating social and inclusive development, a link between the economic, institutional and environmental sectors, to diversify economies, generating new demands for services for the community, reducing the exodus of the population, consolidating new employment opportunities for women and young people.

Thus, we propose to review the general context related to the genesis, phases and consequences of the depopulation of the Spanish rural environment, the programs associated with rural activity, the state of public actions in terms of attention to the demographic challenge. Subsequently, we will enter into the study of public policies and actions related to the promotion of rural development and the regulatory framework that supports the sustainable development of the rural environment, together with the characteristics of sustainable tourism.

Finally, we propose to present the strategy of sustainable tourism as an essential public action for demographic revitalization, a strategic axis for rural territorial development, especially in the most economically and socially depressed areas, diversifying the industry, within a productive cycle and responsible consumption that allows facing the demographic challenges, taking advantage of the resources destined to consolidate employment opportunities and stable work, providing homogeneously distributed socioeconomic benefits.

## 2 The Abandonment of Rural Areas

The first enlightened experiences of colonization in the interior date back to the nineteenth century, with the approval of agricultural colonies, and later with the concept that emerged in 1866 of "coto redondo acasarado" as the basis for an individualist colonization system [3]. Later we had the presence of agrarian liberalism and the search for agrarian reform. Then, in 1907, we had the approval of the colonization and repopulation of the interior (distribution of land among poor farmers) of little practical significance.

From 1905 onwards, the Canalejas (1911) and Alba (1916) projects followed, which was succeeded by the Dictatorship of Primo Rivera and the actions of the Second Republic: focused on land distribution. These were followed in time by the 1931 Constitution, the 1932 Agrarian Reform Law, and Royal Decree 118 of 1973, to name but a few.

As has been analyzed in recent years, the low effectiveness of these actions is well known, as they have not addressed at all the crisis generated by the depopulation of the Spanish countryside in areas of large abandoned agricultural areas, a paradoxical situation in comparison with the European scenario, in which the areas of greatest poverty are located in urban centers, finding that in today's globalized economy local territories are discovered as the main sources for promoting [3].

From the mid-twentieth century onwards, the situation has not changed much, with depopulation advancing because of a prolonged historical process in which migratory movements can be framed as a result of two parallel processes [2]. On the one hand, we have the development of industrialization models centered basically in the urban and capital area with little implementation in medium-sized cities or rural areas, and on the other, the imbalances derived from the unjustified difference in the provision of essential public services, which were reduced in accordance with the decrease in the point of equilibrium necessary to make their maintenance profitable.

For this reason, life in the Spanish countryside has gradually become an impossible and uprooted option that is economically uncertain and highly discriminatory because, among other things, local administrations are not equipped to offer the conditions that motivate citizens to establish permanent residence in the rural environment [2]. The migration of the rural population has been constant towards urban environments, as they aspire to a better quality of education, better employment, health, housing, in short, to substantially improve living conditions. Among the multiple causes that have led to depopulation in rural environments we have:

- Impossibility of maintaining an active and competitive primary sector in the food demand, together with the inadequacy of soils, the lack of capital and the bad structure of the properties of the agricultural exploitations.
- Inadequate supply of cultural, recreational, and social services.
- The industrialization of the agricultural sector, which in some areas drives urban migration due to the decrease in job opportunities.
- The reduction of the labor market.
- The aging of the population.
- Loss of labor force.
- Reduction in the number of inhabitants of municipalities with the consequent suppression in the provision of public services.
- Negative vegetative growth.

This is why, although in principle Spain has experienced significant demographic growth, since between 2001 and 2019, the country went from 41.1 to 47 million inhabitants, increasing by almost 6 million more people, which represents a growth of close to 15%; the truth is that in the twenty-first century the process of depopulation has intensified, and this process of loss has accelerated in the last decade. This is especially the case in four autonomous communities that have lost population during the twenty-first century (Extremadura, Galicia, Castilla y León and Asturias). Especially at the municipal level, since of the 8131 municipalities in Spain, 5102 have lost population since 2001. Similarly, in the last decade, 6232 municipalities have lost population. This phenomenon, as has been mentioned, is eminently rural, with 926 municipalities with a density of less than 12.5 inhabitants/km$^2$, the threshold considered by the EU to be at demographic risk, which has consequently translated into negative vegetative balances since the 1980s [10].

In the case of Castilla y León, the community has an area of 94,225 km$^2$, almost undoubtedly the largest region in Europe, reaching 19% of the national territory but with a population of less than 2,500,000 inhabitants, with a great dispersion of the population essentially in the rural world with 2116 municipalities with less than 2000 inhabitants, 1981 with less than 1000 inhabitants and 1724 with less than 500 inhabitants, and on the other hand only 15 cities in the community have more than 20,000 inhabitants [4].

## 3 Status of Public Actions to Address the Demographic Challenge

Thus, the objective of the demographic challenge must be equal rights and opportunities for people wherever they live, which is also a symbol of social cohesion and due legal protection in basic guarantees that the State must provide to all citizens. It is not possible to reverse economic trends if it is not initially clear how the rural territory is to be sustained and developed. With such a perspective, there is a need for change in the public policy framework of the economic and territorial development models in both urban and rural areas [2], insofar as it is intended to preach a true social cohesion that is basically impacting the democratic models on which society is based.

The union between law and these problems is reflected in the use of administrative instruments to motivate and activate the actions of the administration in search of the necessary social cohesion in these territories, as well as the guarantee of constitutional rights, thus ensuring the effective realization of the social rule of law model such as:

- Real equality (Articles 14 and 9.2. C.E.)
- Dignity of the population of rural areas (article 10 C.E.)
- General interest (article 103.1 C.E.)
- Economic progress (articles 40.1, 130.1, 131.1 C.E.).

The demographic evolution of the last decade may affect the sustainability of the welfare state and jeopardize social cohesion, territorial structuring and the model of coexistence [3]. For this reason, the Ministry of Ecological Transition and Demographic Challenge has pointed out that the demographic challenge is a fundamental dimension of social and territorial cohesion in our country and one of the priority axes in the agenda of pending reforms.

In the short term there are no clear, rapid and uniform solutions to combat it, so it is essential to establish plans and programs that articulate actions at all levels of territorial power, combating the complex web of economic, social, environmental and cultural causes described above. These solutions must be based not only on rural migration [11], but also on the generation of capital, large investments, public sector decisions, personal desires for liberation and process, as well as the generation of productive and sustainable environments.

It is necessary to bear in mind that the problem of depopulation is, above all, a legal problem because it is largely based on inadequate normative regulation and the formulation of strategies and public policies that govern not only the relationships between people but also between people and public authorities and between citizens and their environment. It is becoming increasingly evident that the administration, with its excessive legal regulations, contributes to further aggravating the problems of the rural world, making its revitalization more and more difficult, partly because the formulation of these regulations is never based on the reality of the territories they are intended to regulate.

## 4 Public Policy for Rural Development and Sustainable Tourism Strategy

Policies to address demographic challenges do not refer to the analysis of social factors in the explanation of variations in the so-called natural movement of the population (birth rate, mortality, municipality), but precisely the opposite: the attempt to modify the demographic structure of a population to improve its situation, development, or processes of inequality [3].

Despite the antiquity of the phenomenon, it is only in recent times that attention has been paid to it through the following instruments:

- 2015 Senate Report on the adoption of measures in relation to rural depopulation in Spain [12].
- VI Conference of Presidents of January 2017, in which the need to address demographic changes or challenges is determined [13].
- Creation of the government commissioner to address the demographic challenge: Royal Decree 40/2017 of January 27 [14].
- Report 1 of 2018 of the Economic and Social Council on the rural environment and its social and territorial structuring [15].
- General Guidelines of the National Strategy for the Demographic Challenge [16].
- Creation of the Ministry for Ecological Transition and the Demographic Challenge: Royal Decree 139/2020 of January 28 [17].
- Creation of the General Secretariat for the Demographic Challenge by Royal Decree 500/2020 of April 28 [18].

In turn, with the General Guidelines of the National Strategy for the Demographic Challenge [16], 7 cross-cutting objectives have been established, which are:

- Guarantee full territorial connectivity, with adequate co-opening of broadband internet and mobile telephony throughout the territory, in accordance with the European Digital Agenda 2020.
- Ensure an appropriate provision of basic services to the entire population in conditions of equity, adapted to the characteristics of each territory.
- Incorporate the impact and demographic perspective in the preparation of laws, plans and investment programs, favoring territorial redistricting in favor of greater social cohesion.—Advance in regulatory and administrative simplification, for small municipalities, in order to facilitate the management of municipalities.
- Eliminate stereotypes and enhance the image and reputation of the territories most affected by demographic risks.
- Improve mechanisms for greater public–private collaboration, enhancing the incorporation of demographic factors in the social responsibility of the private sector, to turn all territories, without exclusions, into scenarios of opportunities.
- Align the lines of action and purposes of the Strategy with the fulfillment of the Sustainable Development Goals and the 2030 Agenda.

Among the measures promoted is the promotion of tourism, and within this, mention should be made of Law 45/2007 of December 13 for the Sustainable Development of the Rural Environment (LDSMR), which is an ambitious instrument that has sought to reverse the situation of depopulation. Its purpose, as stated in its first article, is to regulate and establish measures aimed at promoting sustainable rural development as a suitable mechanism for counteracting the growing territorial differences and guaranteeing equality among Spanish citizens as a whole.

According to the second article of this law, the aim is to support and progressively expand the economic base of the rural environment, maintain and improve the demographic situation of rural areas by increasing the well-being and quality of life of the citizens through the conservation and recovery of the heritage and natural and cultural resources of these areas. In addition, Article 22 establishes specific and particular objectives that must be included in the policies adopted and developed by the different administrations.

The realization that the Spanish rural environment continues to show a development differential with respect to the urban environment, especially marked in certain rural areas, revealed the shortcomings of this essentially agrarian model and the need for a change in the focus of public policies, which, in order to attend to frequently marginalized territories and populations, should move from an agrarian and sectoral approach to a fundamentally territorial and integral approach.

Territorial cohesion, and with it environmental sustainability and human habitability, must then be understood as an opportunity within a new country model aligned with the international sustainable development agendas—Agenda 2030 of the Sustainable Development Goals, the Paris Agreement on climate change and the New Urban Agenda—that place people at the center of their actions, since the main challenge must be to combat inequality in access to services.

In this set, 130 measures were proposed in response to the demographic challenges facing Spanish communities, with sustainable tourism being one of the axes of development, seen as an economic and social engine and a lever for the sustainable development of the territory, which can contribute to halting the depopulation of the rural environment and its consequent deterioration, to the protection and promotion of heritage and the natural environment and to the improvement of the quality of life of people, promoting among others 7 measures for its promotion [19]:

- Tourism Sustainability Program in Destinations
- Sustainable Tourism Product Development Plan
- Plan for the Promotion of the Circular Economy in tourism
- Maintenance and sustainable rehabilitation of historic heritage properties for tourist use
- For a healthy tourism: cultural and natural heritage and sports activities
- Plan for the Digital Transformation of Tourism Destinations
- Plan for the Digital Transformation of Companies in the tourism value chain through Artificial Intelligence and other enabling technologies.

Despite the above, the instrument, although ambitious, has not had the corresponding investment from the administration to carry out its initiatives that would allow to reverse the situation of depopulation of rural areas in a decisive and forceful way. This has meant that, for example, new activities planned to promote the sector, such as rural tourism or the recovery of historical and cultural heritage, have been lost. Additionally, the lack of coordination and planning at the time of designing the actions to develop to revitalize the rural environment by the public administrations are in frank retreat, which, added to the gradual forgetfulness of the organisms in charge of the citizen participation, have made unfeasible, in spite of the multiplicity of instruments, strategies, the construction of a true model of sustainable territorial development.

Finally, we consider that all these actions should be urgently reviewed in order to adapt them to the concrete and specific needs of small and medium-sized municipalities. Indeed, as a national strategy, the obvious rule of territorial, cultural and population diversity of the Spanish territory. For this reason, although as an incipient framework it may be indicative, in practice, like so many other regulations, it does not meet the needs of rural areas. It is imperative to make the requirements more flexible in order to implement the various lines of action, to promote economic activities and to favor regulations that take into account the various municipal realities, along with a more flexible regime for achieving the objectives set forth therein.

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# Autonomous Smart Electric Vehicle Integrated into a Smart Grid Type System

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**Abstract.** This paper briefly presents the creation of an intelligent electric vehicle with self-driving capabilities that can be integrated into both the new Smart Grid and Smart City concepts, as well as its use as a prosumer element in an electricity supply network. The realization of a small electric vehicle obtained based on a conversion of its thermal engine into an electric engine, the integration of communication systems based on the LoRa network and the use of LiDAR sensors for the purpose of mapping an area of interest is briefly presented. A concept for the development of an electricity supply system with the help of photovoltaic panels installed in the city of Petroșani is also presented. The entire designed system, even if part of it is only at a conceptual level, represents a starting point in terms of the development of integrated systems around an autonomous electric vehicle with autonomous driving capabilities that can be considered truly 100% non-polluting through given the fact that the vehicle's batteries will be powered by renewable sources.

**Keywords:** Electric ATV · Smart city · Prosumer · Autonomous vehicle

## 1 Introduction

According to many researches, toxic emissions from diesel and petrol cars have caused serious air pollution problems in European cities and cause tens of thousands of premature deaths every year. According to the competent authorities in the field, transport is responsible for a quarter of the greenhouse gas emissions of the European Union, and the emissions generated in this sector continue to increase. A transition to a non-polluting transport system is vital especially in large urban agglomerations. Sustainable alternatives to driving, such as electrified public transport or cycling, are also needed. When there are no sustainable alternatives, the electric car can be an efficient means of transport, especially if it is used by several people or in a car-sharing system [1].

At the moment, Romania can be traveled from any point to any point with an electric car with an autonomy of at least 150 km. Electric car models available on the Romanian market in 2021 have an autonomy between 200 and 500 km. Over 300 locations are available throughout Romania where an electric car can be charged. Each location has on average about 3 charging points per location, that is, there are 900 charging points in Romania [2].


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Free charging stations have almost completely disappeared, but the indicative price at public charging stations for 1 kWh is between 0.13 € and 0.51 €, much lower than on the liberalized market for home users.

To fully charge an electric car with a 50 kWh battery at public charging stations, the price is between 9.14 € (the cheapest tariff plan) and 25.38 € at charging stations (the most expensive tariff plan) being able to get an autonomy of about 300 km. This means that you can travel 100 km paying an average of around 8 € with an electric car. The same 100 km traveled by a car with an internal combustion engine (which consumed on average 8 L/100 km) cost on average about 15 € [3].

If we discuss how much $CO_2$ a car produces, we must consider not only the $CO_2$ emissions during use, but also the emissions generated by its production and scrapping. The production of an electric car is less environmentally friendly than that of a car with an internal combustion engine, and the level of emissions from electric vehicles varies depending on how the electricity that powers the car is produced. But as the share of electricity from renewable sources will increase in the future, electric cars will become even less harmful to the environment [4].

## 2 The Electric and Plug-In Hybrid Vehicle Market in Romania

Although we are living in uncertain economic times marked by big problems related to the increase in energy prices, Romania has started to count in terms of sales of electric and plug-in hybrid cars, while the network of recharging stations for these vehicles benefits from important support both from the authorities and from the private sector. Romania had, on December 31, 2021, a total of 7,6111,039 cars, of which 13,310 vehicles electrical.

In the ranking of the best-selling 100% electric cars in Romania, in 2022, the first place was: Dacia Spring, with 3068 units, model launched in 2021, followed by Volkswagen Up with 435 units and Hyundai Kona 384 units. As far as hybrid plug-in cars are concerned, the top sales in Romania is led by Renault Captur—with 269 units, Ford Kuga 261 units (model produced in Romania, in Craiova) and Hyundai Tucson 229 units [5].

## 3 Identification of the Problem

After consulting several specialized works in the field of electric vehicle development, it was observed that at least in Romania, but even in Europe, the niche of electric vehicles usable in closed spaces is rather poorly represented. Whether we are talking about small electric vehicles or whether we are talking about larger ones, they all currently lack certain smart capabilities that would allow them to be successfully integrated into a Smart Grid system. Also, even if they are used in certain industrial facilities, electric vehicles still lack autonomous driving capabilities. So, this is where the objective of this work comes from, the design and realization of a system that integrates electric vehicles, a communication network suitable for use in closed industrial spaces and a system for locating vehicles in this type of space as well as a mapping system then usable for autonomous driving [6].

## 4 The Solution to the Problem

The research fits perfectly into the current concerns regarding the realization of small electric vehicles with intelligent capabilities that can be used in closed industrial spaces. A small electric vehicle has been created starting from the functional platform of an ATV. An induction motor and two command and control strategies were chosen for the drive part. The first strategy was based on the motor controlled with the help of a frequency converter and for the second strategy a specific controller was made with the help of IGBTs (Fig. 1).

**Fig. 1** Electric ATV

The entire system is powered using a continuous electric voltage of 72 V obtained by connecting 6 12 V (40Ah) batteries in series. The 3 IGBTs are powered using copper plates for efficient energy transfer ($U_{max} = 72$ V). The system control is done using the PWM method (U/f = constant).vIn addition to creating an electric vehicle, it is also desired to create a communication system that can be used according to the V2V (vehicle to vehicle) or V2X (vehicle to everything) concepts. In order to achieve this goal, the research focused on finding an innovative communication protocol, still little used in Romania, the LoRa communication system [7].

Built four LoRa devices using ESP8266 and LoRa RFM96W transceiver modules, each with the ability to be either a node or a base station (Fig. 2).

To make an autonomous electric vehicle, we need more data about its control method, as well as data about the environment and its location in a given reference space. The first and most important of the tasks is to accurately determine the position of the vehicle in real time in an indoor space. Due to the fact that in an indoor space, and especially one that has a resistance structure that has strong metal reinforcements, a classical GPS-based localization method cannot be used, it is necessary to use another method to determine the position of the vehicle in the reference space with acceptable accuracy. To achieve this goal, an algorithm for determining the vehicle's position using the RSSI (received signal strength indicator) of the LoRa modules was created. The results obtained also by

**Fig. 2** Manufactured LoRa modules

implementing a machine learning algorithm using the measured RSSI data of the LoRa devices used for localization are relatively good, being able to determine the position of a LoRa network node with respect to a central device with a small error (0.7%) up to a distance of 100 m [8]. Even if the position of the electric vehicle in real time is known in a closed perimeter, there are not enough data to define and make a route that can be followed by the purpose of taking certain data of interest. Thus, it is necessary to introduce in the whole system of specific sensors. A special category of sensors introduced into the functional structure of the electric vehicle is that of the sensors with which the distance of the vehicle can be determined to a certain obstacle and then a map of the enclosure can be generated. The 360° RPLIDAR A2 laser scanner developed by SLAMTEC has a highly reliable and highly accurate laser measurement system and has excellent performance in indoor and outdoor working environments (Fig. 3). The realization of the map of the interior space as well as the representation of the route taken by the electric vehicle can be found in Fig. 4.

The result presented briefly in this paper is realized by making a small electric vehicle adaptable to any type of terrain. It can be used both outside, for example in the middle of urban agglomerations and inside closed industrial facilities. The electric vehicle is operated with the help of an induction motor controlled with the help of a special inverter made in the laboratories of the University of Petrosani. The effective command and control part was made with the help of a Raspberry PI 4 development board. The Robotic Operating System (ROS) application was also installed on the Raspberry PI 4 development board, which has the role of integrating the Lidar system used for mapping the space where it circulates the electric vehicle with the rest of the command and control elements [9]. The whole system must be seen as a unitary whole in which the electric actuation part works together with the LoRa communication system used as a localization system, with the mapping system obtained with the help of a LiDAR sensor and with the rest of the sensor components, actuators and transducers. Due to the fact that the entire mechanical system is built from recycled parts, it is proposed that the next stage of development be the creation of a charging station using solar energy, as well as the installation of flexible solar panels on its functional surface, then being able to truly say that this electric vehicle is 100% non-polluting [10–12]. The batteries of this electric vehicle can constitute an energy input within the general electricity production network, being able to transform into a prosumer type element when needed [13]. So that within this project we can say that we have reached the vehicle to grid component,

**Fig. 3** The hardware assembly of the LiDAR mapping system mounted on the electric ATV

**Fig. 4** Generation of the route made by the electric ATV

laying the foundations for future developments regarding the future of electric vehicles in the Smart City concept, and especially in the Smart Grid within the University of Petrosani.

The entire concept briefly presented in this work is the subject of a patent application. The invention described in the patent application number A/00201/28-03-2019 has obtained several gold, silver and bronze medals at various national and international invention salons held up to now [14].

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# Physical Processing in Waste Printed Circuit Boards Recycling: Current State of Research

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**Abstract.** The article presents and compares the results of metal separation from pulverized printed circuit board waste (PCBs) using physical and physicochemical processing methods. PCBs type FR4 were used for the research, which were ground at cryogenic temperatures using a knife mill. Separation processes for the same feed were carried out using electrostatic and gravitational separation, and flotation. Compared to the other PCB recycling methods, the ones presented in the paper have a lower environmental impact and allow the reuse of both metals and non-metallic parts. The highest efficiency was for electrostatic separation, as a result of which the following products were obtained: 26.2 wt% metal product, 2.8 wt% middlings and 71 wt% a product containing non-metallic parts. The products obtained in this way are easy to use in other processes. A product containing valuable metals can be processed in local metal processing plants, while shredded non-metallic parts can be a good filler for epoxy resin composites. Furthermore, electrostatic separation in comparison to other used methods has the lowest environmental impact because there was no need to use water and complications associated with it. Thus, the technology of PCB recycling proposed in the work is characterized by high efficiency and is environmentally friendly.

**Keywords:** WEEE · Recycling · PCB · Physical separation · Circular economy

## 1 Introduction

Due to the increasing amount of waste electrical and electronic equipment (WEEE) and the possible shortage of various raw materials, sometimes referred to as critical, the assumptions of the circular economy should be introduced. Namely, it is a business model aimed at extending the life of the product by reusing, repairing, recovering, and using secondary raw materials in the production process [1]. According to the new approach, the produced good after application must be used in the following production cycle, reducing the amount of waste generated. An important aspect is that the fundamental element of almost every WEEE are printed circuit boards (PCBs), which contain valuable


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metals. Therefore, it was decided to loop the printed circuit boards (PCBs) market, by applying a new concept of product life cycle using environmentally friendly methods, which was presented in the article.

For environmental, cost, and economic reasons, the physical and physicochemical processes of mineral engineering appear to be very promising for use in industrial technologies at an early stage of processing. It is at this stage that materials that were previously tightly bonded can be separated and then used directly or processed through more invasive methods. As a result, this action complies with the "do no significant harm" principle written in the article 11 of Regulation EU No 2020/852 [2] and can be considered as an environmentally sustainable action. Figure 1 shows an example of the application of this concept for printed circuit boards. In 2019, the global production of WEEE was 53.6 Mt and is expected to increase to 74.7 Mt in 2030. The estimated value of raw materials contained in e-waste produced in 2019 was 57 billion USD but considering the current level of WEEE collection and recycling, the potential value for the recovery of raw materials was 10 billion USD [3].

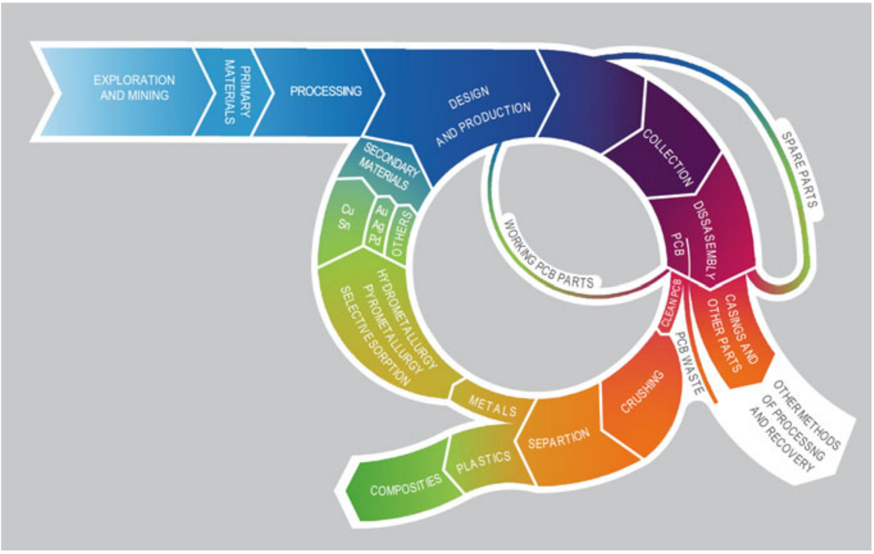


**Fig. 1** The concept of WEEE processing on the example of PCBs

The process of recovering metals from PCBs can be carried out using ecological and cheap physical or physicochemical methods, for example using gravity, electrostatic separation or flotation [4–6]. Before these processes, PCBs should be properly shredded to release individual parts of the boards.

The article aimed to present and compare the key results from the used separation methods, as well as to indicate examples of the use of the products from the most efficient method.

In Sect. 2. Material and Methods characteristics of the PCBs and separation methods, i.e., flotation, electrostatic and gravitational separation, as well as the process of preparation of the feed, were determined. The following Sect. 3. Results present the key research results obtained from the authors' previous works, which were comprehensively discussed in Sect. 4.

## 2 Material and Methods

### 2.1 Material

PCBs consist of two basic elements: a board with metal paths and electronic components mounted on the board's surface, i.e., transistors, resistors, batteries, LEDs, microprocessors, and various types of connectors. Depending on the type of board, it can be made of materials such as reinforced paper, aluminum, or reinforced fiberglass. For the research, the most common FR-4 type PCBs were used, whose boards were made of 70 wt% of materials such as epoxy resin and polyesters, and 30% of metals (Cu, Fe, Al, Sn, Ta, Ga, Au, Ag, and Pd) in a free state [7, 8].

### 2.2 Preparation for Separation

Before the grinding and separation, the previously mentioned electronic components were demounted, which could disrupt the grinding and separation processes due to their physical properties. Then, the clean PCBs were cut into 3 × 3 cm pieces and cooled to cryogenic temperatures by placed them in a tank with liquid nitrogen. Subsequently, the pieces of PCBs were ground using a TESTCHEM laboratory knife mill, in which a sieve with a 1 mm mesh perforation was attached.

### 2.3 Separation Methods

The recovery of metals from the remaining parts of PCBs was carried out using the following processes and devices:

- electrostatic separation—drum electrostatic separator Boxmag-Rapid Ltd.,
- gravity separation—concentration table and laboratory cyclofluid separator,
- flotation—Mechanobr laboratory flotation machine using dimethoxy dipropyleneglycol (concentration of 157 mg/dm$^3$).

The methods were selected to evaluate different separation methods, belonging to the physical processing. During electrostatic separation, the process occurs as a result of differences in the electrical conductivity of the grains and their ability to accumulate surface charges, while in gravity separation as a result of differences in specific densities. It is important to emphasize that the grains are separated horizontally on the concentration table, and vertically in the cycle fluid separator. Whereas in the case of flotation, the grains are divided due to differences in hydrophobicity.

An important aspect of selected methods is also the separation conditions. In the case of electrostatic separation, the grain must be dry, while in other methods the separation takes place in an aqueous medium. In flotation, it is additionally necessary to use flotation reagents to increase the efficiency of the process.

The detailed methodology of the research and the test results were presented for the electrostatic, flotation and gravity methods, respectively, in the papers of Suponik and Franke [4–6].

## 3 Results

As a result of grinding, the feed was obtained, which mainly consisted of grains with a size of less than 0.5 mm (83%) and grains with dimensions from 0.5 to 1 mm (16.6%) (Table 1). However, a trace number of grains 1–1.4 mm (0.4%) was identified. These grains were mainly needle-shaped, and thus, they got through a sieve in the mill [5].

**Table 1** Particle size distribution of grounded PCBs [5]

| Grain classes, mm | 1.4–1.0 | 1.0–0.5 | 0.5–0.36 | 0.36–0.09 | < 0.09 |
|---|---|---|---|---|---|
| Yield, % | 0.4 | 16.6 | 57.9 | 8.5 | 16.6 |

The main characteristic feature of the feed was the variety in the shape of grains. It can be generally concluded that the metal grains were mostly globular and patch-shaped, while needle-shaped and fibrous grains were derived from reinforced fiberglass [5, 6].

The results of research with the use of flotation, gravity and electrostatic separation are shown in Fig. 2. The best separation of the metallic product (concentrate) from plastics was obtained for electrostatic separation (Fig. 2). The yield of this product was 26.2 wt% and had the highest number of valuable elements (above 93.3%, mainly 68.5% Cu, 11.5% Sn, 0.1074%Ag and 0.0092%Au), and furthermore, it had the lowest number of impurities (less than 3%). In this method, the yield of plastics product was 71 wt% and had 0.54% valuable elements (mainly Cu). In the case of electrostatic separation, 2.8 wt% middlings were obtained, which mainly consisted of conglomerate grains (plastic-metal) [5]. The products obtained by the method of gravity separation were of lower quality—they were contaminated with each other. Through use of a shaking table, the following products was obtained: 25.7 wt% metals product (72% valuable elements, mainly 59.2% Cu, 6.3% Sn, 0.2160% Ag and 0.0072% Au; 8.35% impurities), 28.9 wt% middlings (9.5% Cu), and 45.4 wt% plastics product (5.8% of valuable elements, mainly Cu) [4]. The products obtained using a cyclofluid separator were similar to those obtained from the shaking table [4]. The use of flotation to recover metals from PCBs was also an inefficient process. In the case of flotation, two products were obtained (waste and concentrate) and both were unfortunately heavily polluted. The yield of concentrate was relatively high and amounted to 43 wt%, but the content of valuable metals in it was only 53% [6]. Hence, the concentrate density was the lowest compared to other separation methods and was only 7.4 g/cm$^3$. In summary, a highly efficient, ecological, and economical method of PCB processing consists in grinding PCBs cooled to a temperature of $< -150$ °C in a knife mill to a particle size of $< 0.5$ mm and electrostatic separation of metals from non-metallic powders.

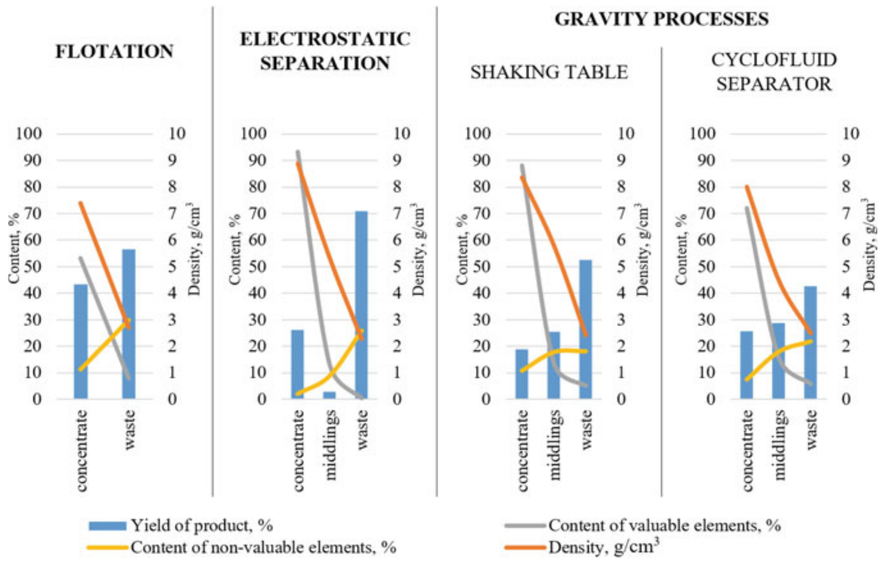


**Fig. 2** Yield of separation products as a function of their density and quality parameters - based on [4–6]

## 4 Discussion

In the case of physical methods, the purity of the product is one of the most important aspects determining the recycling success [9]. In fact, metals such as Cu, and trace amounts of Au, Ag and Pd constitute the main value of waste PCBs. Therefore, their even small losses might be the reason to refrain from applying physical methods in PCBs recycling, which mainly occurs in the case of insufficient grinding process or its poor adaptation to the separation method [10]. As has been written above, the best products were obtained from electrostatic separation. Nearly all valuable metals were in concentrate, making it valuable. Thus, mixture of metals may be easily sold to the local metal ores processing factories or other production facilities using pyrometallurgical or hydrometallurgical processes.

The second equally important aspect is the circular economy principle, in line with all obtained products should be reused [11]. In this case, physical methods have an advantage over other metal recovery methods from PCBs, because obtained products are chemically unchanged, and hence allowing for a wider range of applications [12]. Therefore, the non-metallic powder can be easily reused for example in composite materials production using epoxy resin [13]. Furthermore, these methods have a less negative impact on the natural environment because no toxic waste or emissions to the atmosphere are produced, and the products themselves are environmentally neutral. At this point, the middlings product should also mention, which in case of large amounts could be problematic due to substantial losses of valuable metals. Although, in case of electrostatic separation its content was negligible and could be processed using biohydrometallurgy or returned to the grinding process in order to release the metals from conglomerate grains.

In subsequent works, it is planned to assess the use of non-metallic PCBs parts for the production of composites especially as regards their impact for mechanic properties.

## 5 Conclusions

Compared to gravity separation and flotation, electrostatic separation was the most effective method of metal recovery from PCBs. The obtained products were characterized by high-quality parameters. In the concentrate were identified over 93 wt% of metals, while in a product containing fiberglass and plastics only 0.54 wt% (mainly Cu). Due to the dry process conditions, electrostatic separation was also the most environmentally friendly and less energy-consuming, because there was no need for additional water filtering and drying products installations. Furthermore, no chemical reagents were used, which could cause the toxicity of the products. The concentrate (a mixture of metal), due to its high purity, can be sold to other processing factories, e.g., copper smelters and refineries, and thus generate economic profits. On the other hand, products containing plastics and fiberglass can be applied for composite production.

Thereby, the proposed in the article technology is near zero-waste and minimizes the negative influences of recycling on the environment.

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# The Zero Pollution Ambition. European Main Cities Urban Sound Environment Analysis

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**Abstract.** Noise is considered the second largest environmental cause of ill health in western Europe. Despite the efforts made, the current situation in European cities reflects that the zero pollution ambition from the European Green Deal vision regarding noise exposure reduction is far away. The tendency shows that noise exposure may continue increasing with a global increase of the analyzed data of 7% in 2017 compared to 2012. The present work reflects on the policies and challenges that the sound environment in Europe is facing, exemplify through 2012 and 2017 data from the European main cities situation regarding population noise exposure and the following actions to improve the city sound environment. An exposition of a series of aspects that may help to change the trend regarding noise exposure and the irresponsible territory consumption practices.

**Keywords:** Urban sound environment · Zero pollution · European green deal · Noise exposure · Noise map · Noise action plan · Europe · Health

## 1 Improving the Sound Environment. Policies and Challenges Regarding the Cities' Sound Environment in Europe

### 1.1 Noise Pollution in Europe

According to the World Health Organization (WHO), noise from transport is considered the second largest environmental cause of health problems in western Europe, just after the impact of air pollution regarding particulate matter [1, 2]. The report form 2020 on noise pollution in Europe estimated that most of the European countries have more than 50% of inhabitants within urban areas exposed to road noise levels of 55 decibels (dB) or higher during the day-evening-night period (Lden) [3].

With this framework, Europe has been for decades in front of a tremendous challenge regarding sound environment and population protection, with no clear success. Policies have been implemented guided by main programs such as the "7th Environmental Action


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Programme" (7th EAP) from 2013 [4], setting a series of environmental targets, including noise reduction, to be achieved by 2020, and the recent "European Green Deal", setting new goals for 2030 and the zero pollution vision for 2050 [5]. The following sections present the current leading documents regarding noise pollution reduction in Europe.

### 1.2 The Environmental Noise Directive

At the heart of the noise policy in Europe, the Parliament launched in 2002 the Environmental Noise Directive (END) as a common instrument "intended to avoid, prevent or reduce on a prioritized basis the harmful effects, including annoyance, due to exposure to environmental noise" [6]. The intention is that countries have to take action to reduce noise exposure, while providing standard mechanisms to report data.

Agglomerations with more than 100,000 inhabitants are obliged to submit data about area and population exposed to high noise levels every five years (noise mapping rounds 2012, 2017 and the forthcoming 2021), estimate health effects and communicate results to the citizens. The END obliges to present this data analyzed through noise maps on the estimated total number of people living in dwellings that are exposed to each of the following bands of values of Lden (day-evening-night average noise exposure) in decibels (dB), 4 m above the ground on the most exposed façade: 55–59, 60–64, 65–69, $>$ 70 dB, separately for road, rail and air traffic and for industrial sources. It is also mandatory to report data exclusively for the night period.

Despite setting these ranges, the main drawback of the END is that it does not set binding environmental values. In this sense, the guiding levels are set by the WHO, who strongly recommends "reducing noise levels produced by road traffic below 53 dB (Lden), as road traffic noise above this level is associated with adverse health effects" [7]. Moreover, the END sets as well the need to protect quiet areas and improve environmental quality through the so called Noise Action Plans (NAP) that follows the noise mapping procedure.

The END has recently adopted a common noise assessment method with the intention to harmonize the obtained data about noise exposure within the European countries. The authorities are obliged to use this new calculation method, named the "Common Noise Assessment Method in Europe" known as the CNOSSOS-EU [8, 9] in the noise mapping round data from 2021.

### 1.3 The European Green Deal: Implications Regarding the Sound Environment

The European Green Deal (EGD) is the main driving document towards zero pollution vision for 2050 in Europe: "Air, water and soil pollution is reduced to levels no longer considered harmful to health and natural ecosystems and that respect the boundaries our planet can cope with, thus creating a toxic-free environment." In order to speed up pollution reduction, the European Green Deal vision of a "Healthy Planet for All", sets six main actions for 2030, where noise pollution is explicitly included in one of them: by 2030 the EU should reduce by 30% the share of people chronically disturbed by transport noise [5].

### 1.4 The 7th Environmental Action Programme

Before the EGD irrupted in the European environmental agenda, the 7th Environmental Action Programme [4] had the goal of decreasing noise pollution and moving towards people exposure by 2020. The document from 2013, stated that available data regarding long-term average noise exposure (Lden) set that 65% of Europeans living in major urban areas are exposed to high noise levels (Lden > 55 dB), and more than 20% to night time noise levels (Lnight > 50 dBA); above these noise levels, adverse health effects occur frequently.

## 2 Analysis. Evolution of Noise Exposure in Main European Cities

### 2.1 Noise Mapping Information from European Main Cities (2012 and 2017)

The present analysis has been performed according to official data from the European Environment Agency (EEA) from noise mapping rounds corresponding to the years 2012 and 2017 [10, 11]. Despite the obligation to submit information regarding population noise exposure from agglomerations with more than 100,000 inhabitants, there is a substantial amount of missing information; from the 395 European agglomerations obliged to present data in 2017, 137 have not reported noise exposure data. Regarding European main cities, from the EEA37 plus the United Kingdom (UK), Athens, Skopje lack information both from 2012 and 2017; Brussels misses data from 2017, and no data from Ankara is collected. On the other side, Liechtenstein is not obliged to submit data (< 100,000 inhabitants). For the present analysis, information from the 28 European main cities that deliver information both in 2012 and 2017 is studied (see Table 1).

Grouping the 28 cities, there is an increase in the percentage of people exposed to harmful noise levels from 2012 to 2017 (see Table 2).

Despite delivering data, there is a series of cities where authors recommend data to be revised by authorities: Riga, Lisbon, Paris, Zagreb and Budapest. In this sense, Riga and Lisbon have the same number of people exposed to the different ranges of noise exposure (Lden) in 2012 and 2017. Paris, Zagreb, Lisbon, Prague and Budapest have the same population size in 2012 and 2017. The cities were included in the analysis, but it is important to consider that data should be revised.

The analyzed cities have been grouped according to their sound environment situation regarding population exposure to day-evening-night (Lden > 55 dB) period.

A large number of main cities (17) with data included both in 2012 and 2017 have increased the number of people exposed (Lden > 55 dB): Paris and Vienna with an exponential growth (more than double of population exposed in 2017 compared to 2012); followed by Stockholm (80% more people exposed), Luxembourg, Valletta and Vilnius with increases in noise exposure between 45 and 25%. The following cities experience as well an increase in population noise exposure: Copenhagen, Berlin, London and Bern with increases between 15 and 10%; Bucharest, Budapest, Amsterdam, Bratislava, Oslo, Warsaw with increases between 9 and 2%, and Ljubjana, with less than 1% (see Fig. 1).

In general, nine main European cities have experience a decrease in 2017 in population noise exposure (Lden > 55 dB) respect to the year 2012 and presented in Fig. 2:

**Table 1** List of European main cities studied

| Country | Agglomeration name | Country | Agglomeration name |
|---|---|---|---|
| Austria | Vienna | Lithuania | Vilnius |
| Bulgaria | Sofia | Luxembourg | Luxembourg |
| Croatia | Zagreb | Malta | Valletta |
| Czech Republic | Prague | Netherlands | Amsterdam |
| Denmark | Helsinki | Norway | Oslo and adjacent agglomerations |
| Estonia | Tallinn | Poland | Warsaw |
| Finland | Helsinki | Portugal | Lisbon |
| France | Paris | Romania | Bucharest |
| Germany | Berlin | Slovakia | Bratislava |
| Hungary | Budapest | Slovenia | Ljubljana |
| Iceland | Reykjavik | Spain | Madrid |
| Ireland | Dublin | Sweden | Stockholm |
| Italy | Rome | Switzerland | Bern |
| Latvia | Riga | United Kingdom | London |

**Table 2** Percentage of people exposed to high noise levels in the European main cities in 2012 and 2017 (data from 28 cities from the EEA33 + UK)

| Noise exposure indicator[a] | 2012 (%) | 2017 (%) |
|---|---|---|
| Lden (day.evening.night) > 55 dB | 42.3 | 49.2 |
| Lnight > 50 dBA | 30.3 | 34.8 |

[a] Lden states for long-term day-evening night noise exposure indicator. Lnight states for long-term noise exposure indicator during the night period

Helsinki (42% reduction), Bratislava (38%), Reyjkavik (23%), Sofia (17%), London (16%), Dublin (12%) Zagreb (12%), Copenhagen (7%) and Rome (4%).

Remarkable is that even though Helsinki, Tallinn and Dublin have increased their population size from 2012 to 2017 (11, 9 and 2% respectively), they have managed to reduce population noise exposure (see Fig. 2), with Helsinki reducing 42% of it in 2017 respect to the year 2012. However, the city of Helsinki states that this reduction is a result of a change in accounting the population exposure to the latest European methods, taking into account that some of the residents' homes are located on the quieter façade of the building, contrary to 2012 mapping, where all residents where located in the noisiest façade [12]. The case of Tallinn differs, where a strong focus on local plans and initiatives included in the Noise Action Plan, considering urban development and mobility as a priority has had an impact on Tallinn´s noise levels reduction. The plans have targeted buildings, traffic development and traffic management plans together with

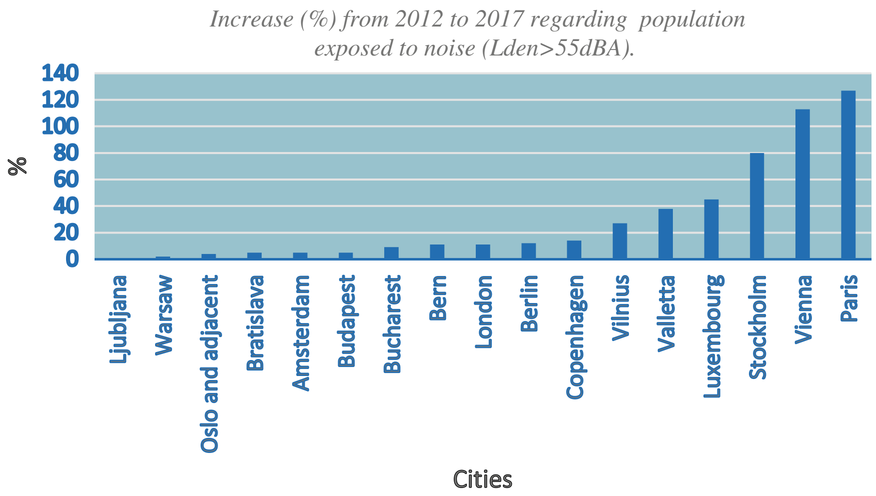


**Fig. 1** Increase in the percentage of the exposed population in 2017 compared to 2012 in the main European cities

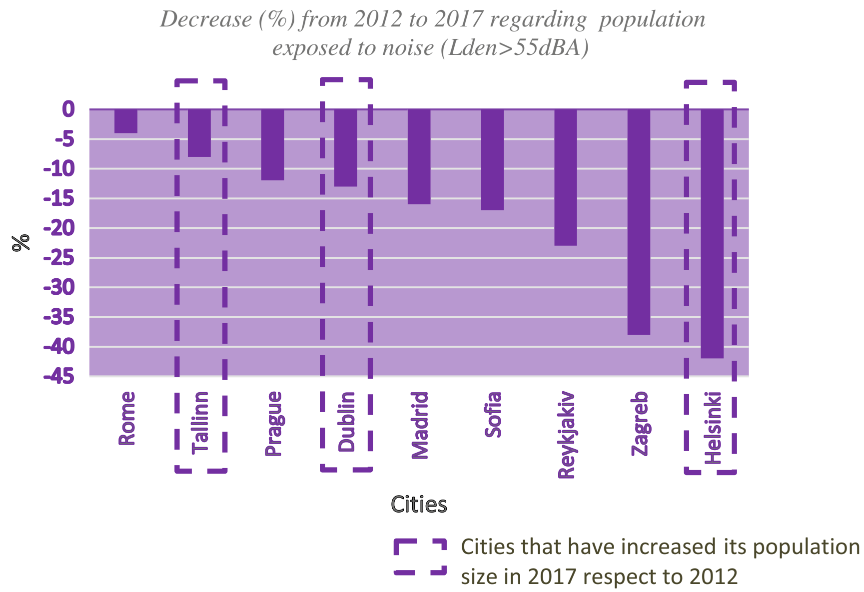


**Fig. 2** Cities that have decrease population noise exposure in 2017 respect to 2012

the long-term environmental strategy named "Tallinn 2030" [13]. Other cities that have decease noise exposure (Lden), however, have lost population are: Reyjkavik has lost 33%, followed by far by Madrid and Sofia (3% each of them) and Rome with 1% less population in 2017 respect to data presented from 2012.

Regarding Noise Action Plans that follow the noise maps situation, only 36% of the total number of agglomerations in Europe (EEA32 excluding Turkey and including UK) have reported on action plans for the noise maps from 2017 [14, 15]. This lack of information reflects the generalized lack of commitment, tools and capacity from authorities to pursue a better sound environment and a considerable effort is needed to pursue the administrations to embrace the vision of "Health for All" in their agendas.

## 3 Discussion and Conclusions

Despite the efforts made by the EU to improve the sound environment of European agglomerations and by end, to reduce the noise exposure of citizens, there are no significant changes regarding population exposed reduction. Contrary, the tendency reflects that the noise exposure may continue increasing in the following years, failing to achieve the so called "zero pollution ambition".

It is important to state that data evaluation is essential, and the sound environment status cannot be addressed if cities do not provide the noise maps and the noise action plans that are required by the EU. Some progress has been made, but yet, a large part of the European cities (35%) do not provide noise maps information in the last noise maps round in the year 2017.

Data from the year 2021 is still not available for the main European cities. A good start for them is that the EU has agreed to establish a common noise assessment method for all noise maps, named CNOSSOS-EU [8]. The noise maps produced with 2021 data will be the first time with a common method among all European agglomerations. This could lead to better comparisons from now on, since previous noise mapping rounds had different calculation methods for assessing noise exposure, being a drawback for common assessment and criteria.

Since no binding noise environmental values are set, the EC can only launched infringement procedures against the Member States that do not comply with the Environmental Noise Directive rules of producing noise maps and the consequent noise action plan. As a consequence, in 2020 the EC has already brought to the European Court of Justice the case of Portugal and Slovakia, and 10 other members are under infringement procedures [13]. The costs regarding health burden of this non-compliance has been estimated between EUR 24.6 and 36.8 billion per year [16]. In this sense, the latest driving document to guarantee and promote health for all Europeans, the European Green Deal, is probably going to be able to set limit values regarding noise exposure. The document states that it will review progress regarding noise exposure in 2022, and take into consideration whether there is a need to set noise reduction targets at EU level in the END. This will push forward the objectives regarding zero pollution, having, finally, binding environmental noise values working together with better integrated policies, setting probably rapid urbanization changes and urban mobility plans at the core of it. This rapid urbanization changes must aligned with the EU agenda, where planning has been identified as one of the most efficient instruments regarding the improvement of the sound environment [13]. As the European Green Deal states [5], it is time to "reverse the pyramid" of hierarchy and being more efficient, taking action in prevention, minimizing at most pollution, and if pollution is already present, it should be remediated. However, for this pyramid shift to occur regarding noise exposure, a transition period should take place, whereas a horizontal hierarchy preventing, minimizing and repairing in parallel must be carried out, as consolidated cities are suffering the failures and sometimes, the inaction regarding urban health.

An opportunity to consume the territory in a responsible way is ahead of us, and urban health for all must lead all policies regarding the environment. Knowledge about health effects from noise exposure has been there for decades and better practices to improve the sound environment are constantly developed; it is only the effort from governance and industry, the citizen community commitment and the integration of policies who will make possible to achieve the desired zero pollution ambition.

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# Impact of the Operation Conditions on the Reverse-Water-Gas Shift Reaction

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**Abstract.** The reverse water gas shift (rWGS) reaction represents a key technology to realize an end-to-end power-to-liquid process chain. In this work, experimental tests of a nickel catalyst are reported. The influence of operating temperature (650–950 °C), pressure (ambient pressure up to 6 $bar_a$) and gas hourly space velocity (6000–40 000 $h^{-1}$) on the conversion of $CO_2$ and hydrogen is investigated. The results of this experimental evaluation show that the rWGS reaction favors high temperatures and low pressures. Thermodynamic equilibrium is approached with the used catalyst. Higher gas hourly space velocities favor the rWGS reaction and inhibit methane formation.

**Keywords:** Carbon capture and utilization · Catalyst performance · Power-to-liquid · Reverse water gas shift

## 1 Introduction

The cement industry emitted 9 % of Austria's ETS (EU Emission Trading System) certified emissions, which corresponds to 3.3 % of Austria's carbon dioxide emissions in 2019 [1]. Austria's target is to reduce 40 % of greenhouse gas emissions by 2030 and achieve climate neutrality by 2040 [2]. In cement production process-related $CO_2$ emissions are unavoidable, which are generated by the decarbonization process of limestone and account for two-thirds of the total greenhouse gas emissions. [3]. One option for the reduction of $CO_2$ emissions is the implementation of a carbon capture and utilization (CCU) plant. A possible Power-to-Liquid route is a Fischer–Tropsch synthesis. The produced synthetic oil can be further converted in steam- and hydrocrackers to propylene or ethylene, which is the feedstock for polypropylene and polyethylene production [4]. The Fischer Tropsch synthesis requires syngas (a mixture of carbon monoxide and hydrogen) as feedstock, the direct hydrogenation of $CO_2$ is currently not yet commercially available [5].

Therefore, a pre-conversion of $CO_2$ to CO is required which can be achieved with the reverse water gas shift reaction. Basically, the rWGS reaction (Eq. 1) is endothermic and catalytically converts carbon dioxide with hydrogen to carbon monoxide and water (steam) [6, 7].

$$CO_2 + H_2 \leftrightarrow CO + H_2O \qquad \Delta H_r^{298K} = +41 kJ/mol \tag{1}$$


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The $CO_2$ conversion ($X_{CO_2}$) is defined as the ratio between the difference of inlet ($\dot{n}_{CO_2,in}$ in kmol/h) and outlet ($\dot{n}_{CO_2,out}$ in kmol/h) mole flow, and the $CO_2$ inlet mole flow as given in Eq. 2. Furthermore, Eq. 3 defines the CO selectivity ($S_{CO}$) as the ratio of the obtained CO mole flow ($\dot{n}_{CO}$ in kmol/h) in the product and the converted $CO_2$ [8].

$$X_{CO_2} = \frac{\dot{n}_{CO_2,in} - \dot{n}_{CO_2,out}}{\dot{n}_{CO_2,in}} \tag{2}$$

$$S_{CO} = \frac{\dot{n}_{CO,out} - \dot{n}_{CO,in}}{\dot{n}_{CO_2,in} - \dot{n}_{CO_2,out}} \tag{3}$$

Considering the thermodynamics of the reaction, a complete conversion of $CO_2$ is not feasible. Side reactions that occur, such as methanation, Bosch reaction or the Boudouard equilibrium, must also be taken into account in the catalytic conversion process. The last two lead to coke formation and deactivation of the catalyst. To counteract this and improve the $CO_2$ conversion, the equilibrium can be shifted by running the rWGS reaction with an over-stoichiometric ratio of $H_2$:$CO_2$ of 3:1 [9]. Thus, a syngas composition with a desired $H_2$:CO ratio of 2:1 is obtained. Figure 1 shows the thermodynamic equilibrium in a temperature range of 300–1100 °C and pressures of 1, 5 and 30 bar$_g$ [10].

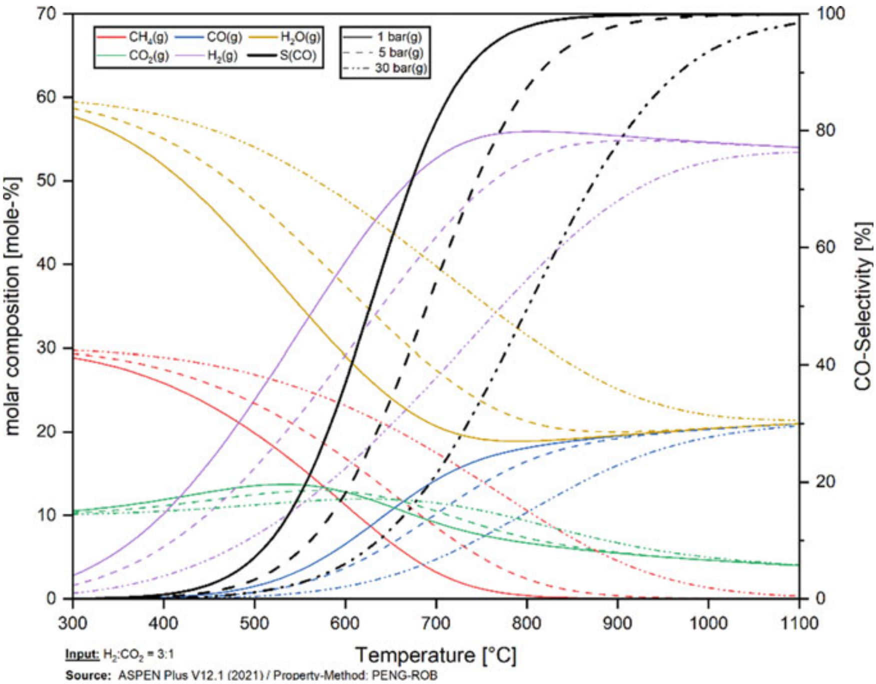


**Fig. 1** Thermodynamic equilibrium considering an inlet ratio of $H_2$:$CO_2$ of 3:1 in a temperature range of 300–1100 °C and pressures of 1, 5, and 30 bar$_g$

In this work, an experimental investigation of the rWGS reaction is carried out. The experiments provide insights into temperature, pressure, and gas-hour-space-velocity (GHSV) dependence of the reaction. A comparison of the experimentally obtained product compositions with the thermodynamic equilibrium is performed.

# 2 Methods

## 2.1 Experimental setup

The experimental setup is constructed as shown in the P&ID diagram (Fig. 2), starting with a gas mixing station (X1, mass controller of hydrogen/0–12 Nl/min, carbon dioxide/0–10 Nl/min, and nitrogen/0–20 Nl/min), a quartz-glass reactor in a tube furnace, a cooling and water condenser unit, followed by the gas analysis and flare. The quartz glass is designed for an operating pressure of 10 $bar_a$ and temperatures up to 1100 °C. The plant settings and the registration of the measured values are handled by the "Lookout" software. The pressure is controlled by adjusting the automatic valve (V038) at the reactor outlet.

The glass reactor has a length of 1700 mm and an inner diameter of 15 mm. The connections from the glass tube to the piping are made via crimp connectors, which allow a maximal operating inlet pressure of 6 $bar_a$. The gas mixture is fed directly to the crimp connectors without heating. To achieve high temperatures, the catalyst is located at the end of the reactor, while the furnace is also used as gas preheating unit. The nickel-based catalyst used has a cylindrical shape (3.2 mm $\times$ 3.2 mm). The catalyst bed has a length of 75 mm and a total bulk volume of 12.37 $cm^3$. The remaining volume of the glass tube is filled with inert balls, ensuring sufficient heat exchange in the preheating zone. Six thermocouples are implemented in the reactor to obtain the axial temperature profile. The position of the thermocouples is depicted in Fig. 3.

## 2.2 Catalyst tests

Activation of the catalyst started with heating the fixed bed to temperatures of 500 °C (thermocouple T3) in the furnace. Nitrogen at 10 Nl/min was used to purge the system. When the temperature was reached, the ratio of nitrogen to hydrogen was gradually changed and after 30 min, pure hydrogen was fed into the system for catalyst activation. After one hour, the temperature was increased to 950 °C and the catalyst was ready for catalyst testing.

In the initial experimental tests, the operation pressure was gradually increased from atmospheric pressure to 6 $bar_a$ with a starting temperature of 950 °C (measured at thermocouple T3) and a constant GHSV of 20 000 $h^{-1}$. Temperature variation continued for 850, 750 and 650 °C according to the experimental design (Table 1). In the second series of catalyst tests, the effect of temperature and GHSV on the rWGS reaction was investigated. The experiments started with temperatures of 650 °C measured at the beginning of the catalyst bed (thermocouple T3), and the GHSV was varied between 6000 and 40 000 $h^{-1}$. The design for the second experimental test series is detailed in Table 2.

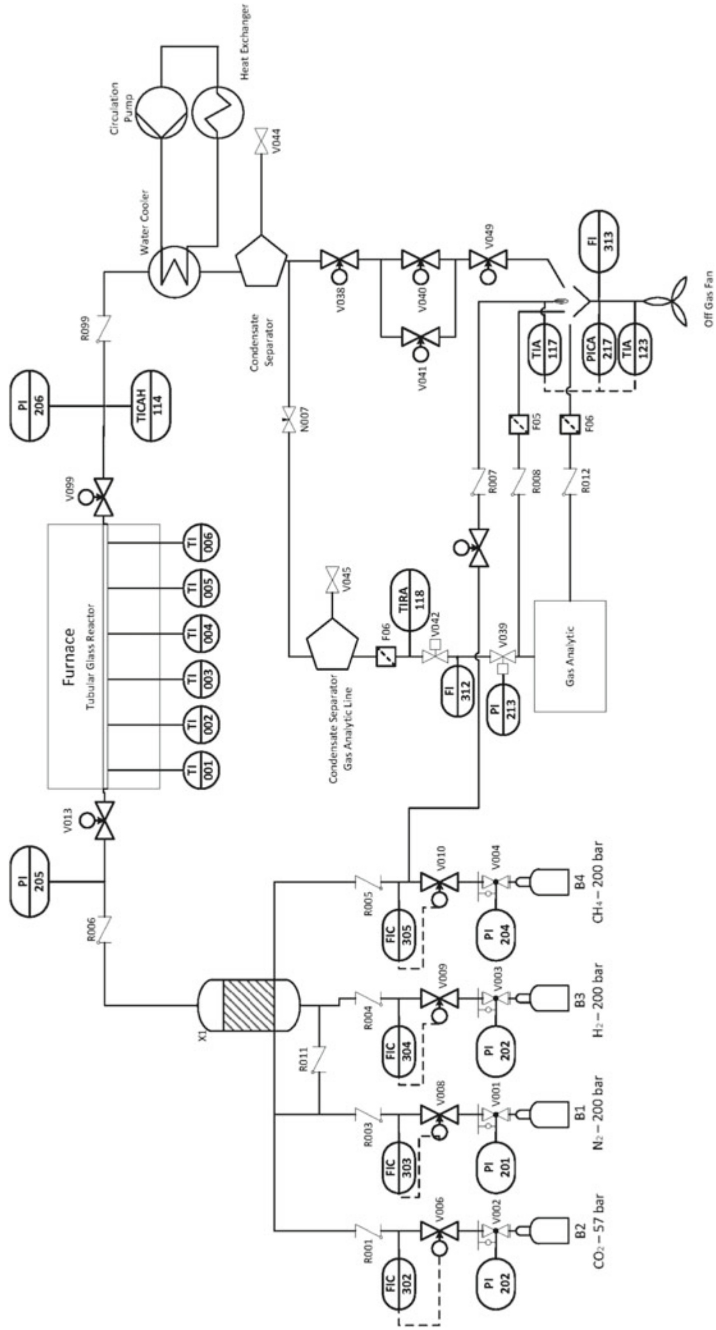


**Fig. 2** P&ID of the experimental setup

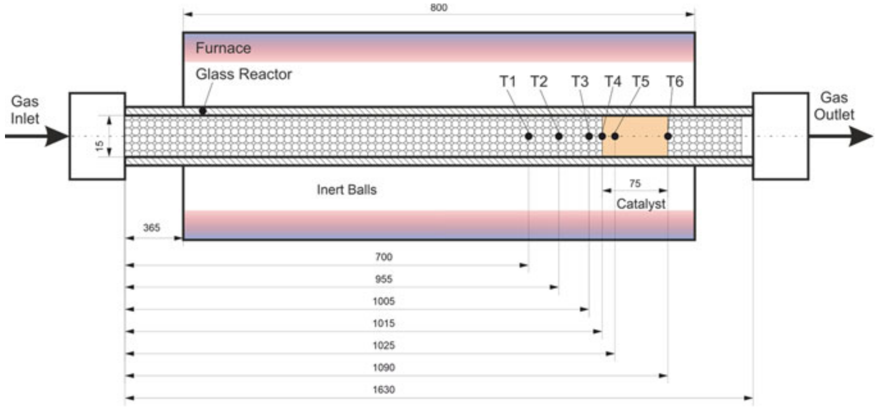


**Fig. 3** Experimental setup and position of the thermocouples in the glass reactor

### 2.3 Evaluation of the experimental data and calculation of the thermodynamic equilibrium

The inlet flow of the feed gas is measured by mass flow meters, and the molar flow is subsequently calculated. The gas analyzer is implemented behind the water condenser (Fig. 2). It measures $CO_2$, CO, $CH_4$ and the ratio of $H_2$:$N_2$. The figures are registered in the "Lookout" software. The equilibrium conversions are calculated in ASPEN HYSYS V12, which implements a Gibbs reactor that minimizes the Gibbs-free energy. The values of the gas analysis are recalculated for the dry gas flow, and are directly compared with the equilibrium calculation from ASPEN.

## 3 Results

According to Fig. 1, the rWGS reaction generally favors high temperatures (900 °C) and low pressures for achieving the thermodynamic equilibrium. At pressures of 10 and 30 $bar_g$, even elevated temperatures of 950 °C and higher are necessary.

In the first experimental test series the influence of pressure on the rWGS reaction is investigated. Figure 4 compares the thermodynamic equilibrium with the experimental results for pressures of 1.4, 3 and 6 $bar_a$. The full lines describe the development of the molar fractions in thermodynamic equilibrium for the components CO, $CO_2$, $CH_4$ and $H_2$ calculated from ASPEN HYSYS. Here, steam is not included in the evaluation due to the separation upstream of the gas-analyzer. The comparison of the pressure influence is also shown in Fig. 4.

In the second experimental tests, the influence of the gas-hourly-space-velocity (GHSV) and temperature at ambient pressure is investigated. The deviation of experimental results from the thermodynamic calculation is shown in Fig. 5 for the GHSV values of 6000, 10 000, 20 000 and 40 000 $h^{-1}$. Again, the full lines describe the development of the molar fractions of CO, $CO_2$, $CH_4$ and $H_2$ in thermodynamic equilibrium. The absolute deviation of each GHSV value is shown in the last plot of Fig. 5.

**Table 1** Design of experiments with variation of temperature and pressure at constant GHSV

| Exp. number | Temperature | Pressure | GHSV | $CO_2$ | $H_2$ |
|---|---|---|---|---|---|
| # | (°C) | ($bar_a$) | ($h^{-1}$) | (Nl/min) | (Nl/min) |
| 1.1 | 950 | 1 | 20 000 | 1.1781 | 3.5343 |
| 1.2 | 950 | 2 | 20 000 | 1.1781 | 3.5343 |
| 1.3 | 950 | 3 | 20 000 | 1.1781 | 3.5343 |
| 1.4 | 950 | 4 | 20 000 | 1.1781 | 3.5343 |
| 1.5 | 950 | 5 | 20 000 | 1.1781 | 3.5343 |
| 1.6 | 950 | 6 | 20 000 | 1.1781 | 3.5343 |
| 1.7 | 850 | 1 | 20 000 | 1.1781 | 3.5343 |
| 1.8 | 850 | 2 | 20 000 | 1.1781 | 3.5343 |
| 1.9 | 850 | 3 | 20 000 | 1.1781 | 3.5343 |
| 1.10 | 850 | 4 | 20 000 | 1.1781 | 3.5343 |
| 1.11 | 850 | 5 | 20 000 | 1.1781 | 3.5343 |
| 1.12 | 850 | 6 | 20 000 | 1.1781 | 3.5343 |
| 1.13 | 750 | 1 | 20 000 | 1.1781 | 3.5343 |
| 1.14 | 750 | 2 | 20 000 | 1.1781 | 3.5343 |
| 1.15 | 750 | 3 | 20 000 | 1.1781 | 3.5343 |
| 1.16 | 750 | 4 | 20 000 | 1.1781 | 3.5343 |
| 1.17 | 750 | 5 | 20 000 | 1.1781 | 3.5343 |
| 1.18 | 750 | 6 | 20 000 | 1.1781 | 3.5343 |
| 1.19 | 650 | 1 | 20 000 | 1.1781 | 3.5343 |
| 1.20 | 650 | 2 | 20 000 | 1.1781 | 3.5343 |
| 1.21 | 650 | 3 | 20 000 | 1.1781 | 3.5343 |
| 1.22 | 650 | 4 | 20 000 | 1.1781 | 3.5343 |
| 1.23 | 650 | 5 | 20 000 | 1.1781 | 3.5343 |
| 1.24 | 650 | 6 | 20 000 | 1.1781 | 3.5343 |

The measured temperatures of thermocouples are shown in Fig. 6. The reactor temperature profile is shown for a catalyst bed inlet temperature of 650 °C and 950 °C as well as for gas hourly space velocities of 6000, 10 000, 20 000 and 40 000 $h^{-1}$.

## 4 Discussion

The operating conditions, temperature, pressure and GHSV, influence conversion and yield of the rWGS reaction on a nickel catalyst significantly. The unwanted methanation reaction is suppressed by high temperatures and low pressure levels, as it can be seen in Fig. 4. The experimentally obtained product compositions approximate fairly good to

**Table 2** Design of experiments with variation of temperature and GHSV at constant pressure

| Exp. number | Temperature | Pressure | GHSV | $CO_2$ | $H_2$ |
|---|---|---|---|---|---|
| # | (°C) | ($bar_a$) | ($h^{-1}$) | (Nl/min) | (Nl/min) |
| 2.1 | 650 | 1 | 6000 | 0.3534 | 1.0603 |
| 2.2 | 650 | 1 | 8000 | 0.4712 | 1.4137 |
| 2.3 | 650 | 1 | 10 000 | 0.5890 | 1.7671 |
| 2.4 | 650 | 1 | 20 000 | 1.1781 | 3.5343 |
| 2.5 | 650 | 1 | 40 000 | 2.3562 | 7.0686 |
| 2.6 | 750 | 1 | 6000 | 0.3534 | 1.0603 |
| 2.7 | 750 | 1 | 8000 | 0.4712 | 1.4137 |
| 2.8 | 750 | 1 | 10 000 | 0.5890 | 1.7671 |
| 2.9 | 750 | 1 | 20 000 | 1.1781 | 3.5343 |
| 2.10 | 750 | 1 | 40 000 | 2.3562 | 7.0686 |
| 2.11 | 850 | 1 | 6000 | 0.3534 | 1.0603 |
| 2.12 | 850 | 1 | 8000 | 0.4712 | 1.4137 |
| 2.13 | 850 | 1 | 10 000 | 0.5890 | 1.7671 |
| 2.14 | 850 | 1 | 20 000 | 1.1781 | 3.5343 |
| 2.15 | 850 | 1 | 40 000 | 2.3562 | 7.0686 |
| 2.16 | 950 | 1 | 6000 | 0.3534 | 1.0603 |
| 2.17 | 950 | 1 | 8000 | 0.4712 | 1.4137 |
| 2.18 | 950 | 1 | 10 000 | 0.5890 | 1.7671 |
| 2.19 | 950 | 1 | 20 000 | 1.1781 | 3.5343 |
| 2.20 | 950 | 1 | 40 000 | 2.3562 | 7.0686 |

the thermodynamic equilibrium for each pressure level. Only at temperatures higher than 650 °C a larger deviation ca be observed for carbon monoxide, particularly in comparison to $CO_2$, $CH_4$, and $H_2$. Methane formation is below thermodynamic equilibrium at 650 °C. This may be caused by the exothermic nature of the methanation reaction which heats up the catalyst bed locally, and thus suppress methane formation. Nevertheless, the experimental investigation confirms that temperature and pressure have a corresponding influence on the conversion of $CO_2$ to the desired synthesis gas. Low pressure and high temperature favor the rWGS reaction, while high pressure and lower temperatures promote methane formation.

The influence of the GHSV value is not so decisive as temperature and pressure. The comparison of the experimental results of the five different GHSV values (Fig. 6, 6000, 10 000, 20 000, 40 000 $h^{-1}$) reveals that the methane content in the product gas decreases with increasing gas velocity. The temperature drops at a specific gas velocity of 40 000 $h^{-1}$ to 900 °C (measured at thermocouple T4) what changes the thermodynamic equilibrium significantly in the direction of methanation. However, even at 900 °C,

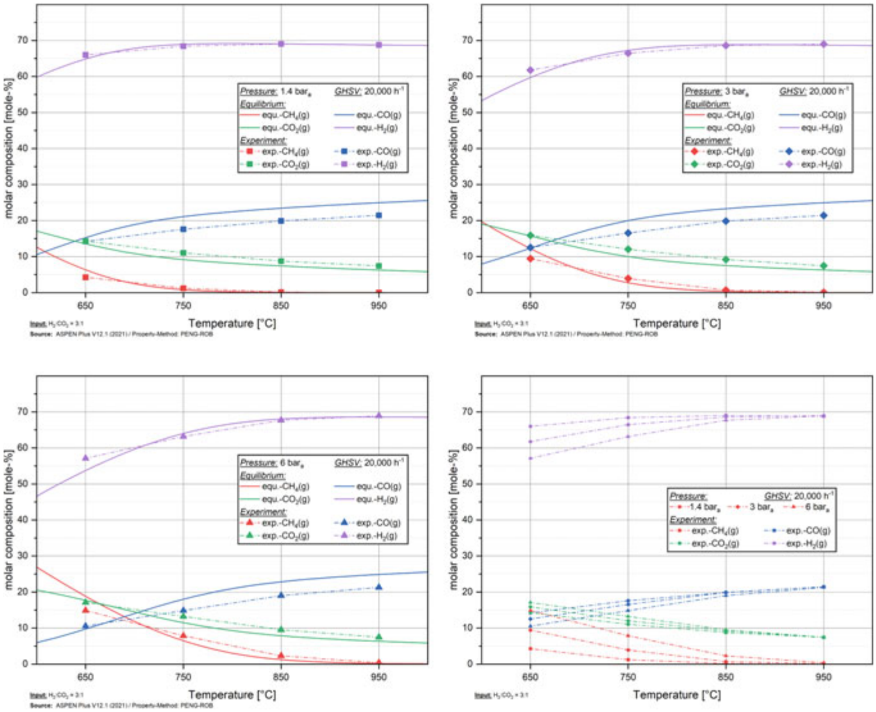


**Fig. 4** Experimental results and thermodynamic equilibrium for constant GHSV values and variation of pressure levels (1.4, 3, 6 bar$_a$)

methane formation is very low. On the other hand, the higher gas velocity makes the flow in the reactor more turbulent, allowing better heat and mass transfer between the catalyst surface and the gas particles.

A similar trend can be observed at 650 °C, however due to the increased heat release by the exothermic methanation, the temperature deviations are less pronounced. As shown in Fig. 6, the higher gas velocity leads to higher heat generation in the catalyst and this also results in the shift of the thermodynamic equilibrium towards the endothermic rWGS reaction, which can also be seen by a small temperature drop at thermocouple T4. With higher pressure and increased methane formation, the temperature continues to increase. In order to maintain constant temperatures of 650 °C, the reactor would have to be cooled instead of heated in this case. Additionally, the higher GHSV value allows a higher exit temperature from the catalyst and thus a lower selectivity to $CH_4$. The CO content increases accordingly.

The second series of tests was carried out completely independently of the first series of tests. This allows validation of the product composition at temperatures 650, 750, 850 and 950 °C and ambient pressure for a GHSV value of 20 000 h$^{-1}$.

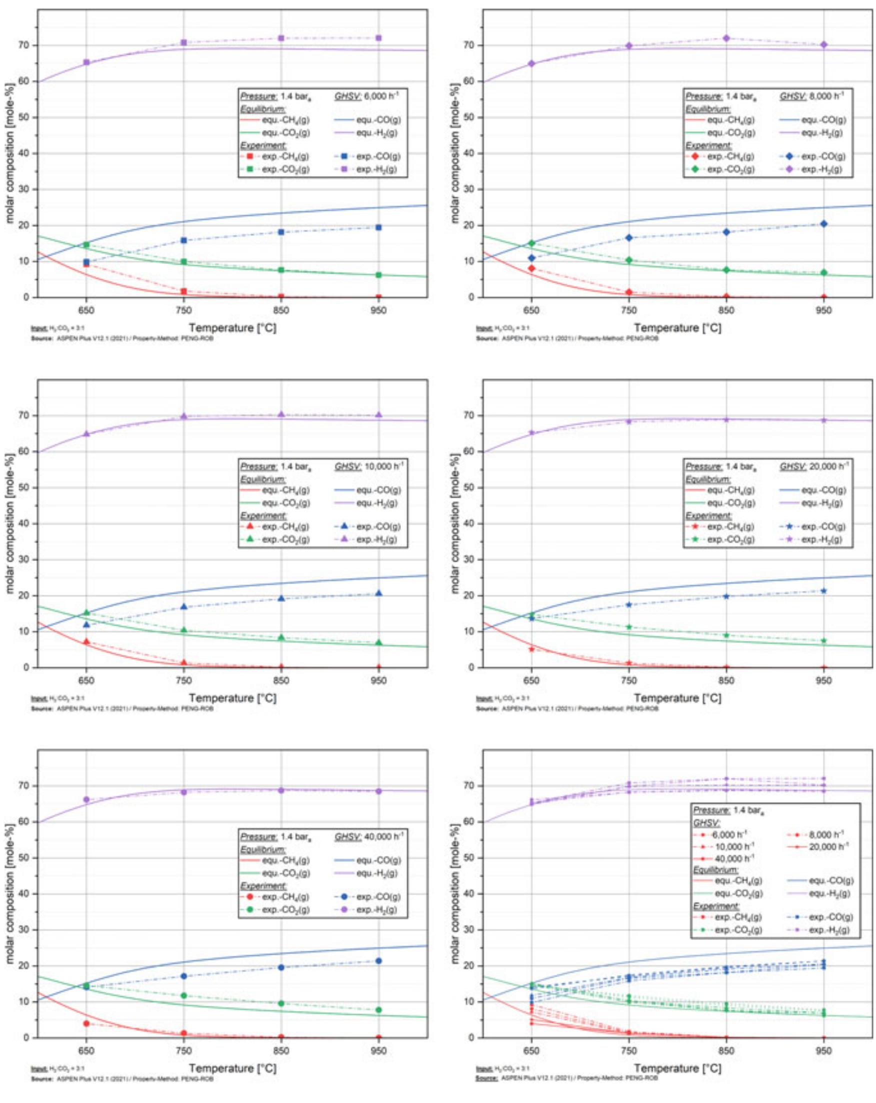


**Fig. 5** Experimental results and thermodynamic equilibrium for ambient pressure and GHSV variation (6000, 8000, 10 000, 20 000, 40 000 $h^{-1}$)

## 5 Conclusions

The reverse water gas shift reaction enables the conversion of $CO_2$ and hydrogen into synthesis gas, which is used as a feedstock for a wide variety of syntheses. The experimental results in this work show that the rWGS reaction can be performs on nickel catalysts. The conversion of $CO_2$ and hydrogen into synthesis gas is favored at higher temperatures and lower pressures, since methane formation is inhibited. Therefore, the rWGS reaction should be operated at temperatures higher than 900 °C and pressures

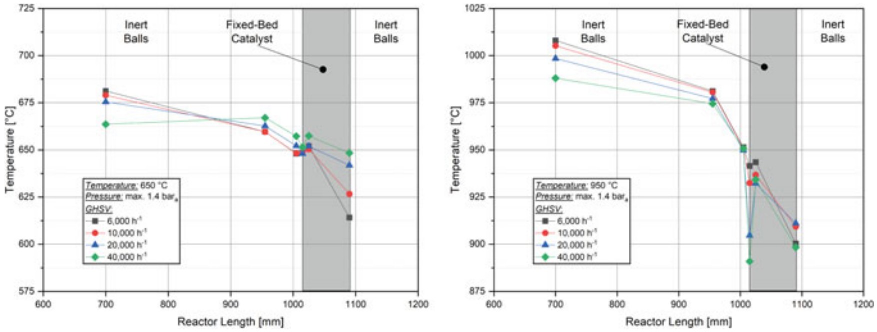


**Fig. 6** Reactor temperature profile for 650 and 950 °C (measured at thermocouple T3) and GHSV values of 6000, 10 000, 20 000, 40 000 $h^{-1}$

lower than 6 $bar_a$ to suppress undesired methane formation. However, the selection of the operating pressure level is also influenced by the pressure requirements of further downstream catalytic conversions.

The gas hourly space velocity in the fixed-bed reactor has only a minor effect on the $CO_2$ conversion. In this experimental study, higher gas velocities favor the rWGS reaction and inhibit methane formation. A general recommendation for an optimum gas hourly space velocity cannot be given, since the simplified experimental set-up does not allow for a transformation to industrial reactor systems.

Further studies should deal in particular with a more detailed analysis of the product gas stream for other by-products, as only $CH_4$ and no longer chain hydrocarbons were measured in these initial series of experiments. Furthermore, the influence of the over-stoichiometric hydrogen feed on coke formation, conversion, selectivity and the turbulence in the catalyst bulk should be investigated.

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# Consumption Behaviour in the Context of Sustainable Energy: Theoretical Approach

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**Abstract.** Increasing production and consumption have a growing environmental impact. The challenge for all countries is to decouple economic growth from the environmental impacts of consumption, resource use and waste generation. The economic sectors with the highest environmental impacts are electricity, gas and water supply, transport services and agriculture. It is there-fore becoming important to improve energy efficiency and invest in innovative and resource-efficient technologies, recognising the need to change consumption patterns and behaviours. The Sustainable Development Strategy focuses on sustainable production and consumption. Although historically the focus has been on production and the associated environmental problems and solutions such as pollution control, cleaner production and recycling. Production and consumption as interdependent indicators have only recently come into focus as researchers have realised that production and consumption are highly interrelated. Sustainable Development Goals have stressed the importance of promoting consumption and production that have the least possible impact on the environment and are able to meet the basic needs of humanity.

**Keywords:** Sustainable consumption · Sustainable production · Sustainable energy · Consumer behaviour

## 1 Introduction

Consumption changes are continuously monitored by collecting and analysing data on consumer behaviour in individual countries or regions. During the quarantine of the COVID-19 pandemic, consumers started to realise how much influence they have on their decisions. For example, according to the European Environment Agency (EEA) (2020), one of the unintended consequences of such sudden socio-economic shocks has been a reduction in the concentration of air pollutants, mainly due to the restriction of traffic and other activities, especially in parts of China and Europe (e.g. during the period of isolation in the north of Italy) [1, 2]. The emergence of the COVID-19 pandemic has highlighted the relationship between people and nature, and has raised awareness that our health, our ecosystems, our supply chains, our patterns of consumption and production, and the planet's capacities are inextricably linked, and it has highlighted the basic principles of the trade-offs we are constantly faced with: that human beings have


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infinite needs, but that the planet's capacities to meet those needs are limited. Therefore, it is necessary to protect and restore nature immediately. Before we can have a negative impact, we need to try to understand and assess the limits to human destruction of nature. These limits must be reflected in our consumption and production behaviour. There is a realisation that current patterns of consumption and production are unsustainable, and that new sustainable patterns of consumption and production are needed that stay within the planet's boundaries and move towards more sustainable practices. Of course, reducing consumption would improve the environment, but we are dealing with human habits, cultures and emerging customs. As consumption behaviour raises complex issues, it is necessary to study this topic in a coherent way. Insights from behavioural economics can help understand the direction of change.

**The aim of the research** is to identify the scientific assumptions that determine the need of change of consumer behaviour in the context of sustainable energy.

**Research methods**—scientific literature analysis and synthesis related to consumer behaviour, sustainable consumption, sustainable energy, innovative energy technologies, abstraction. The scientific literature analysis is the basis on which new knowledge related to the research being conducted is based [3]. The abstraction aims to focus on the main, essential features of the phenomenon under consideration, revealing their essence and creating generalized concepts, theories, classifications, categories, principles, etc. [4]. Information search for analysis was performed using Scopus, ScienceDirect, Google Scholar. Basic search parameters were defined as such: search by name, period from 1985 until 2022, using keywords: consumer behaviour, sustainable development, sustainable consumption, sustainable production, sustainable energy, innovative energy technologies, sustainable energy technologies. A chosen approach to investigate the issue at hand is widely used in many theoretical studies [5, 6].

## 2 The Origin of Sustainable Consumption and Production

In the context of sustainable development, most authors provide essentially the same definitions of sustainable development, emphasising the long-term development of a country in order to rationally reconcile the economic, social and environmental interests of a society in order to ensure the global well-being of present and future generations, while staying within the limits of acceptable environmental impacts [7–12]. For example, the use of inventions of new machines, equipment, and other mechanical instruments during the industrial revolution enabled humans to enhance economic growth and living standard; however, simultaneously threatened the environment and ecosystem [13]. Likewise, the use of energy in industry and services was driven by the quest for more effective forms of fuel to respond to the needs of a rapidly growing industrialization to fulfill the demands of large-scale accessible, reliable, and adaptable forms of energy [13].

In a document related to sustainable development, the European Union's Green Deal (2020) establishes a new strategy for sustainable and inclusive growth, which emphasizes the need to rethink the supply of clean energy for the entire economy and commits Member States to achieving full carbon neutrality by 2050 and to a full transition to renewable energy sources. As part of the European Green Deal, the European Commission has developed European industrial strategy (2020) to better identify and overcome existing barriers to sustainable consumption and production, raise public awareness and change consumption behaviour. The transformation of consumption and production behaviour has become a key factor in the transition to a sustainable economy in order to achieve the green transformation.

Sustainable consumption is intrinsically linked to the principles of sustainable development [14], as it is the changes in consumption that have led to the emergence of sustainable development principles in the first place [15, 16], which is why more and more attention has been paid to sustainable consumption in particular in recent years [17–22]. Sustainable consumption broadly refers to efforts to promote more efficient consumption and the progressive conservation of energy and natural resources used. Sustainable consumption can be said to be an essential prerequisite for sustainable development and an integral part of green, sustainable economic growth. Scientific studies and analysis of EU and national documents show that incentives for sustainable consumption need to be focused on the areas where the impact of consumption is felt most strongly, i.e. private transport, the housing sector (including heating, hot water, electrical appliances, construction), and to pursue deeper systemic changes [17, 22–26]. In these areas, the environmental impact of consumption depends on consumer behaviour and the factors that influence it.

## 3 Relationship Between Sustainable Consumption and Sustainable Energy

The greatest sustainability challenge facing humanity today is the greenhouse gas emissions and the global climate change with fossil fuels led by coal, natural gas and oil [27]. Energy is currently recognized as one of the most important factors that influence the rate of progress as well as sustainable development of all nations [28], because the production and consumption of energy are posing serious environmental problems: concentrations of greenhouse gases and air pollutants are increasing in the atmosphere, leading to climate change. Therefore, sustainable energy is one of the EU's priority policy areas in implementing sustainable development goals. Sustainability is an important paradigm in the global energy transition where all dimensions of sustainability are addressed any policy formulation and implementation, planning, operation, and dispatch of the energy resources in both generation and consumption [29]. For a longtime, energy did not seriously factor in sustainable development [27]. However, sustainable development and sustainability issues now play a central role in energy and electricity by anchoring the evolution of the sustainable development paradigm [27].

The transition to sustainable energy is inseparable from consumers, which is why consumers have recently been encouraged to reduce their energy consumption and contribute to a sustainable environment. By using sustainable energy, we are promoting the very idea of sustainability to consume responsibly, to avoid wasting precious resources and to choose environmentally friendly ways of getting energy. The best examples of sustainable energy are solar and wind power, hydropower and geothermal energy. Modern technologies that ensure energy efficiency have an important role to play in the transition to sustainable energy. These technologies help to reduce energy waste in Europe. For example, smart meter technologies digitally optimise processes such as lighting and temperature control, reducing energy bills in factories, homes, hospitals, offices and elsewhere. For example, the "Empower Demand" report on 'The potential of smart meter enabled programs to increase energy and system benefits: a mass pilot comparison', written and published by VaasaETT, shows that, depending on the user's involvement, after installing smart meter technologies, savings on average are between 5 and 8.7% electricity.

Sustainable energy is in line with the concept of sustainable consumption and production—it's more and better to use less. It also means decoupling economic growth from environmental degradation, increasing resource efficiency and promoting sustainable lifestyles.

## 4 Research of Topic

Consumer behaviour, which refers to the human activities directed towards the acquisition, consumption and use of products and services through pre- and post-purchase decisions, has been a topic of research interest for several decades [30–32]. Consumer behaviour science is at the heart of a wide range of research questions related to the acquisition or non-acquisition of goods and services, from the simple who, what, how, where, when, why to complex research questions [31–33]. Consumer behaviour science has as its content the study of the consumer decision-making process and the external and internal environmental factors that influence it [32–34]. Historically, successive theories of consumer behaviour have attempted to explain how and why individuals behave when making certain decisions. This has led to the development of several theories of consumer behaviour that emphasise different motivational aspects [32, 33]. Theories of consumer behaviour were actively constructed in the 1970s–10s [30, 33]. During this period, *theories of economic man* (Bernoulli, N., Von Neumann, J., Morgenstern, O.) based on the rational, self-concerned consumer, who makes decisions in a utility-maximising and effort-less manner; *psychodynamic theories* (Freud, S.), according to which consumers' behaviour is determined by unconsciously and instinctively acting biological forces; *bioheuristic theories* (Pavlov, I, Watson, J., Skinner, B.) according to which a consumer can learn a certain behaviour under the influence of external factors; *cognitive theories* (Hebb, D. O., Neisser, U., Howard, J. A., Sheth, J. N., Blackwell, R. D., Miniard, P. W., Engel, J. F., Fishbein, M., Ajzen, I.), according to which the consumer is an information processor, active seeker, influenced by the environment and by social stimuli, and a decision-maker and response-maker, with a focus on perception, learning, memory, cognition, motivation, emotions, etc.; *humanistic theories* (Bagozzi, R, Warshaw, P. R., Perugini, M.) which consider the roles of consumers' emotions, volition (lying between consumers' purchase intentions and their actual purchase behaviour), desire, altruism-egoism motives, attempts and goals in decision making [33, 35]. This period saw the emergence of the major models of consumer behaviour [33, 36]. A consumer behaviour model is the form that consumer behaviour theory takes (an accurate representation of the phenomenon related to the consumption of goods and services that it attempts to explain). There are a number of models that can be found in the scientific literature that describe consumer behaviour, but the more widely used are the classical ones, i.e. the Nicosia model; the Howard-Sheth model; the Engel-Blackwell-Miniard model [33, 35–39]. The basic concept of these models is to focus on conscious, sufficiently rational and detailed consumer decision-making, emphasising the infinite perceptual and learning capacities of consumers, the evolution of their attitudes and their possible actions towards a wide range of alternative choices.

While consumption has long been seen as a key driver of economic growth, today's consumption has negative environmental impacts [22, 40–43], for example, such as energy production from traditional sources, increased energy consumption and transport [44], a growing group of scholars and practitioners, with an increasingly diverse set of perspectives on the recent issues, are advocating for sustainable consumption [17–22], because "man-driven factors can overcome these issues" [44].

P. C. Stern (1997) observes, as quoted by J. N. Sheth, N. K. Sethia and S. Srinivas (2011), environmental damage caused by consumption threatens human health, welfare, and other things we value. Humanity's resource use and pollution already far exceed Earth's carrying capacity [43]. In 2007, the total global ecological footprint of humanity, with a population of 6.7 billion, was estimated at 18 billion global hectares (gha), or 2.7 gha per capita. However, the Earth's biocapacity—the total amount of renewable resources provided by the planet—was only 11.9 billion gha that year, or 1.78 gha per person. This nearly 50% overshoot meant that in 2007, human consumption was equivalent to 1.5 times the Earth's resources, and natural resources were being depleted faster than they could regenerate [43, 45]. High consumption footprint shows humanity's debt to nature. To date, developed countries have of course been responsible for most of the environmental impacts from consumption and production [22]. For example, US households represent 4% of the global population, however, they account for 20% of global emissions of greenhouse gases, with per capita emissions four times the Chinese level [22]. However, these problems are not only found in industrialised countries, where mass consumption is one of the main causes of global and local environmental problems, but also in rapidly developing countries, where wealth is created in resource-intensive ways [43]. A similar trend can be observed in Europe, where the old EU Member States still have the highest consumption costs, but the new Member States are catching up fast. For example, the results of a study conducted by researchers [46], disclosure that income is the main driver of global emissions between 1980 and 2015, while energy intensity is the most important factor holding back global emissions [46]. The research shows that energy intensity was the primary mitigating factor of global $CO_2$ emissions, followed by energy consumption structure; in contrast, income was the primary driving force of increasing global $CO_2$ emissions, followed by population over the four periods (i.e. between 1980 and 1990 global $CO_2$ emissions increase by 13.6%; between 1990 and 2000 global $CO_2$ emissions increase by 23.9%; between 2000 and 2010 global $CO_2$ increase by 34.5%; between 2010 and 2015 global $CO_2$ emissions increase by 7.3%).

Future sustainability squarely on the shoulders of decoupling economic growth from environmental impacts through technological innovations that support efficiency improvements (particularly in energy systems) [22]. Authors O'Rourke and Lollo [22] underline, that there are some encouraging signs of decoupling in developed countries.

For example, there have been noticed energy use reductions in homes and increases in ride-sharing services in US. However, as scientists Štreimikienė et al. [47] note, that the residential sector was responsible for almost 30% of final energy consumption in the EU in 2020 and has a huge GHG emission reduction potential which is not yet realized. Energy use efficiency improvements and the use of renewable energy sources in households are one of the main climate change mitigation measures linked to sustainable energy consumption [48].

Currently, the emissions from the energy sector contribute for over 80% of the total emissions [49], thus, there is a need to divert to other energy production resources that are environmentally friendly, like renewable energy technologies [44]. Sustainable energy topics are widely analysed in scientific papers [47, 50, 51]. Scientists argue that we need to modernise our economies to introduce sustainable consumption and production patterns, produce, consume energy and design buildings sustainably for our well-being [8, 23, 52–54].

McDonald et al. [55] points out that it is consumers who determine the laws and regulations, as well as the measures taken to achieve a more sustainable way of life. Researchers have found that all consumers can be divided into three groups when it comes to sustainable consumption: *translators* (in some aspects of their lifestyle, they consume sustainably, but not in others); *exclusive-confident consumers* (sustainable living is a priority for these consumers); *choosers* (consumers are distinguished by the fact that they mostly consume goods and services as a regular consumer, but also consume a few eco-friendly products or goods, for example; they may always sort rubbish, advocate recycling, but in all other aspects of their life, they do not pursue any sustainable consumption) [55].

## 5 Conclusion

To overcome the sustainability challenges we face, interventions and policies must include not only technological improvements, but also strategies to change the behavior of individual consumers, broader initiatives that aim to change systems of production and consumption. Structural interventions and measures to promote sustainability must be integrated into sustainable innovation through universal education and sustainable consumption efforts. Consumer behavior is determined by the interaction of many socio-cultural, economic, and technological factors, therefore, in order to make consumer choices more environmentally friendly, it is necessary to change their attitude in forming the need for environmentally friendly products and services. It should be noted that the support of the central and local authorities to achieve fundamental changes in the entire production and consumption system is very important. Advances in sustainable consumption and sustainable production can be achieved by ensuring the participation of stakeholders in the consumption and production system. Such cooperation would encourage consumers and producers to change their behavior patterns.

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# Research on Hard Drives in the Context of the Construction of Shredding Knives in the Recovery of Rare Earth Elements

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**Abstract.** The publication presents an inventory of waste electrical and electronic equipment (WEEE) equipped with neodymium (NdFeB) magnets, which, when decommissioned, will be able to become a source of REE procurement. These magnets contain Rare Earth Elements (REEs) such as neodymium, dysprosium and praseodymium. Products equipped with NdFeB magnets have been identified: computer hardware, consumer electronics, wind power generators, and electric-powered vehicles. A prospective source of REE acquisition could be HDDs and speakers in laptops and phones, which account for about 10% of the analysed equipment containing NdFeB magnets. A study of the selected WEEE—hard disk drive in terms of material properties was carried out. The following analyses were performed: phase composition studies (XRD), microstructure studies (SEM–EDS), micro-area chemical composition studies (S/TEM) and hardness studies. Based on the studies, the material for the cutting knives of the twin-shaft shredder was selected. Three variants of cutting knives differing in the number of blades on the perimeter were developed in Autodesk Inventor 2023. Variants with three, four and five blades were considered. Strength calculations were then carried out using the Nastran plug-in. A force was applied to the cutting knife blades, from which von Mises stresses and strains were determined.

**Keywords:** Rare earth elements · WEEE recycling · Waste shredding

## 1 Introduction

Rare Earth Elements (REE) are used, among others, in the production of neodymium magnets (NdFeB). These magnets mainly contain neodymium (Nd), dysprosium (Dy) and praseodymium (Pr) [1] and are used in various electrical and electronic devices (Table 1). In line with the circular economy principle, these devices should be recycled after their use, so that valuable materials such as REE can be recovered from them. The remaining part of the materials created during processing should be utilized optimally by producing new components or products from them. The group of end-of-life devices is called "waste electrical and electronic equipment (WEEE).


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**Table 1** Masses of neodymium magnets present in the electrical and electronic devices sold

| Sector | Product | Usage method | The mass of the magnets per device | Global sales of the new devices in the world, million | Mass of NdFeB magnets in products expressed in kg/% |
|---|---|---|---|---|---|
| Hardware | HDD | HDD head positioning system | 10–20 g [1] | 316.3 in 2019 [10] | 4,744,500/9.0 |
| | | Loudspeakers in telephones | 0.046–0.120 g [11] | 1 378.7 in 2020 [12] | 114,432/0.2 |
| Consumer electronics | Home electronics | Laptop speakers | 1–2.4 g [13] | 167.0 in 2020 [14] | 283,900/0.5 |
| | | Motors in air conditioners | – | 5.91 in 2020 [15] | – |
| Renewable energy | Energy generators | Wind turbine generators | 400 kg/MW [1] | 93.0 GW in new installations in 2020 [16] | 37,200,000/70.9 |
| | | Permanent magnet motors in electric vehicles | 2.1 kg [17] | 1.9 in 2021 [18] | 3,990,000/7.6 |
| Transport | Vehicles | Permanent magnet motors in hybrid vehicles | 1.4 kg [17] | 3.5 in 2021 [19] | 4,900,000/9.3 |
| | | Permanent magnet motors in electric bikes | 300–350 g [1] | 3.7 (only in UE) w 2020 [20] | 1,202,500/2.3 |
| | | | | Sum, kg | 52,435,332 |

For the processing of WEEE containing REE, the Magnet-to-Magnet method [2–4] can be used. In the first stage of recycling, this equipment should be processed using preferably non-invasive processes in the field of mineral engineering. The purpose of these processes is to obtain a powdered, fine-grained mixture of the NdFeB alloy. This mixture, after further metallurgical treatment, is used to produce new products, i.e. new NdFeB magnets [5].

From 2011 to 2019, the amount of WEEE in the EU increased from 7.6 million tonnes to 11.2 million, which means an increase of 46.9% [6]. In the same period, the total amount of WEEE collected increased from 3.0 to 4.5 million tonnes, which means an increase of 47.6% [6]. To estimate the number of devices that will be excluded from use in the future, and thus the mass of magnets necessary for processing in the future, the current sales of new devices were analysed (Table 1). They differ in the direction of application, the content of magnets in them and total sales. NdFeB magnets are found in hard drives (hard disk drives—HDD), loudspeakers, wind turbine generators and engines of hybrid and electric vehicles [7–9]. Table 1 shows the total mass of NdFeB magnets sold with the devices, calculated based on the amount of product produced and the magnet content in it.

WEEE containing NdFeB magnets differ in their life cycle length. For consumer electronics and computer hardware it is 4–10 years [21], for vehicles it is 5–10 years [22], and for wind turbines it is 20–30 years [23]. There is also a difference in the mass of the magnets used, which is: $< 1$ g for mobile phones, from 1 to 2 kg for hybrid and electric vehicles, and from 1000 to 2000 kg for wind turbines [23]. Data for 2020 indicate that only 6.67% of used NdFeB magnets will be reused [24]. This proves a very low recovery of REE from NdFeB magnets.

As can be seen, a significant number of NdFeB magnets are found in wind turbine generators and electric and hybrid car engines (Table 1). They can be reused by disassembling them from the generator that is being phased out and, after processing, reassembling them in a new device [23]. More troublesome to recycle are smaller devices, such as HDD, in which a small mass of magnets is present. Manual reworking of such devices is troublesome and very expensive. Hence the idea of preparing a process line for recycling neodymium magnets from HDD and other small WEEE, using physical methods of mineral engineering in the first stage of processing. The key element at the beginning of this line is the use of a suitable HDD shredding device, which is to be made of materials that allow HDD shredding and neodymium magnets built into them. It is well known that these magnets are characterized by the ability to generate a very strong magnetic field. Therefore, great difficulty in recycling with the use of various machines and devices is the appropriate selection of materials that build them. They must either be constructed of non-magnetic materials or the magnets can be demagnetized at a temperature $> 400$ °C [25]. In the case of a shredder, because magnetized materials are present in HDD, non-magnetic components with appropriate properties should be used. To be able to choose the appropriate material for the construction of shredder knives, the hardest HDD elements, such as the casing and the neodymium magnets themselves, were characterized. The number of blades of the cutting knife was then optimized for the selected material. 3D models of various variants of cutting knives planned for use in the shredder are shown and the results of strength analyses for knives, which were performed in Autodesk Inventor 2023 with a Nastran plug, were presented. Autodesk Inventor 2023 is CAD software. This software is used to design three-dimensional models of parts and machines, and to create two-dimensional drawings. Cutting knife models were designed with Inventor 2023. The Nastran plug-in extends the functionality of Autodesk Inventor 2023 with the ability to perform strength calculations using the finite element method (FEM). Using the Nastran plug, the strength analysis of the cutting knife blade was performed, loading its edge and its surface. The following devices were used to characterize the HDD material: X'Pert PRO MPD X-ray diffractometer by Panalytical, ZEISS AxioObserver light microscope, SUPRA 35 scanning electron microscope by ZEISS and Rockwell hardness tester by Zwick.

The total mass of neodymium magnets from HDD and loudspeakers annually in the world amounts to 5,142,832 kg, which is about 10% of all products presented in Table 1. REE content in NdFeB magnets located in 2.5 "and 3.5" HDDs for neodymium, praseodymium and dysprosium are respectively 22.9–30.4%, 0.3–2.7% and 0–1.5% [8, 26–29]. Discrepancies in the concentration of these elements result from the presence of many classes of NdFeB magnets on the market, which differ in the content of alloying elements and magnetic properties, such as remanence or maximum energy density [30, 31].

## 2 Materials Used and Research Methods

In this study, the test samples are fragments of the HDD casings used. The casings were tested because it is the most difficult element to grind in the shredder, which is due to its thickness and the material from which it is built. Using a machine tool, fragments of the casing of used HDDs were separated, which were then subjected to a phase composition test, a microstructure test, a micro-area chemical composition test and a hardness test. The hardness of the NdFeB magnets was also examined because the magnets will be additionally ground in the later stages of recycling. These casings and magnets come from the disassembly of used 3.5" HDDs manufactured between 2005 and 2010.

Phase composition studies were performed in an X'Pert PRO MPD X-ray diffractometer from Panalytical, equipped with a cobalt anode X-ray tube ($\lambda K\alpha = 0.179$ nm) and a PIXcel 3D detector. Diffractograms were recorded in Bragg–Brentano geometry in the 20–110° 2θ angle range with a step of 0.05° and a counting time per step of 100 s. X-ray qualitative phase analysis was performed using HighScore Plus software (v. 3.0e) and the PAN-ICSD dedicated database of inorganic crystal structures. The graphs obtained are shown below.

To determine the microstructure of the alloy from which the HDD casings under study were made, metallographic observations were made using a ZEISS AxioObserver light microscope.

Another test carried out is the examination of the chemical composition in micro areas (EDS) of HDD casing fragments was performed on sample No. 3 in a high-resolution SUPRA 35 scanning electron microscope from ZEISS, using an EDS energy-dispersive X-ray spectrometer from EDAX.

Hardness tests on samples taken from HDD casing and NdFeB magnet samples were performed on a Zwick brand universal Rockwell hardness tester. A 1/16″ diameter ball indenter was used when testing HDD casing fragments, and a diamond cone for NdFeB magnets. Based on the knowledge of the HDD characteristics, a cutting knife material was selected.

Autodesk Inventor 2023 with Nastran plug-in was used to determine the optimal number of blades embedded in the cutting knives. First, using the program's basic functionality, 2D sketches of the cutting knives were made. These sketches were then transformed into 3D models, using the extract function. The next part of the work, involving strength calculations, was carried out using the Nastran plug-in and the assumptions presented later in the paper. It is necessary to properly prepare the geometry for strength calculations, by removing details that are not important for the analysis. The 3D model of the cutting knife is characterized by considerable simplicity of shape, so no simplification was carried out. The next step is to create a discrete model, i.e. a computational mesh with an assumed density. Then the boundary conditions, that is, the assumed restraints and loads were assigned. After correct input, calculations were carried out and the results obtained were read out.

## 3 Research and Analysis Results

### 3.1 Material Analysis of HDD Casing

The results of the X-ray qualitative phase analysis of a sample from the HDD casing are shown in Fig. 1. On the X-ray diffraction pattern obtained as a result of examining a sample taken from the HDD casing, diffraction lines were identified in angular positions characteristic of three crystal phases: the α (Al) phase, silicon (Si) and a smaller proportion of the $Al_2Cu$ intermetallic phase.

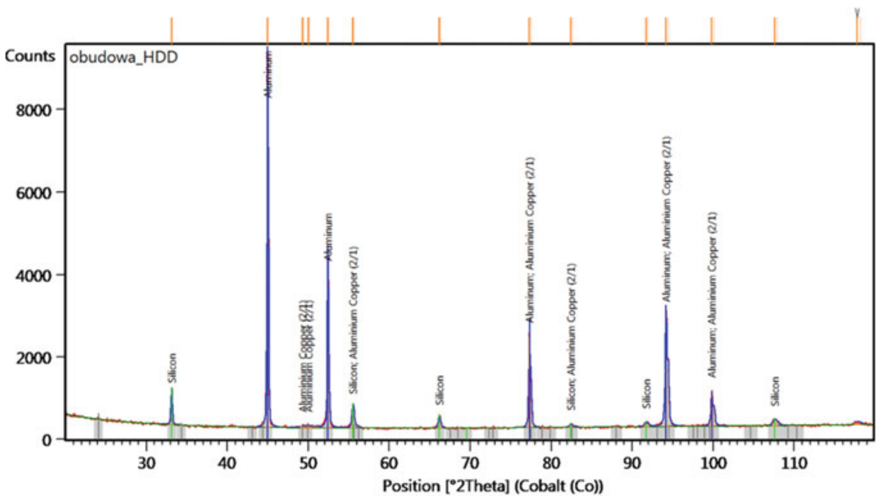


**Fig. 1** X-ray diffraction pattern obtained for HDD casing material sample

Figure 2a–d presents pictures of the microstructure of tested HDD casing material. The observation shows a coarse-grained eutectic α(Al) + β(Si) on the background of a solid solution of α(Al). Also, a few primary silicon precipitates and microvoids are observed.

Figure 3 shows the results of EDS analysis performed in the micro-areas of the sample, taken from fragments of the HDD casing. The obtained results indicate the predominant share of aluminium in the investigated alloy (> 80% by weight). Lines of silicon (about 11 wt%), Copper (up to about 4 wt%), and iron (up to about 1 wt%) were also identified on the EDS spectra Table 2.

The results of hardness measurements of the HDD casing samples and the FeNdB magnet are shown in Table 3.

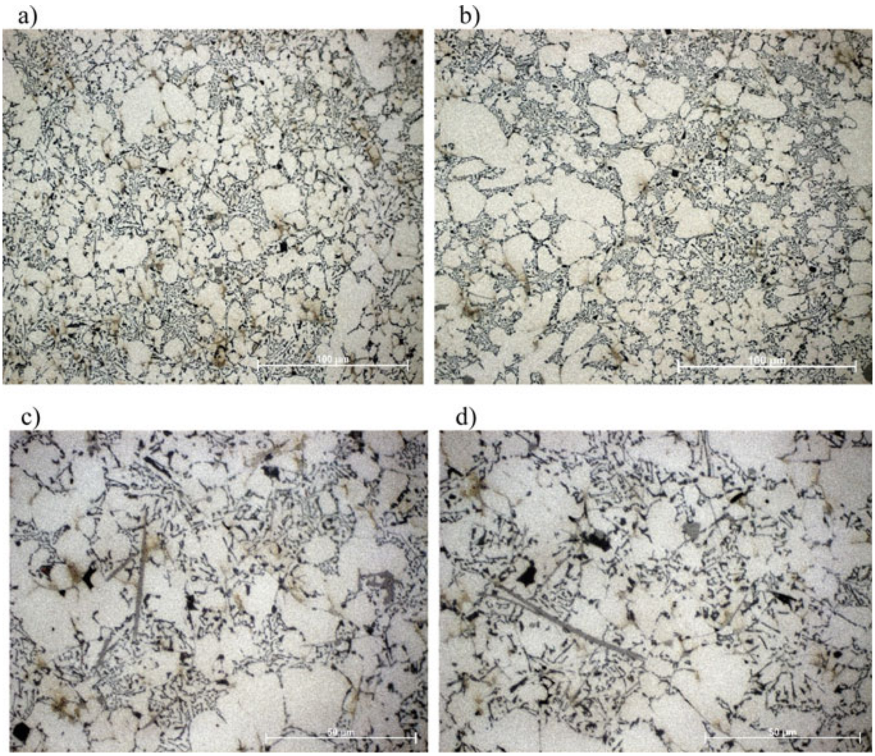


**Fig. 2** Pictures of the microstructure of the HDD casing material. Light microscope, bright field observations; **a**, **b** magnification 500×, **c**, **d** magnification 1000×

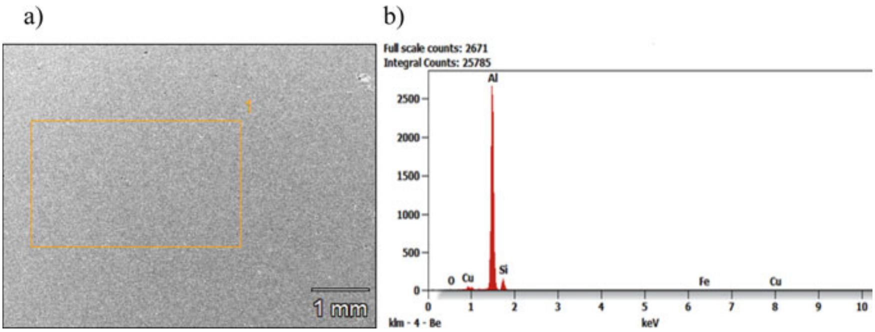


**Fig. 3** Results of chemical composition analysis (EDS) in micro-areas of HDD casing material sample; **a** view of microstructure with a marked area of the EDS test, **b** the EDS spectrum from the area marked in Fig. 3a

The obtained results of material tests of fragments of HDD hard drive casing indicate that for their production was used aluminium alloy from the group of aluminium–silicon alloys, commonly known as silumin. Metallographic observation confirmed the presence

**Table 2** Results of chemical composition analysis (EDS) of HDD casing material sample

| Chemical composition (wt%) | | | | | |
|---|---|---|---|---|---|
| Element | O | Al | Si | Fe | Cu |
| Weight | *1.5* | 81.7 | 11.4 | 1.1 | 4.2 |

Area 1 marked in Fig. 3a, wt%

**Table 3** Hardness test results for HDD case and FeNdB magnet samples

| Lp | HDD casing (HRB hardness) | NdFeB magnets (HRC hardness) |
|---|---|---|
| 1 | 46.2 | 52.3 |
| 2 | 48.1 | 51.5 |
| 3 | 49.5 | 51.6 |
| 4 | 42.2 | 50.4 |
| 5 | 42.5 | 53.4 |
| 6 | 42.5 | 53.6 |
| 7 | 41.7 | 49.1 |
| 8 | 48.4 | 52.5 |
| Average value | 45.14 HRB | 51.8 HRC |

of a coarse-grained eutectic α (Al) + β (Si) on the background of a solid solution of α (Al), with a few primary silicon precipitates. The occurrence of these phases was also confirmed through of X-ray diffraction analysis, supported by the chemical composition microanalysis (EDS). Based on the obtained research results, it can be concluded that the analysed alloy is the eutectic Al-Si alloy. The samples obtained from the HDD casing had a hardness ranging from 41.7 to 49.5 HRB. The observed difference in hardness between the individual measurement points on the HDD casing may result from the differences in thickness on the wall cross-section and the concentration of the hard crystalline phases. Which is characteristic of elements made by casting methods.

### 3.2 Design Results of Cutting Knife Blades for Shredder

This chapter presents the work leading to the design of the cutting knife, which is part of the main working element of the shredder—the cutting shaft. The cutting shaft consists of a set of cutting knives superimposed on an inner shaft. In the shredder, the material will be shredded using two cutting shafts, rotating in opposite directions. The cutting knives should be constructed of a material that will have sufficient strength to shred waste electrical and electronic equipment. As mentioned, the knives must also be constructed of non-magnetic material so that fragments of shredded NdFeB magnets do not adhere to them. It is planned that the designed device will also be able to shred other WEEE-containing NdFeB magnets, constructed of materials of similar hardness and characterized by small sizes, such as speakers containing neodymium magnets. First, three variants of cutting knives were developed that met the assumptions shown in Table 4.

**Table 4** Assumptions for the 3D model of the cutting knife

| Knife shape | Round with cutting blades |
|---|---|
| Apex diameter, mm | 110 |
| Pitch diameter, mm | 105 |
| Foot diameter, mm | 100 |
| Rounding of the knife base, mm | 1.5 |
| Width, mm | 12 |

The shape of the cutting knife blade used in this study and presented in Fig. 5 was considered optimal at the present stage of the research. It was established based on experimental research. The best shape of the cutting knife blade will be considered in further research. It was also assumed that the minimum number of blades is three. It was examined whether a larger number of knives had an impact on their durability. The following figures show the cutting knife variants developed with Autodesk Inventor 2023: Fig. 4a—a knife with three blades, Fig. 4 b—a knife with four blades, Fig. 4c—a knife with five blades. The number of blades also affects the productivity of the machine. The greater number of blades on the cutting shafts increases the productivity of the machine while increasing the demand for drive power. The effect of the number of cutting knife blades on productivity is not the subject of this discussion. The performance of the prototype device will be determined experimentally, once it has been manufactured.

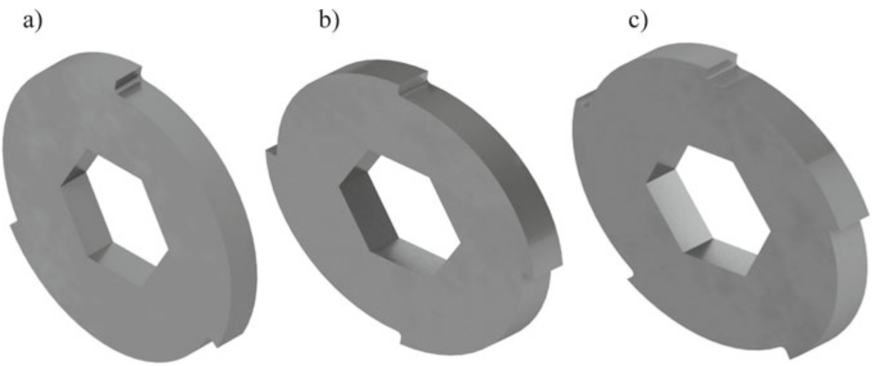


**Fig. 4** Variant of the cutting knife with **a** three, **b** four and **c** five blades

The HDD casing is made of an aluminium–silicon siluminium alloy, whose tensile strength—Rm = 240–280 N/mm$^2$, yield strength Re = 130–180 N/mm$^2$ [32], and average hardness HRB = 45.15. The NdFeB alloy from which the magnets are composed

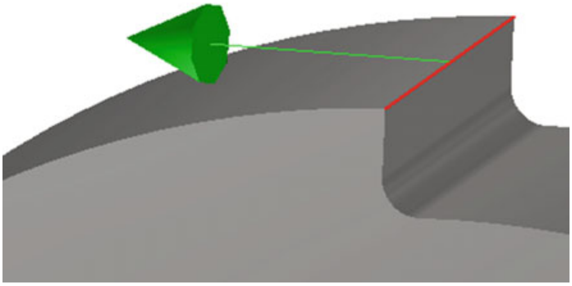

**Fig. 5** Force applied to the edge of the cutting knife

is characterized by low tensile strength—Rm = 82.7 N/mm$^2$ [33], with high average hardness HRC = 51.8. The structural material of the cutting blade will be austenitic steel X6CrNi2520, whose strength properties (Rm = 540 N/mm$^2$, Re = 225 N/mm$^2$ HRB = 95 [34]) will make it possible to grind the previously mentioned HDD components. This steel was also selected for its lack of magnetic properties.

The strength analysis of the developed 3D models was then carried out using the Nastran plug-in for Autodesk Inventor 2023 software. The assumptions for the analysis are as follows:

- The load force on the cutting knife edge in the first variant (Fig. 5) and the cutting knife surface in the second variant (Fig. 6) of 12,600.00 N,

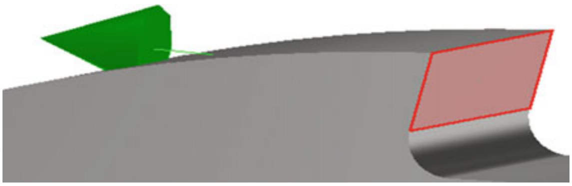

**Fig. 6** Force applied to the cutting knife surface

- Material—austenitic steel,
- Fixed supports at the points of contact with the shaft,
- Grid made by triangulation method with a segment size of 3 mm.

The locations of the force application are presented in Figs. 5 and 6. At the initial stage of cutting, the cutting knife exerts pressure on the shredded material with its edge only, which is mapped in Fig. 5. After that, the cutting knife penetrates the material and begins to act on the shredded material with the entire surface marked in Fig. 6. The results of the maximum Von Mises stress and the total displacements for each variant are presented in Tables 5, 6 and 7.

Loading the edge and the surface of the cutting knife with a set force gave different results for each variant. When loading the cutting knife edge, the lowest Von Mises stress was obtained for the variant with 4 blades—2425.0 MPa and the lowest strain was

**Table 5** Results of strength analysis of the variant of the cutting knife with 3 blades

| | Force applied to the edge of the blade | Force applied to the blade surface |
|---|---|---|
| Solid von Mises stress, MPa | 2587.0 | 429.7 |
| Total displacement, mm | 0.081 | 0.034 |

**Table 6** Results of strength analysis of the variant of the cutting knife with 4 blades

| | Force applied to the edge of the blade | Force applied to the blade surface |
|---|---|---|
| Solid von Mises stress, MPa | 2425.0 | 431.8 |
| Total displacement, mm | 0.085 | 0.035 |

**Table 7** Results of strength analysis of the variant of the cutting knife with 5 blades

| | Force applied to the edge of the blade | Force applied to the blade surface |
|---|---|---|
| Solid von Mises stress, MPa | 2668.0 | 476.7 |
| Total displacement, mm | 0.083 | 0.036 |

obtained for the variant with 3 blades—0.081 mm. By loading the surface, the lowest Von Mises stress was obtained for the variant with 3 blades—429.7 MPa. Also for the same variant, the lowest surface deformation was obtained—0.034 mm. Based on the stress and strain analysis, a variant of the cutting knife with three blades was selected. This variant was chosen because of the smallest strain determined during the strength analysis. The smaller value of the blade strain, determined for the same given loading force, means that the cutting knife will have a longer operating time. This will translate into a reduction in the operating costs of running the grinding process in the shredder, related to overhaul and stoppage of operation.

## 4 Conclusions

As a result of the material analysis of the HDD casing, such as X-ray diffraction study, microstructure study, micro-area chemical composition study and hardness study, it was found that the structural material of the casing is an aluminium–silicon alloy—silumin. On this basis, the material for the cutting knives was selected—austenitic steel, grade—X6CrNi2520.

The design of the cutting knives consisted in studying the effect of the number of blades embedded on the periphery of the knife on obtaining Von Mieses stress and strain. It was implemented using Autodesk Inventor 2023 with the Nastran plug-in. It was found that the optimal number of blades should be 3. Each increase in the number of blades causes an increase in the von Mises stress, as well as causes an increase in deformation. Faster blade wear results in a time-consuming blade replacement process, which can significantly increase operating costs in the production cycle.

In the conclusion of the paper, the use of replaceable cutting knife blades was proposed. Their disassembly and reassembly will be made possible using a screw connection fastening. Countersunk screws will be used. The blades will be made using the selective laser melting method. This method is one of the additive powder processes, which has the advantage of being able to realise complex shapes or the strength of the manufactured parts similar to injection moulded parts.

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# The Cost of Going Green in the Jiu Valley

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**Abstract.** The current study aims to argue, as objectively as possible, the importance of a transition to green energy, and also tries to cover several perspectives, but with an emphasis on the social and financial economic perspectives. It is an attempt to raise awareness of the importance of the growing eco-friendly economy, and also to educate as much as possible the civil society and the political class as well as the businesspeople and the citizens, trying to convince them that this transition to green and renewable energy is profitable from all points of view. Transitioning to green energy is more difficult in the mining areas due to the non-industrial aspect and must take into consideration all the socio-economical aspects that arise from the closing of the mines. Also, we have to be aware of the fact that the transition to green energy is a long process that will reshape communities and futures.

**Keywords:** Sustainable development · Eco-friendly growth · Transition from coal

## 1 Introduction

The purpose of sustainable development is to ensure a strong and lasting balance between the economic, environmental, and social aspects of human activities.

The Brundtland Report, published by the World Commission on Environment and Development (WCED), states that "sustainable development is the development that seeks to meet the needs of the present, without compromising the ability of future generations to meet their own needs" [1].

Economic development, although it is desirable, has a negative and continuous impact on the environment, which is certainly threatening the future of humanity. This problem was discussed for the first time during the Conference on the environment organized in Stockholm in 1972 and thus the premises of what today we call sustainable development were created. In 1983, the WCED headed by Gro Bruntland, begins its work, following a resolution adopted by the United Nations General Assembly.

Two years later (in 1985) the hole in the ozone layer above Antarctica is discovered and, through the Vienna Convention, attempts are made to find solutions to reduce the consumption of substances that damage the protective ozone layer that surrounds the planet. In 1986, one year after the Chernobyl catastrophe, the Brundtland Report of the WCED appeared. At the same time, the Brundtland Report admitted that economic development cannot be stopped, but that strategies must be changed to fit the ecological


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limits provided by the environment and the planet's resources. At the end of the report, the commission supported the need to organize an international conference on sustainable development.

Thus, in 1992, the "Earth Summit" took place in Rio de Janeiro, attended by representatives from approximately 170 countries. Following the meeting, several conventions were adopted, related to climate change (reducing methane and carbon dioxide emissions), biological diversity (conserving species) and stopping massive deforestation. Also, a plan to support sustainable development, Agenda 21, was established.

Ten years after the Rio Conference, in 2002, the Summit on Sustainable Development was held in Johannesburg.

Lester R. Brown created the "Worldwatch Institute" in 1974 and is the promoter of a series of studies, materialized in the annual reports on the progress on the path of structuring a sustainable society: "The State of the World" or "Vital Signs". He draws attention, in the work "Plan B 2.0" to the conflict between industrial civilization and the environment, and mentions related aspects such as:

- the tendency to exhaust natural resources of energy, raw materials and food;
- consumption of renewable resources at a rate higher than their regeneration capacity;
- physical damage and pollution of vital environmental factors: water, air, soil.

In this context, Brown points out the importance of waste recycling.

A sustainable society is a society that shapes its economic and social system so that global natural resources and life support systems are maintained.

Sustainability starts from the idea that human activities are dependent on the environment and resources. Health, social security and economic stability of society are essential in defining the quality of life.

How do we reduce or manage to stop consuming so much? how do we keep energy consumption as low as possible? There are several "levers" we can pull to reduce energy consumption or replace it with clean energy: energy efficiency is one, dematerialization is another, the circular economy—to reuse as much of what we have and so on—yet another, and increased taxes on energy or ideally carbon yet another. And, of course, the rapid expansion of low-carbon, nuclear and renewable energy sources. "Renewable energy is an important piece of the puzzle in meeting growing energy demands and mitigating climate change, but the potentially adverse effects of such technologies are often overlooked" [2].

Hence the difference between sustainability and efficiency.

## 2 Importance of Going Green and the Financial Benefits of Being Eco-Friendly

The concept of eco-friendly growth was originally linked to environmental issues and the crisis of natural resources, especially those related to energy 30 years ago. The term itself is very young and was imposed in the summer of 1992, after the Conference on Environment and Development, organized by the United Nations in Rio de Janeiro.

There is a continuous growth in number of businesses going eco-friendly as the fight for climate change goes on. There are several entrepreneurs who are doing this transition out of sheer morality, and there is other who is making this eco-friendly step just so that they don't get left behind.

"Lately, it has become rather popular to change a business so that it is environmentally friendly and sustainable. There is a plethora of information available to the general public that describes the advantages of such an operating model, but somehow very few sources providing a clear description of how a business can estimate the financial benefit from the transition to a "green" model" [3].

Among the multitude of the financial benefits of being eco-friendly, we are going to focus only on the following:

(1) **Eco-friendly goods are in high demand.**

Even though the prices of eco-friendly goods are higher, there is an increased demand for them, and they generate higher profits. The top deciding factors in choosing eco-friendly services are:

- the quality and source of the ingredients;
- the environmental policy of the company;
- the policy of social responsibility of the company;
- environmentally friendly packaging;
- the social and environmental benefits of using these products.

(2) **Financial incentives.**

Governments in the EU region and the USA government understood very well the need for sustainable and renewable energy, therefore they are offering financial incentives to all the businesses that go green. These advantages are translated into tax credits, bonuses, or business deductions. These incentives are offered for businesses that:

- reduce the power use by installing hvac, economic lighting or hot water systems;
- use of alternative energy properties;
- use of vehicles with high fuel-efficient standards;
- recycle and reuse certain equipment or machinery.

(3) **Grants and financing programs.**

The financial incentives are one of the advantages offered by the governments for the green businesses. The companies can also access one of the numerous grants and financing programs in order to be more eco-friendly. Also, grants are provided for qualified programs related with environmentally responsible approaches.

These are but a few of the many government subsidies available to companies that effect environmentally friendly practices and solutions.

(4) **Increased savings from the use of organic and natural materials and smart energy use.**

All eco-friendly business measures naturally lead to savings. Using this kind of energy conservation, use of water saving devices, use of alternative energy sources, and reduction of waste can significantly reduce the costs. The effect is keeping costs down, and by doing that it is proven yet again to be more efficient and cost effective compared to traditional energy use.

Most of us knows that in these days being eco-friendly is a much more positive way to be seen while being an entrepreneur. This means that partners with wide perspectives are more likely willing to collaborate with you (due to shared values) and will hold you in higher regards.

## 3 The Financial Implications of Going Green in the Jiu Valley

"Ensuring a balance between economic and ecological well-being has emerged as a key concern for governments worldwide. In the contemporary era, the global economies, especially the developing ones, emphasize the relevance of achieving eco-friendly growth whereby the ecological footprint figures are aimed to be contained alongside higher economic growth" [4].

The energy sector, both at the European level and in Romania, is in full transition to "green, clean energy". The most important component of this transition is the decarbonization of the energy systems, simultaneously with the increase in energy production from renewable sources, without affecting the security of the electricity supply, on the one hand, nor the well-being of the final consumer, on the other hand. Another objective of this transition is to reduce greenhouse gas emissions. The role that Romania will assume in approaching the energy transition will determine whether our country will succeed in benefiting from this change or whether it will rather bear its costs.

The main positive aspect of this transition will be the development of the industry in the field of renewable resources. This will primarily lead to the creation of new jobs. The positive effects will not be limited only to this area, but, according to the snowball principle, the effects will also be felt in other areas and sectors of the national economy, such as: the automotive industry, transport, industrial production and last but not least in constructions. According to a Deloitte Ramania study, the investments in wind farms and in all these related fields will have a positive direct impact on Romania's GDP in the 2021–2030 period.

But these benefits cannot materialize without a well-defined strategy at European, national and local level.

Even today the Jiu Valley is strongly associated with the exploitation and production of electricity and thermal energy based on coal, but there is a tendency to transform the area.

The pillars on which sustainable development in Jiu Valley must be based are:

- improving the quality of life and creating a healthy and sustainable environment for future generations;

- economic diversification, innovation and entrepreneurship;
- sustainable exploitation of local specifics;
- accessibility, mobility and connectivity [5].

EU member states are obliged to re-engineer energy production units, so that starting from 2021 they comply with the limits provided by European regulations. The Paroseni Power plant underwent major transformations as a result of the decline of the mining activity. Thus, the power plant situated in the Jiu Valley has to be modernised.

In order to modernize the power plant from Paroseni, the investments already planned, or in progress, must be completed. The cost–benefit analysis takes into account the maintenance of subsidies for operation until 2024, and the granting of compensatory salaries following the redundancies, estimated at a value of 75.1 million lei, provided that both plants operate.

This scenario starts from the idea that the Paroseni power plant and the Vulcan and Livezeni mines will remain functional until 2030, and the Lonea and Lupeni mines will be closed in 2024.

The University of Petrosani has carried out an analysis that shows that the annual expenses for the operation of the thermal power plant would increase by 21.4 million lei. It is necessary to buy material for the desulfurization installation, but also other variable expenses [6].

The unit cost related to the electricity produced thus adds a cost of 21.1 lei/MWh produced, and 25.4 lei/MWh delivered. This results in a higher production cost for the plant, which leads to the maintenance of higher production costs. If we consider that the selling price of electricity covers 30% of the production cost, this additional cost will deepen even more the problems faced by the unit. Moreover, if we analyse the budgetary impact and consider only the salaries and jobs lost as a result of the reduction of the mining activity, in the conditions of a sector interdependent with other economic sectors, the resulting effects are translated into losses of almost 2 billion lei cumulatively and another 1231 of jobs in the rest of the economy, most of which are in the manufacturing industry (448) and constructions (73). This scenario, in which the 2 mines and one factory are kept, will lead to the loss of more than 2000 jobs by 2030. The cost-benefit analysis of preservation of two mines and one power station is presented in (Table 1).

The Jiu Valley has the chance to remain a traditional area in the production of electricity, but by changing the sources it uses. The potential of renewable energy sources, especially solar and wind can be a development factor, and thus the Jiu valley can be kept on the energy map of Romania.

The study done by Deloitte [8] shows that the investments in renewable sources of wind energy returns in a proportion of 42% in the local economy, which leads to the creation of new jobs and also an increase in added value. An in-depth technical understanding of the area's potential is necessary; the estimates are based on some minimum investment values for the installation of 10 MW of solar energy and 10 MW of wind energy until 2030 [9].

Therefore, a total investment of 102.7 million lei is necessary to be able to develop the 2 sectors simultaneously, taking into account a cost of approximately 5.1 million lei per MW.

**Table 1** Cost–benefit analysis of preservation of two mines and one power station

| Preservation of Livezeni mines and Vulcan and the Paroşeni Power Station up to in 2030 (and mine closure Lonea and Lupeni in 2024) | Direct costs until 2030 (million lei) | Direct benefits until 2030 (million lei) | Costs (−)/direct benefits (+) net by 2030 |
|---|---|---|---|
| Subsidies | 563.5 | | – 563.5 |
| Involvement of European funds + private business | 7367.0 | 4772.5 | – 2594.5 |
| Wages paid | | 1510.1 | 1510.1 |
| Total | 7930.5 | 6282.6 | **– 1647.9** |

*Source* Greenpeace Report: "Just Transition in Hunedoara", 2019 [7]
Bold indicates the estimated loss by the year 2030 in the scenario that Livezeni mine, Vulcan mine and Paroseni Power Station will be preserved and Lonea mine and Lupeni mine will be closed

For this reason, considering the possibility and potential of creating new highly qualified and well-paid jobs in this sector, it is automatically necessary to carry out feasibility studies that provide in detail both the technical aspects of the investment and the economic effects.

In accordance with the ITCU methodology regarding the creation of jobs in a green economy, it can be observed that in the case of investments in solar energy, 32 new jobs are created in the installation stage, and a job in the operation stage per MW. If we look at wind energy, installation creates 2.7 jobs per MW in the installation phase, and approximately 1 job for operation.

The phases of the investment assume the maintenance of jobs from one stage to another, and additional investments generate new jobs. Therefore, a direct impact of 257 jobs is obtained (Table 2).

**Table 2** Cost–benefit analysis in the renewable energy sector

| The renewable energy sector | Direct costs until 2030 | Direct benefits until 2030 | Costs (−)/direct benefits (+) net by 2030 |
|---|---|---|---|
| Involvement of European funds + private business (million lei) | 102.7 | 48.3 | – 54.4 |
| Jobs | | 257 | 257 |

*Source* Greenpeace Report: "Just Transition in Hunedoara", 2019 [10]

In essence, the modernization of the power plant brings both costs and greater benefits, and thus the balance tilts clearly towards the benefits.

## 4 Conclusions

Post-coal transition is possible and as proof stands the many rehabilitated mines and reintroduced into the economic circuit, and also the transformation of the economic profile of the affected regions, but it is a difficult process, which requires a lot of involvement and mobilization from the numerous actors and decision-makers, everything starting from local communities.

On the social side, the impact of closing the mines will be a major one. Unemployment is the one that will increase, thus leading to the layoff of more than 4000 people by 2024.

There are of course alternative activities that offer opportunities for some of them, and which opportunities would create over 2500 jobs.

In the end, all the proposed alternatives can be carried out with the aim of ensuring the optimal operating framework, with multiple perspectives: the creation of a coherent framework for training and instruction, the increase of administrative capacity and last, but not least, the development of the area's promotion identity, in order to attract new opportunities.

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# How Implementing SDG 12 in Teaching Helps Students Develop Prosocial Skills?

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**Abstract.** The world is witnessing various substantial risks and how ecological and climate changes can affect our daily lives, such as ecological and climate ones. The United Nations has established the SDG17 goals for sustainable development till the year 2030. Governments and organizations were assigned to engage people and individuals in societies to contribute in the maintenance of sustainability. Higher education institutions took part as they are the vital agents for change and enhancing students' prosocial behaviours, by adapting policies and curriculums that the core subject is sustainable development and responsible production and consumption. This study is a systematic review to analyze how universities' implementation of SDG12 helps students develop prosocial behaviours. Findings demonstrated that students' approach to positive environmental actions is due to the activities, campaign and educational models offered by universities. Also, it shows that joining forces with universities can contribute in achieving more goals on a larger scale.

**Keywords:** Sustainable development · Responsible production and consumption · Higher education institutions

## 1 Introduction

Since 2015 the United Nations established the Agenda 2030 with seventeen (17) sustainable development goals (SDG) to be attained by the year 2030 to solve social, economic, and environmental challenges [1]. They are integrated and indivisible and balance the three dimensions of sustainable development: the economic, social, and environmental [2]. SDG12's goal in particular is to ensure responsible consumption and production by all people with the contribution of organizations, and education institutions. It is essential to direct all activities towards sustainability and responsible consumption and production.

Higher education institutions are fundamental in the promotion of SDG12 by integrating it into policies and curriculum. Therefore, higher education institutions have the responsibility to address global changes and problems with the aspiration of finding solutions by developing new tools to shift students towards actions of sustainability and responsible production and consumption [3].


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The achieving of the SDG goals contribute with the enhancement of students' prosocial behaviours and soft skills such as collaboration, communication, emotional intelligence, social skills, and. interculturality. Soft skills help students excel in their professional career, as well as, it helps them gain awareness of their surroundings and become more approachable to engaging in social, economic, and environmental activities [4]. In this sense these skills improve prosocial behaviours as individuals and in societies.

Prosocial behavior represents voluntary behavior intended to benefit either another individual or society as a whole [5, 6] by engaging in helping, volunteering, donating, and cooperating. These behaviours can be reinforced through the emphasis on soft skills [6] through encouraging students in volunteering activities, organizing awareness days and campaigns, cultural exchanges, and context stimuli. All these actions are conducted to prepare students for the demands of society while highlighting the need of making positive decisions regarding sustainability and responsible consumption and production that are beneficial for the individual and the society.

In this paper, we will review studies that focus on the development of students' prosocial behaviours through the achievement of SDG12 in higher education. This is to demonstrate that the success of one SDG goal is the achievement of all goals, and that change starts from education. The more we implement concepts, courses and opportunities for students to thrive as individuals, the more we are producing effective citizens that contribute to the success of society in all its social, economic, and environmental aspects. However, how do higher education institutions contribute achieve the development of students prosocial behaviours?

## 2 Method

For this paper, we followed the steps of a systematic literature review. We have analyzed 11 articles (Table 1) in relation to the implementation of sustainability and the responsible consumption and production (SDG12) in teaching, and the prosocial behaviours. Time frame was set from 2019 to 2022. Articles were selected through ScienceDirect, and Google scholar. Criterias of selection were:

1. Articles related to SDG12 goals.
2. Include studies on how education contributed to the development of students' prosocial behaviours and skills.
3. Studies conducted in Europe.

Crieterias of exclusion were:

1. literature review, systematic review, and meta-analysis of articles.
2. Not related to higher education.
3. Studies conducted outside Europe.
4. Not related to prosocial behaviours, SDG, and soft skills (Fig. 1).

**Table 1** Articles selected

| No | Title | Authors | Year | Journal |
|---|---|---|---|---|
| 1 | Competences to address sdgs in higher education—a reflection on the equilibrium between systemic and personal approaches to achieve transformative action | Dlouhá, Heras, Mulà, Salgado, & Henderson | 2021 | Sustainability |
| 2 | Transformative policies for the social and Solidarity Economy: The new generation of public policies fostering the social economy in order to achieve Sustainable Development Goals. the European and Spanish cases. Classroom: Perspectives from Teachers and Learners | Chaves-Avila, R., & Gallego-Bono, J. R | [7] | Sustainability |
| 3 | The path toward a Sustainable Green University: The case of the University of Florence | Fissi, S., Romolini, A., Gori, E., & Contri, M. | [3] | *Journal of Cleaner Production* |
| 4 | Social Marketing and higher education: Partnering to achieve sustainable development goals | Hübscher, C., Hensel-Börner, S., & Henseler, J | 2021 | *Journal of Social Marketing* |
| 5 | Promoting sustainable consumption in higher education institutions through integrative co-creative processes involving relevant stakeholders | Longoria, L. C., López-Forniés, I., Sáenz, D. C., & Sierra-Pérez, J | 2021 | *Sustainable Production and Consumption* |
| 6 | Eureca-Pro: The European University on Responsible Consumption and production | Pichler, L., Egger, J., Feiel, S., Kircher, V., & Kosciuszko, A | 2021 | *BHM Berg- Und Hüttenmännische Monatsheftes* |
| 7 | Higher Education for Sustainability: A Global Perspective | Žalėnienė, I., & Pereira, P. | [8] | *Geography and Sustainability*, |

(*continued*)

**Table 1** (*continued*)

| No | Title | Authors | Year | Journal |
|---|---|---|---|---|
| 8 | Raising awareness of the Sustainable Development Goals through ecological projects in Higher Education | Manolis, E. N., & Manoli, E. N. | [9] | *Journal of Cleaner Production* |
| 9 | A holistic approach to integrate and evaluate sustainable development in higher education. The case study of the university of the basque country | Sáez de Cámara, E., Fernández, I., & Castillo-Eguskitza, N | [10] | Sustainability |
| 10 | Outcome indicator development: Defining education for sustainable development outcomes for the individual level and connecting them to the sdgs | Günther, J., Overbeck, A. K., Muster, S., Tempel, B. J., Schaal, S., Schaal, S., Kühner, E., & Otto, S | 2022 | *Global Environmental Change*, |
| 11 | Soft skills and STEM education: Vision of the European University Eureca-Pro | Villán-Vallejo, A., Zitouni, A., García-Llamas, P., Fernández-Raga, M., Suárez-Corona, A., & Baelo, R | [11] | *BHM Berg- Und Hüttenmännische Monatshefte* |

## 3 Results

All articles highlighted the importance of implementing all SDG and SDG12 goals in higher education. Universities are agents of change and innovation to help students make more positive and responsible environmental decisions, and in order to achieve any SDG goals, sustainability needs to be the core objective of universities' curriculums and classrooms [12].

Various models and initiatives to implement SDG by higher education institutions. For example, the study of [8] employed a co-creation model to sustainability to engage all members of university with a multidisciplinary approach, aiming at solving global needs to facilitate the transition of consumers towards responsible consumption, showed that it allows stakeholders to understand its community by actively participate in generating more democratic solutions and social involvement for sustainability concerns.

Integrating the use of digital devices and linking institutions with social marketing is an effective way to engage students since social media platforms are part of their daily lives. An example of students' participation in campaign and environmental activities through the social marketing campaigns is the study of [13] conducted on part -time master students of a private business school in Germany set social marketing guidelines to encourage students to consume less, and buy sustainable products to contribute to social change.

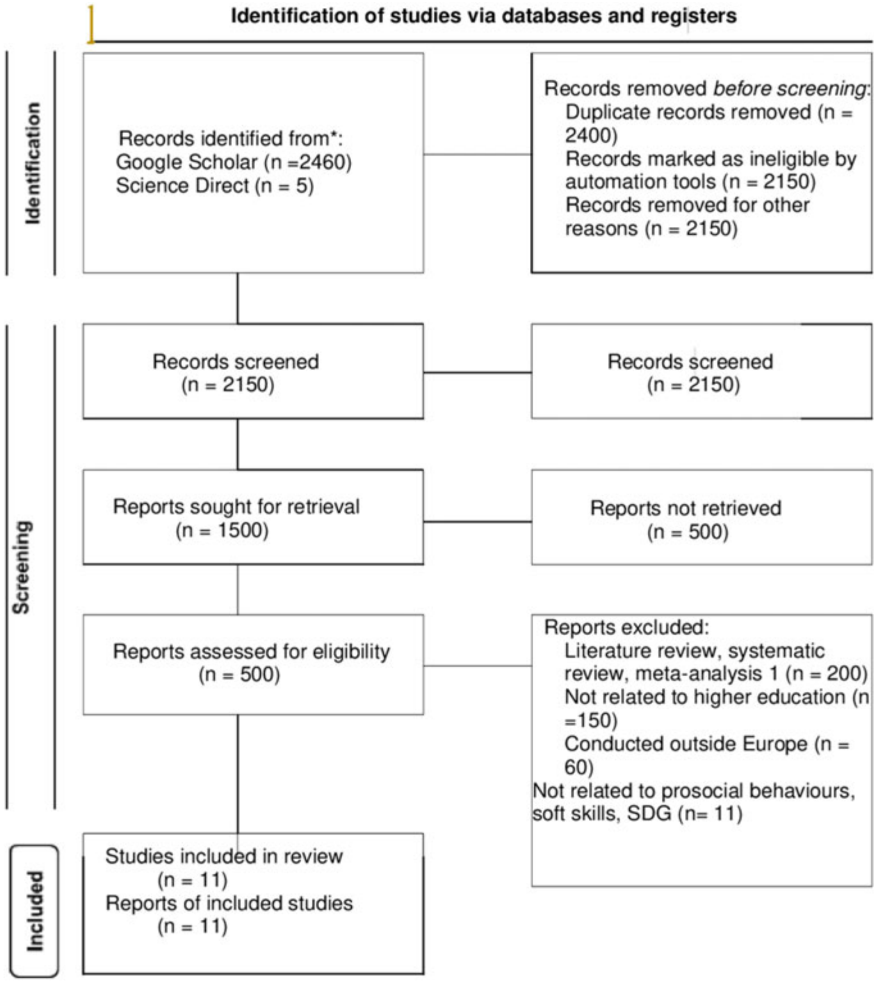


**Fig. 1** PRISMA Flowchart

Different view of how implementing SDG in European universities helps the development of students' prosocial behaviours is joining forces to achieve more results on larger scales. The European university on responsible consumption and production (EURECA-PRO) is an alliance of eight European universities from Spain, Germany, Austria, Romania, Greece, Poland, and Belgium. joined together to become an universal and global educational institution promoting social, economic, and environmental solutions all while engaging students through the creation of a joint European degree in all levels (Undergraduate, master, and PhD) and enhancing research and innovation, through the maintenance of promoting sustainable development and responsible production and consumption [13].

Raising awareness regarding the impact of SDG in society and how to maintain it is another approach adopted by universities. The ecological project [14] of the university of Western Macedonia in Greece where students themselves were included in rising awareness regarding SDG by giving theoretical classes and organizing campaigns.

Adapting social and emotional learning classrooms is another effective concept to enhance the soft skills which eventually will contribute in the development of the prosocial skills. The EURCA-PRO has and still is offering exchange programs (Erasmus programs), research forums, conferences, summer schools, and training courses (the Project based learning (PBL), and cooperative learning) in which sustainability and responsible consumption and production is the core objective. It helps the reinforcement of students' soft skills (Interpersonal communication, listening, time management, decision making, interculturality, public speaking and empathy). As a result, these acquired skills contribute to the excellence of students in their professional career and adaptation of sustainable and responsible environmental actions [9].

## 4 Discussion

According to the articles and the review being conducted, it's clear that all SDGs are a priority to higher education institutions, and achieving each goal can only be done through the promotion of sustainability. European universities are establishing models and conducting studies that show impact and how students are more engaged in maintaining sustainability.

Also, universities all over the world, and in Europe in particular are working together to attain the goals by 2030, because by joining forces greater things can be achieved, and EURECA_PRO is a living example that did and still is working towards that goal by establishing degrees, events, projects, and campaigns to engage students into society and start making positive environmental actions.

Fostering soft skills in higher education institutions can contribute in preparing students to engage in workplaces and society, by establishing the skills of communication, intercultural teamwork, collaboration, and socio-emotional skills. Students are able to engage as professionals in their workplaces and approach prosocial behaviours in their societies.

## 5 Conclusion

United Nations' sustainable development goals are intended to solve social, economic, and environmental challenges and obstacles that are facing both the individual and the society. Not only governments and organizations can be engaged in including and integrating people to act accordingly and establish a healthy, positive lifestyle that can save the environment and maintain sustainability. Higher education institutions are the main and vital agents to make change that can start from classrooms and be executed in societies by equipping students with the appropriate soft skills that can contribute in adapting prosocial behaviours.

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# Multitemporal Optical Remote Sensing to Support Forest Health Condition Assessment of Mediterranean Pine Forests in Italy

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**Abstract.** Forests provide many services to society but climate change, biotic, and abiotic forest disturbances are altering ecological systems. Among these, Mediterranean pine forests, distinctive environmental elements of the Italian coastal area for both natural and historical reasons, are particularly susceptible. As evidenced by numerous wind damages, drought stress, and more recently *Toumeyella parvicornis* infestation in central Italy. On the other hand, there is a lack of reliable and spatialized data on the spread of infestations and stress states. In this context, their monitoring using all available sources of information is essential. In this study, we used Sentinel-2 optical data to monitor the health status and damage that occurred to Mediterranean pine forests in Italy in recent years (2018–2022). In terms of damaged area, we identified a growing trend over the years (4.5% of Italian Mediterranean pine forests in 2018, 4.0% in 2019, 6.4% in 2020, and 14.6% in 2021), with an abrupt increase in 2022 (24.2%). While our model was calibrated using reference data available for a Mediterranean pine forest study area of about 1000 ha in central Italy and 80% accuracy was reported, more exhaustive reference data should be used for providing solid estimates. On the other hand, Sentinel-2 data proved to be a relevant source of information, pointing to a very serious situation for Mediterranean pine forests.

**Keywords:** Google Earth Engine · Infestations · Mediterranean basin · Pine forests · Sentinel-2

## 1 Introduction

Forests provide human societies with multiple essential ecosystem services, have great economic values, and play a key role in mitigating greenhouse gases and fighting climate


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change. However, several environmental stressors, and global warming itself, threaten the integrity and ecological functionalities of forests.

In recent decades, the increase in drought events and forest fires occurrence is negatively influencing forests condition, causing dieback events and higher rates of mortality, especially in the Mediterranean environment, where the effects of climate change are already evident. In addition, both abiotic and biotic disturbances are expected to even intensify in the coming years [1, 2], thus increasing forest vulnerability and the probability of co-occurring damage events such as those due to bark beetle outbreak [3, 4]. As in the case of stone pine (*Pinus pinea* L.) forests recently infested by *Toumeyella* Cockerell in central Italy.

The genus *Toumeyella* Cockerell (Hemiptera: Coccidae) includes 18 species distributed in the Nearctic and Neotropical Regions, among which some are closely associated particularly with *Pinus* species [5, 6]. Among them, *Toumeyella parvicornis* (also called Tortoise) is native to North America and was first described in Florida (USA) on *P. palustris* and *P. taeda* [5].

In Italy, the Tortoise Pine Scale was firstly identified in 2014 in Campania Region [6], from where it started rapidly to spread, mainly infesting *P. pinea* L. trees, which are largely located in urban parks, along streets, and in coastal areas. Symptoms on trees consist of the release of an enormous amount of honeydew [5], and the reduction of shoot development, needle desiccation, and yellowing, with the lack of vegetative recovery, and thus to the decline and decay of large populations of the most infested trees [5, 7].

The moderate detectability of the occurrence of attacks [8], the extent and the rapidity of new beetle infestations across Italy, and the impact of those beetles on forest health conditions require new and accurate forest monitoring systems that exploit remote sensing data to quickly predict damage and act promptly [9]. Remotely sensed data has indeed proven to be an efficient source of auxiliary information for identifying forest disturbance also at the early stages of tree decay [10].

In addition, just like a pest invasion, forest disturbances due to drought are expected to increase in the future. The increase in drought events is due to climate change and involves new stressors that threaten to limit the ability of forests to provide their multiple services. While several studies focusing on forest disturbances in the Mediterranean environment using remote sensing exists [11, 12], just a few of them focus on drought and pest invasion of a specific forest species. Although such analyses over time can help to identify promptly trends that occur with a pest invasion. Especially critical for coastal pine forests, which characterized the Italian landscape for centuries[13, 14].

In this study, we exploit a forest disturbance prediction algorithm [12] implemented on Google Earth Engine [15, 16], which is a cloud-based computing platform allowing for planetary scale remote sensing analysis [17]. The algorithm uses Sentinel-2 time-series and was herein adapted to predict health stress conditions in Mediterranean pine forests (Stone pine, *P. pinea* L., Maritime pine, *P. pinaster* Aiton and Aleppo pine, *P. hapelensis* Mill.), mainly related to *T. parvicornis* outbreak for the period between 2018 and 2022 across Italy.

## 2 Materials and Methods

### 2.1 Study Area

The study was carried out in Mediterranean pine forests located in Italy (*P. pinea*, *P. pinaster* and *P. halepensis*) (Fig. 1).

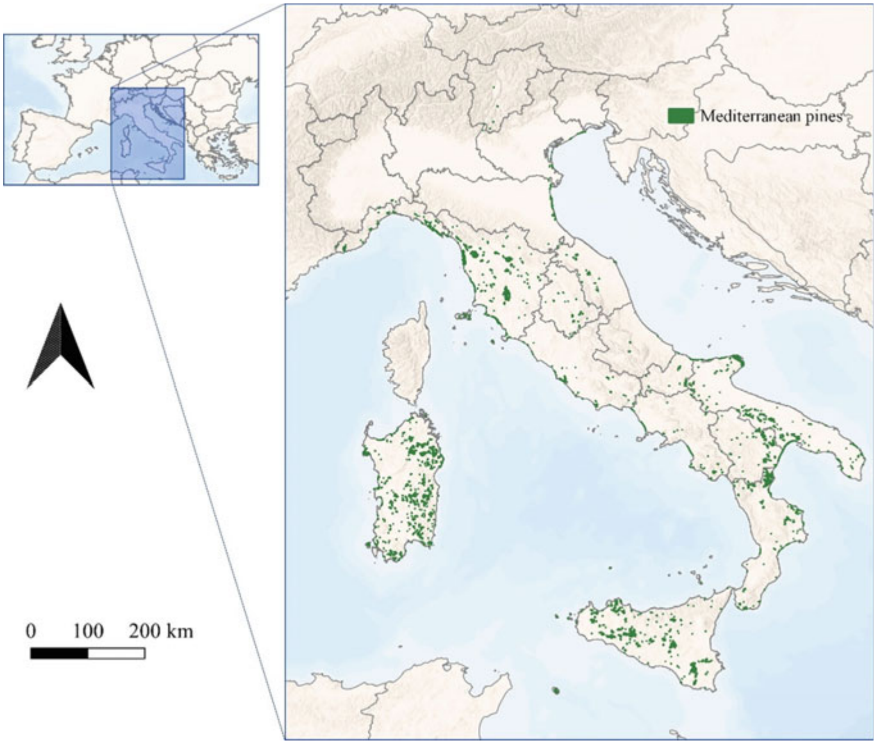


**Fig. 1** Study area represented by Mediterranean pine forest derived from CLC IV level in Italy

Information and distribution of pine forests were derived from the IV level of the Corine Land Cover (CLC) map for the reference years 2018. It consists of land cover maps based on a nomenclature system of 44 classes produced by photointerpretation of fine-resolution satellite imagery. CLC uses a minimum mapping unit (MMU) of 25 hectares [18]. The IV level used in this study were produced by the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Although the limitations of CLC maps in the forest context are well known [19–21], given the different MMU and canopy cover thresholds from those used in the Italian national forest inventory, to date in Italy CLC is the only map that provide the distribution of forest categories at national scale.

### 2.2 Satellite Data

Sentinel-2 (S2) images acquired over Italy were used to analyze Stone pine infection. S2 mission provides imagery with a spatial resolution of up to ten meters and a revisit frequency of 2–3 days at mid-latitudes [22]. The complete S2 imagery archive, with a detailed description of the data, can be found in Google Earth Engine [17]. In this study, we used Medoid cloud-free composites [23] calculated for each year between 2017 and 2022. To do it we selected all S2 imagery acquired over Italy with a percentage of clouds smaller than 40% and acquired between May 20 and Sep 10.

### 2.3 Forest Damage Mapping

The forest disturbance map was constructed exploiting the Google Earth Engine implementation of the Three Indices Three Dimensions (3I3D) forest change detection algorithm (3I3D-GEE [15, 16]). 3I3D is an unsupervised algorithm that was originally designed for predicting forest disturbances with 1-year duration, i.e., those forest disturbances in which the photosynthetic activity is expected to increase already the year after the disturbance (e.g., forest harvesting and forest fires). For this reason, 3I3D was developed to process cloud-free composite imagery calculated over three consecutive years, so that to predict both the photosynthetic activity decrease occurring with the disturbance and the spectral recovery occurring in the subsequent year. However, when beetle attacks occur, the infestation magnitude is expected to increase over time as the photosynthetic activity of the forest is supposed to gradually decrease. By default, 3I3D analyses the trends over three consecutive years for three vegetation indices (3I) in a three-dimensional (3D) space and outputs five multitemporal indices of photosynthetic activity (PMI in [12]) that can be averaged to have the magnitude of the overall change occurring over the three years. The first three PMI, refer to the decrease in spectral activity, i.e., just to the change between the previous year and the current year of analysis. For the reasons mentioned above, in this study, the magnitude of the change was calculated by averaging just those three PMIs. For more details on PMIs calculation see Eqs. 4–6 in Francini et al. [12].

### 2.4 Reference Data and Performance Assessment

The reference dataset on the evolution of Stone pine infection was derived from field surveys and photointerpretation of high-resolution images acquired in the summers of 2017–2021 for the Castelporziano Presidential Estate, located near Rome. The estate covers about 6,000 ha, of which about 1,000 ha is pine forest. Overall, the reference dataset consists of approximately 850 ha affected by the infection detected in 2019 and 2020. The reference dataset is used (1) to calibrate the 3I3D magnitude threshold and (2) to evaluate model performance.

Iteratively, each magnitude value was used as a threshold to create a binary map (damaged, undamaged), from which we calculated (i) the true positives (TP), (ii) the true negatives (TN), (iii) the false positives (FP), and (iv) the false negatives (FN). Those parameters were then used to calculate the Matthews Correlation Coefficient (MCC) (Eq. 1) [24], which, in presence of unbalanced class samples, turns out to be an effective performance parameter, consistently accounting for both omission and commission errors [25].

$$MCC = \frac{(TP \times TN) - (FP \times FN)}{\sqrt{(TP + FN) \times (TP + FP) \times (TN + FN) \times (TN + FP)}} \quad (1)$$

The magnitude value that maximized the MCC was used as the threshold, for which the overall accuracy (Eq. 2) was calculated as the reference standard [26].

$$OverallAccuracy = \frac{TP + TN}{TP + FP + TN + FN} \tag{2}$$

## 3 Results

The forest damage maps, developed for each survey year, return for each pixel a disturbance magnitude value (Fig. 2). Since low values do not reflect disturbances, these were excluded by applying a threshold of 177 (paragraph 2.4). Applying the threshold to annual maps, pixels with higher values were assigned to the damaged class.

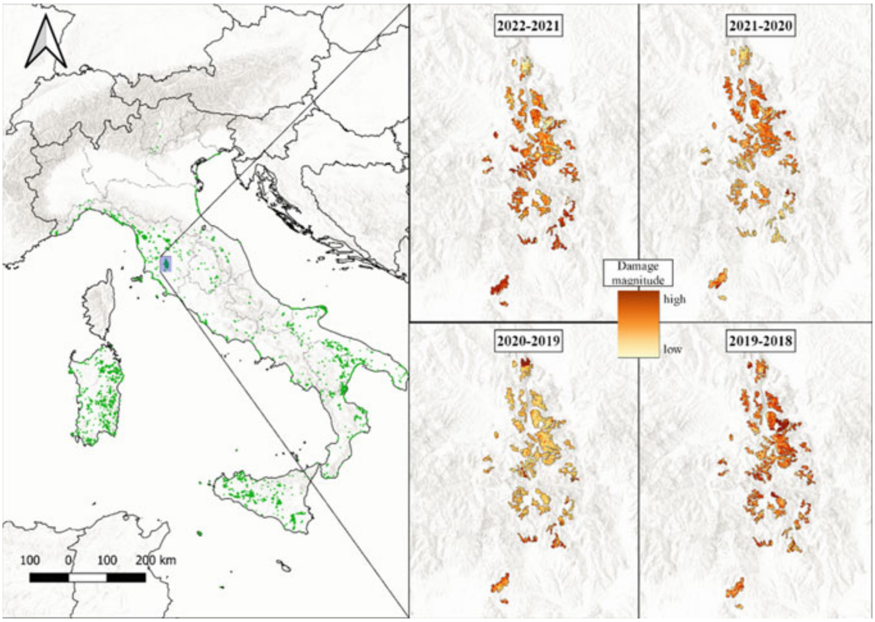


**Fig. 2** Map of disturbances in Italian Mediterranean pine forests. In the box a zoom of the annual damage magnitude

Using the annual damage maps, confusion matrices were calculated against the available reference data for the two years 2019 and 2020 (Table 1). The results show significant changes between 2019 and 2020 in terms of damaged areas. Despite this, the OA values are found to be 0.9 and 0.8 respectively for 2019 and 2020. Due to the promising results recorded both at the early stage of attack (2019) and in the case of widespread infestation (2020), the areas of damaged pine forests across the whole of Italy were calculated for all survey years (2018–2022). To analyze the evolution and distribution of the infestation, data on the areas of damaged pine forests by region and year were calculated (Fig. 3).

**Table 1** Confusion matrices of damaged pine forest for 2019 and 2020 in the reference area (TN = true negatives; TP = true positives; FN = false negatives; FP = false positives)

| 2019 | | Reference | | | 2020 | | Reference | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Undamaged | Damaged | | | | Undamaged | Damaged | |
| **Prediction** | Undamaged | TN 20,984 | FN 1286 | 22,270 | **Prediction** | Undamaged | TN 742 | FN 890 | 1632 |
| | Damaged | FP 1331 | TP 2563 | 3894 | | Damaged | FP 4402 | TP 20,130 | 24,532 |
| | | 22,315 | 3849 | | | | 5144 | 21,020 | |

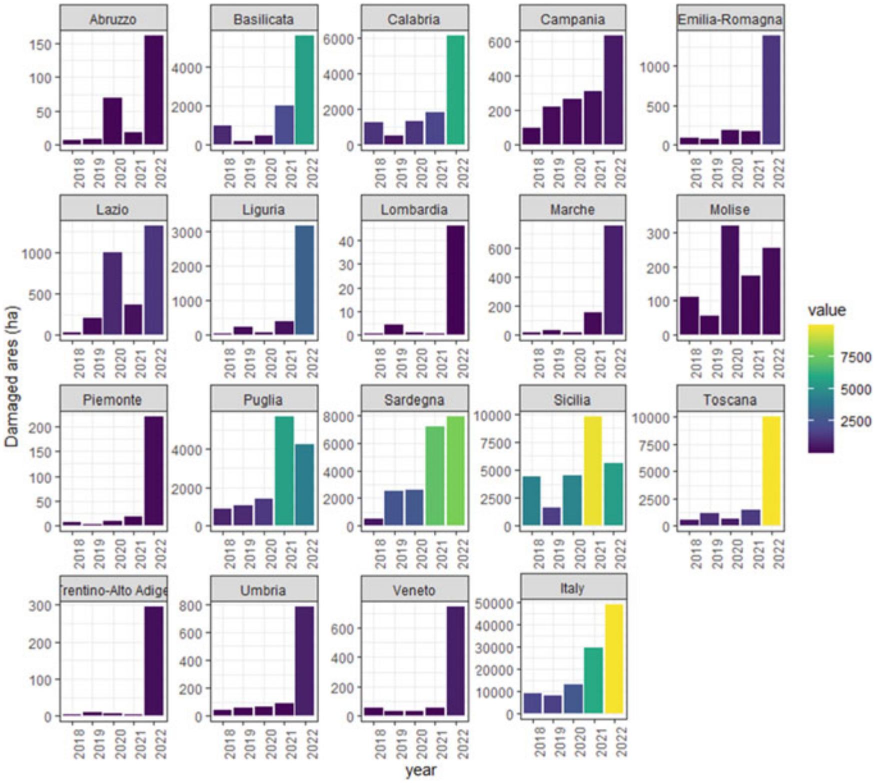


**Fig. 3** Mediterranean pine forest area damaged by region and nationwide per year

The results, both regionally and nationally, showed an increasing trend in pine forest damages over the years (Fig. 3). As early as 2019, the first increases in terms of area are observed, especially for Sardinia and Tuscany, but also in Campania and Lazio, areas where *T. parvicornis* initially spread. In 2020 and 2021 throughout Italy pine forests show increased damage. On the other hand, in Latium, Abruzzo, and Molise, severely damaged in 2020 a temporary reversal is observed. However, in 2022 an abrupt increase in the degradation of Mediterranean pine forests is observed in all regions.

## 4 Discussion and Conclusion

The spread of forest damage, due to biotic and abiotic events, has direct effects on forests. Mediterranean forest ecosystems in particular are largely affected by climate change due to summer warming, simultaneous reductions in precipitation, and extreme weather events that are becoming more frequent over time. Italian coastal pine forests represent a susceptible ecosystem that needs to be monitored and preserved, given their cultural and tourism importance as well. Remote sensing plays a crucial role in forest monitoring because disturbance maps can be predicted using automatic procedures and optical sensor images.

Our work highlighted the effectiveness of remote sensing data and techniques as an efficient tool in monitoring stressed forest ecosystems as in the case of pest outbreaks and bark beetle damage in coniferous forests [9, 27, 28]. In particular, S2 data, with high spatial and temporal resolution, also revealed conditions of early tree decay [10]. Accordingly, we used S2 medoid cloud-free composite [23] and the 3I3D algorithm [12, 16] to predict a total of about 100 k hectares (equal to 53.7%) of pine forest disturbances in Italy occurred between 2018 and 2022. 3I3D, developed to analyze changes in three consecutive years, has been optimized here to provide the magnitude of the forest change also in the current year. Based on the reference data and MCC, the threshold beyond which the magnitude data corresponded to degraded forests was identified. Applying this threshold to all survey years, the large-scale disturbance maps were obtained, which showed an OA ranging between 90 and 80%, in 2018 and 2019, respectively.

The results in terms of the damaged area show an ascending trend, with an abrupt increase in damages by 2022. Following Mazza and Manetti [29], indeed, the multi-year persistence of drought and decreased rainfall results in the decline of growth of *P. pinea* and other Mediterranean pines, despite their drought-tolerant behavior. Moreover, since *T. parvicornis* is positively favored by warmer climate conditions, biotic damages could be further extended, also in urban areas as a result of the heat island effect [5]. Monitoring Mediterranean pine forests, which are increasingly degraded by biotic and abiotic factors, is therefore essential for management planning geared toward their persistence or conscious replacement with species better adapted to climate change.

In this scenario, the remote sensing approach presented here confirms the reliability and effectiveness of 3I3D, together with GEE and S2 time series data in providing useful and timely information that should be exploited to monitor the extent of Mediterranean pine forest damage even at large scales. However, further studies are needed to identify the origin of forest damage. On the other hand, to date, we have no reference data to assess the biotic or abiotic origin of pine forest damage. Potential discrepancies in terms of disturbed areas can be attributed to the use of CLC data. Several studies have already highlighted the limitations of CLC maps in forestry [19, 20] because it was implemented for monitoring land cover, not land uses, adopting an MMU and a crown cover threshold not fine enough to capture the complex patchwork of forest disturbances, especially caused by pest attack and drought. The CLC project did not map forest clear-cuts and other natural or anthropic disturbances as forest land use but rather as bare soil or other non-forest classes, affecting the estimation of forest disturbances. We can expect these mismatches in Sardinia and southern regions in general, where Mediterranean pine forests are more widely distributed and where the MMU is not fine enough to discern the complex mosaic of a rural region's landscape.

Finally, although the results obtained should be relied on more exhaustive reference data to provide statistically rigorous estimates, the Sentinel-2 data proved to be a crucial source of information. According to our results, there is an evident growing trend in the disturbed areas over the years (4.5% of Italian Mediterranean pine forests in 2018, 4.5% in 2019, 4.0% in 2020, and 24.2% in 2021), with an abrupt increase in 2022 (24.2%), from which a very serious situation for Mediterranean pine forests emerges.

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4. FORWARDS;

5. PNRR, funded by the Italian Ministry of University and Research, Missione 4 Componente 2, "Dalla ricerca all'impresa", Investimento 1.4, Project CN00000033.

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# Sustainable Food, Key for the Future of the Planet: Getting to Know the European Consumer of Sustainable Products

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**Abstract.** In recent decades, the unsustainability of mass production and consumption models has become evident. The sustainable food market is born in response to the growing demand for products that are respectful with the Planet and compromised with the health of human beings. Responsible Consumers lead this new market, by being conscious of the impact of their consumption patterns and by choosing the products, to make up their diet and lifestyle, that contribute to build a more Sustainable and Fair Food System. The present study focuses on analyzing and defining Sustainable Consumer profile's: its behavior, its habits, its preferences; as well as those variables and factors that inhibit or motivate the consumption of Sustainable Food. Reaching a better understanding of one the main agents of the transition of the agri-food system towards a more sustainable one is key for both, private and public organizations, as this new market is booming and will continue growing in the coming years.

**Keywords:** Sustainability · Agenda 2030 · Sustainable food · Sustainable agriculture · Sustainable consumer behavior · Lifestyle · Health

## 1 Introduction

In recent years, the situation of lack of sustainability at all levels, environmental, social, and economic, has become evident, due to the mass consumption and production models, that stress and exhaust the capacities of the Planet.

Sustainability emerges as a driver of change and the Sustainable Development Goals set out in the 2030 Agenda, as tools, to solve this situation. One of the implicit objectives is the transformation of the agri-food industry, one of the most polluting and resource-intensive. Within this market there is a tendency to mass production, with-out limits, in which economic interests, are the most important criteria in decision making.

In general, awareness of the social and economic impact of food production has been lost [1]. The price of conventional goods and services does not represent the real environmental and social cost implicit in the production of these products.


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A new type of consumer is born, who conceives Sustainable Food as the compass that guides us towards a healthy lifestyle, in harmony with the Planet. It represents a way of eating that guarantees food security and nutrition for all individuals of the present and future generations, without endangering the environmental, social, and economic foundations of the Planet.

There are numerous variables that influence Sustainable behavior, as well as incentives and barriers to the consumption of sustainable products, which will be studied in the following paper.

This model is based on the following lines of action, on the one hand, sustainable food production and consumption, and on the other hand, the reduction of food waste. Firstly, sustainable agriculture must be developed, adopting natural techniques that preserve the biodiversity and fertility of the land and ensure a decent livelihood for its producers, abandoning mass production and Unfair Trade Practices.

Secondly, from the point of view of the consumer, an awareness of the process behind each food we consume must be generated: its cultivation, its transformation, its transport, its packaging, even how it is consumed. This is where the consumer has more power, when choosing what to consume, where and when, as well as the use that it gives to those foods (being able to reduce the waste).

Finally, the reduction of food waste, by the active action of individuals, companies (restaurants, supermarkets, shops, etc.) and public organizations. How is it possible that 30% of the food produced is wasted, while almost 700 million people are hungry in the world?

The need for a total change in the agri-food industry is evident, therefore, with this work it is intended to clarify what is the path to a more sustainable future, led by Responsible Consumers.

Look to the past to improve the future. To make significant changes, the society needs to be involved and act as a whole. Cooperation and transparency between the society and public and private organizations is key in this Challenge which is Sustainability. It implies that Consumers rethink their lifestyle and consumption habits. If we are what we eat, shouldn't we first analyze what we consume?

## 2 Literature Review

### 2.1 In Search of Sustainability

The term sustainability has its origin in 1987, with the publication of the report "Our Common Future" also known as the "Brundtland Report" by the United Nations. A milestone, as for the first time the concept of sustainable development is defined, as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [2].

### 2.2 Dimensions of Sustainability

Sustainability is perceived as a "Triple Bottom Line" (TBL), an axis of 3 dimensions: economic, environmental, and social [3] (Fig. 1).

**Economic Dimension**: Economic sustainability replaces the established model of mass production and refers to the management of natural resources during the current development of the different economic activities, ensuring the enjoyment of these resources by future generations [4].

**Social dimension**: According to the UN Global Compact [5], social sustainability refers to the management of the impact of economic and business activities on human capital. The actions of companies have positive and negative side effects on the different interest groups, also known as "stakeholders", including employees, suppliers, customers and the community as a whole.

**Environmental dimension**: Environmental sustainability refers to achieving a circular economy. This entails the development of more closed production and consumption systems, in which resources are used efficiently, in addition to reusing and/or recycling products at the end of their useful life, generating added value. In this way, both ends (producer and consumer) are connected, thus the transformation process of raw materials is extended as much as possible, and the waste is reduced to a minimum. Leaving behind the linear model of production based on "use it and waste it", whereby raw materials are extracted from the natural environment, transformed into a product, marketed, consumed and at the end of their useful life, discarded [6].

Public institutions play a crucial role in the development of theories and policies to achieve a circular economy as well as a Sustainable Food System; the United Nations is a global benchmark.

A clear example of this is the 2030 Agenda, by which the General Assembly of the United Nations adopts the 17 Sustainable Development Goals as a Global call to action to ensure a better Future for everyone [6].

**The Sustainable Development Goals as a roadmap and common language.** On September 25, 2015, the United Nations General Assembly adopts the 2030 Agenda, which incorporates 17 SDGs with 169 goals whose time horizon is 2030. These goals make up a plan to transform the world, facing numerous global challenges such as "inequality, climate change, poverty, justice, peace, environmental degradation and prosperity" [7]. Among the Sustainable Development Goals (SDG), many are closely related to the objective of this study "Sustainable Food Consumption", such as SDG 2 "Zero Hunger", SDG 3 "Good Health and Well-Being" but specially the SDG 12 "Responsible production and consumption", which is set to try to mitigate and solve the failures of the current model of food consumption and production, source of unsustainability.

**Issues of the current Agri-food System.** In relation to food consumption and production, the United Nations (UN) points out the following problems [8]:

- Up to 30% of the food produced is wasted. This increases the amount of waste, thus negatively affecting the environment
- The overexploitation of fisheries, the lack of crop biodiversity, the unsustainable management of natural resources such as water and the loss of land fertility, put the present and future food supply at risk.
- Food production consumes around a third of the world's total energy and is the cause of more than 20% of $CO_2$ emissions.

- The lifestyle of consumers and current diets cause negative effects not only on the environment, but also on the health of human beings. Today chronic diseases such as overweight or obesity have fallen to more than 2 billion people.

To face these issues The 2030 Agenda aims to develop models of sustainable production and consumption, demonstrating that economic development is possible without causing harmful effects on nature and the health of human beings. These models are based on some actions such as the following: Promotion of Responsible Consumption; practicing the "4 R" Recycle, Recover, Reduce and Reuse to diminish the use of natural resources and waste; halve food waste; promotion of healthy lifestyles and eating patterns; reduction of Human Footprint; encouraging local consumption, among others.

### 2.3 Sustainable Food Consumption

The need to modify current consumption patterns towards more sustainable ones has become evident. Sustainable Food Consumption is born as a new way of consuming, that covers basic food needs, provides an improved quality of life, while reducing the use of natural resources and toxic chemical materials; It also minimizes the emission of polluting agents and reduces food waste; It represents a way of consuming without compromising the needs of present and future generations [9]. According to Mauleón and Rivera [10], to consider food consumption sustainable, it should be:

Socially feasible: It must be a healthy and sustainable diet in all its senses, nutritious, based on non-genetically modified foods (NGM), local, seasonal, and free of chemical fertilizers and pesticides.

Economically feasible: A consumption that promotes a fair price for both the consumer and the producer, changing the current global supply chain, whose power is concentrated in the retailers.

Ecologically feasible: This pillar is of great importance since it assumes that the consumption of food does not harm the environment. Giving preference to foods from ecological, organic, or sustainable agriculture, avoiding those processed, with a greater ecological footprint.

Based on the respect for the culture: Sustainable diets must be built based on respect for traditional culinary practices, the "know-how" and local culture [11].

**Factors that encourage the consumption of sustainable foods.** Sustainable consumers are individuals committed to the environment and society, with a medium–high level of education.

- Based on GfK market research on Green Consumers, the main reasons for consuming Sustainable Food are [12]:
- Concerns about health and diet: The attributes (pesticide-free, non-GMO, natural or fresh) linked to a sustainable diet are closely related to a healthy lifestyle.
- Search for a higher quality of life: By consuming sustainable or organic food, consumers stay in good physical shape, which makes them feel better about themselves, thus leading to an increase in their quality of life.

- Willingness to protect the environment: Food is a powerful tool when it comes take care of the environment. In addition, sustainability is linked to actions such as recycling and environmentalism, which positively influences the planet.
- Animal welfare, which is a growing concern for consumers.

**Factors that inhibit the consumption of sustainable foods.** According to the authors De Fontguyon, Sans and Schmid [13], the main barriers that stop the consumption of sustainable food products are:

- Price which is the main inhibitor of the consumption of this type of product. The monetary amount to pay for sustainable food is significantly higher than for conventional food.
- Availability and accessibility: This category is not as accessible and does not have a wide variety of products compared to conventional foods, which represents a barrier to Sustainable Consumption.
- The lack of information regarding products and labeling causes mistrust among consumers, in addition to the rejection for the potential "greenwashing" carried out by companies.

## 3 Materials and Methods

As noted in the introduction, the increasing relevance of sustainable development in the agri-food sector has become apparent. Greater concern for the environment, the development of the local economy and social well-being give rise to a new model of production and consumption.

### 3.1 Data Collection and Questionnaire Design

To conduct a more thorough analysis to obtain consumer opinion, an online survey with the support of Google Forms, was designed, and 41 questions were distributed in five sections.

In the different sections, we intend to obtain information on consumer behavior regarding the consumption of sustainable products and their lifestyle, as well as their knowledge about sustainable practices and perceptions about sustainability, in addition to knowing their degree of knowledge about the 2030 Agenda, the ODS and the concept of sustainability. Finally, the fifth section addresses a series of questions to collect data on the socio-economic profile of the sample. To ensure that the sample was representative and acceptable, it was distributed through a variety of channels.

### 3.2 Pilot Test and Sample

Prior to the official launch and mass distribution of the questionnaire, a pilot test was carried out to check the clarity of the survey and identify possible errors. This test clarified some errors that were solved in simple steps.

The final questionnaire was launched on August 5 2022 and was available for completion until August 21, 2022. To reach a broad sample, this questionnaire has been distributed through different channels using the following method:

- Snowball sampling: which is a non-probability sampling technique. Used through different social media (Instagram, Facebook, WhatsApp, and LinkedIn). First, a general distribution message (English and Spanish) is created. Secondly, the potential individuals and organizations are selected among the population so we can get in contact to them and send them the survey. They supposed to fill it and share it with their contacts. The main goal is to reach divers sample and international level.
- Convenience sample: this is a non-probability sampling technique, that allows to reach a desired groups of individuals of population. In this case the survey was sent to some members of the Universidad de León, the University of Wollongong and IPAG Business School.

A total of 249 responses are valid as one of the original 250 responses was eliminated due to lack of information and inconclusive responses. The questionnaire analysis was done by the conduction of an univariate and a bivariate analysis.

The socio-demographic results show that 60.1% of the responses were women and 39.9% were men. It was also determined that the age of most of the respondents is between 18 and 34 years old (60.4%), that more than 70% have a high level of education (graduate, postgraduate, master's, or doctorate) and that more than 60% are workers. It was also possible to determine that 39.2% of respondents have a low-income level (< €1500) and 33.2% have an average income level (€1500–€2500).

The geographical distribution of the sample is allocated in five groups of individuals: Europeans represent the 77.6%, Asians represent the 9.3%, individuals from Oceania represent the 6.7%, Americans represent the 5.6% and almost 1% of the sample were citizens form Africa. As it has been proved most of the individuals reside in Europe, thus getting a representation of European consumer behavior on Sustainable Food Consumption (Table 1).

### 3.3 Results of the Univariate Analysis

**Attitudes and behavior of the consumer of sustainable food.** In this section of the analysis, a series of questions and their corresponding answers (that were addressed to the individuals of the sample) are presented. These questions are related to the attitudes and behavior of the sustainable consumer at an international level. The results are calculated in percentages based on the level of respondents who have selected one or more options proposed as answers for each question. It was possible to determine that most of the individuals (67%) linked sustainable foods with those that are local, but also (to a lesser extent) with healthy (59% of the individuals), fair trade or pesticide-free foods (57% of the individuals). All these attributes are included in the official definition of sustainable products. However, almost 21% of the individuals related sustainable food with a more expensive category; corroborating that the price is a barrier for sustainable food consumption.

**Table 1** Socio-demographic characteristics of the Sample *Source*: Own elaboration

| Sample size | | 249 (100%) |
|---|---|---|
| Gender | Male | 40% |
| | Female | 60% |
| Age | 18–34 | 26% |
| | 35–54 | 60% |
| | > 55 | 14% |
| Sample size | | 249 (100%) |
| Level of studies | Compulsory education | 12% |
| | Undergraduate and postgraduate | 74% |
| | Job training | 15% |
| Occupation | Student | 30% |
| | Worker | 60% |
| | Unemployed | 5% |
| | Retired | 5% |
| Monthly income | Less than 1500€ | 39% |
| | 1500€– 2500€ | 33% |
| | 2500€–3500€ | 19% |
| | More than 3500€ | 9% |

Most of the consumers of the survey show preference for certain categories of sustainable food, being the most relevant: Fruits and Vegetables (up to 84% of the individuals show preference for this category), Eggs (66%), Meat (38%), Bread and Cereals (34), Fish (26%) and Dairy (24%) among others.

Most of the consumers do their grocery shopping in supermarkets (70% of the individuals agreed) and local shops (60% of the individuals agreed), therefor these type retailers must ensure they can offer a wide variety of sustainable products to give response to this rising demand.

In addition, we concluded that some of the reasons that lead consumers to consume sustainable food are:

- Concern for the environment: A sustainable lifestyle implies to carry out some practices like recycling, use of renewable energies, reduce food waste, etc. which contribute positively to the environment.
- Trying to lead a healthy lifestyle: sustainable food consumption is linked to a healthier lifestyle which contributes to a reaching a higher quality of life.
- To support the local economy: when consumers buy local food they reduce the supply chain, thus the negative effect of the transportation and distribution implied in conventional products are diminished.

In addition, a large proportion of the sample has shown preference for social media (59%), public institutions (50%), retailers (56%) and TV (40%) as the best source of information to learn about Sustainability.

According to the survey, up to a 50% of the individuals have been consuming Sustainable Food for more than 2 years, which shows that despite sustainability being a novel concept, it has been established for some time in the agri-food industry.

**Sustainable consumer profile.** To determine which are the attitudes that define sustainable behavior, several statements have been provided with which respondents need to agree or disagree using a Likert scale (The consumer must indicate their degree of agreement or disagreement with the statements made, being: 1 = Totally disagree, 2 = Disagree, 3 = Indifferent, 4 = Agree, 5 = Totally agree).

*Sustainable attitude.* The most relevant attitudes for Sustainable Consumers are minimization of food waste and practice of the 3 R's (Recycle, Reduce and Reuse), which 9 out of 10 consumers do; in addition, more than a half of the individuals consume in their daily life "bio, organic or eco" products. On the other hand, a large proportion of individuals (88%) show preference for fresh and seasonal products and reject the foods that are processed and packaged in plastic. These shows an active attitude to change their consumption habits towards more sustainable patterns.

*Perceived risks.* When consuming sustainable food, consumers perceived different risks which can affect negatively or positively to consumption process:

Perceived physical and performance risk: The statements aimed at measuring consumer perceptions of the quality of sustainable food and its impact on health confirm that individuals perceive the benefits and added value of these products (76% agree or totally agree with the first statement and 74% have the same consideration with the second statement). Therefore, there is no negative conception of these products in this area (health and quality), quite the opposite as it is a very positive perception, as shown in Table 2.

**Table 2** Measured results: physical risk and perceived performance *Source*: Own elaboration

| Variable | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| "*Sustainable food benefits the environment, the economy and health*" | Frequency | 3 | 8 | 24 | 62 | 153 |
| | % | 1% | 3% | 10% | 25% | 61% |
| "*Sustainable foods have a higher quality*" | Frequency | 5 | 9 | 50 | 83 | 103 |
| | % | 2% | 4% | 20% | 33% | 41% |

Perceived financial risk: According to Table 3, 78% of respondents have enough reasons to think that sustainable food is more expensive than conventional food, agreeing with the statement "Sustainable Food is more expensive". The relevance of one of the most influential barriers, the price, when it comes to consuming these products, is confirmed once again.

**Table 3** Measured results: Perceived financial risk *Source*: Own elaboration

| Variable | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| "*Sustainable food is more expensive*" | Frequency | 3 | 7 | 45 | 97 | 98 |
| | % | 1% | 3% | 18% | 39% | 39% |

Perceived temporary risk: 73% of the individuals responded that it is not easy to find sustainable food outlets, versus 27% who say it is easy to find them. This confirms the idea that in this case, availability is a barrier to the consumption of this type of product, explained in the theoretical framework, since it increases the time invested and the complexity when consuming these products.

Perceived psychosocial risk: According to the results presented on Table 4: On the one hand, 72% of those surveyed say they feel better when consuming, sustainable food, leaving behind a small number of individuals (10%) who do not perceive its benefits on their own well-being. The theoretical framework on motivations towards the consumption of these products is corroborated. On the other side, 76% of individuals disagree or feel indifferent, which means that its consumption does not make most individuals feel more socially accepted, thus it is not a motivator for consumption.

**Table 4** Measured results: perceived temporary risk *Source*: Own elaboration

| Variable | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| "*I feel better when I eat Sustainable Food*" | Frequency | 14 | 11 | 45 | 112 | 153 |
| | % | 6% | 4% | 18% | 27% | 45% |
| "*I feel more socially accepted if I consume Sustainable Food*" | Frequency | 53 | 46 | 93 | 34 | 24 |
| | % | 21% | 18% | 37% | 14% | 10% |

### 3.4 Results of the Bivariate Analysis

**Chi-Squared Test.** To perform the bivariate analysis, the Chi-square test is used to determine whether there is a relationship between the two variables or not.

*First part of the bivariate analysis: 2 theories will be proposed:*

**The first theory:** "A sustainable lifestyle brings individuals closer to a healthy lifestyle". A cross-table test is done between the questions "I consider my lifestyle sustainable" and "I consider my lifestyle healthy" to make a hypothesis:

**$H_0$:** A sustainable lifestyle and a healthy lifestyle are independent.

**$H_1$:** A sustainable lifestyle and a healthy lifestyle are not independent.

A healthy lifestyle does not always imply being sustainable, an individual can be very healthy, but consume irresponsibly, waste energy (unnecessarily reducing natural resources), wasting food, polluting the environment, etc. However, does being sustainable bring individuals closer to a healthy lifestyle? Among those surveyed who did define their lifestyle as sustainable, 93% of them also categorized their lifestyle as healthy, compared to the very small percentage of individuals who do not consider it healthy (7%). The results show that the significance level is 0.001 and that the value of $\chi^2$ is 28.410, by ruling out the hypothesis that these two variables are independent, and we can conclude that a sustainable lifestyle can bring individuals closer to a healthy lifestyle.

This indicates that a sustainable lifestyle can bring individuals closer to a healthy lifestyle. This is due to the pillars on which sustainability is based:

Sustainable and healthy eating go hand in hand: FAO and WHO [11] came together to establish guidelines for achieving this dietary challenge. They define this type of diet, as one based on fresh and seasonal foods (full of fruits and vegetables, legumes, and whole grains), free of processed foods and plastic packaging, as well as one that guarantees balance and minimizes food waste. In addition, it should ensure the respect for local culinary traditions and cultures. This diet needs to be accompanied by an active lifestyle (by practicing sports) and living in harmony with the society and the environment; Health is not only the absence of disease, but it also implies being endowed with full physical, mental and social health [11]. A more sustainable lifestyle will not only have physical benefits, but individuals will also perceive well-being at a psychological and social level, thanks to the previously mentioned practices. An idea that is consistent with the statements made by Anna Bach Faig, an expert in the field of health and nutrition*:* "*We can no longer separate healthy from sustainable food, the environment matters and of course also health.*"

**The second theory** proposed is: "Sustainable food is part of a sustainable lifestyle". For this a cross-table test is elaborated between the variables "Do you eat sustainable food?" and "I consider my lifestyle sustainable".

**$H_0$:** Sustainable food and a sustainable lifestyle are independent.

**$H_,$:** Sustainable food and a sustainable lifestyle are not independent.

The results show that the level of significance is 0.001 and that the value of $\chi^2$ is 24.546, by ruling out the hypothesis that these two variables are independent, and we can determinate that both variables are closely related and that a consumption of sustainable foods it helps individuals consider their lifestyle sustainable.

*Second part of the bivariate analysis:* The second part of the bivariate study will be based on the research of the most influential sociodemographic characteristics in consumer behavior.

As show in Fig. 2, the different factors that influence consumer sustainable behavior could be divided in 3 major groups: Internal Factors, External Factors and Demographic Characteristics. Thus, the relationship between the independent variables (**education level**, **gender,** and **income level**) with other dependent variables related to sustainable behavior will be studied.

- Cross-table tests were made with the **level of studies** and questions related to **sustainable behavior**; it was possible to determine several relationships with various questions:

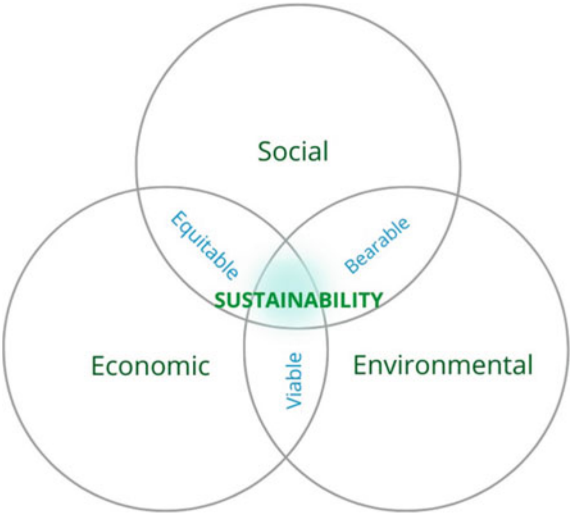


**Fig. 1** The 3 dimensions of sustainability *Source*: Own elaboration

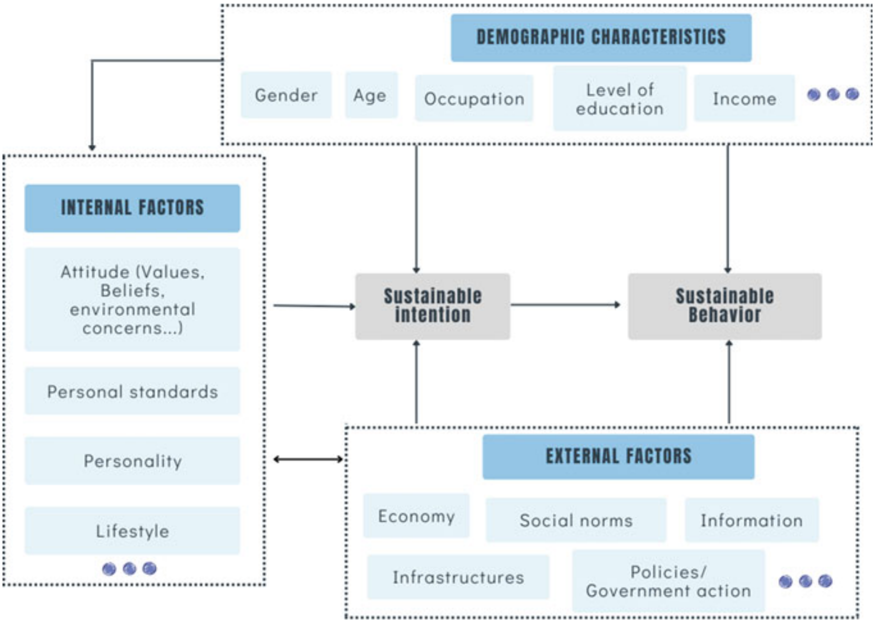


**Fig. 2** Factors that influence sustainable behavior *Source*: Own elaboration

1. First, it was possible to conclude that there is a close relationship between people who consume sustainable products and their level of education, with more than 60% of people with a high level of education consuming these products (as shown in Table 5).

**Table 5** Measured results variable: "do you consume sustainable food?"

| | | Education level | | | |
|---|---|---|---|---|---|
| | | Compulsory education | Undergraduate and postgraduate | Job Training | Total |
| Yes | Frequency | 25 | 163 | 24 | 212 |
| | % | 10% | 65% | 10% | 85% |
| No | Frequency | 4 | 21 | 12 | 37 |
| | % | 2% | 8% | 5% | 15% |
| | | | | | 249 |
| Significance level: 0.001 | | | $\chi 2$: 13,12 | | |

2. It is proved, that individuals with an initiative to make changes to achieve a sustainable lifestyle have a higher level of education. Out of the total of respondents who agree/totally agree with being willing to change their consumption patterns to help the environment, 76% of individuals have a level of education equal to or higher than a degree (master's or doctorate) compared to 9% of them with a compulsory education level and 15% with Vocational Training. It is concluded that most of the individuals with an initiative to make changes to achieve a sustainable lifestyle have a high level of education.

The results of the cross tables between **gender** and questions related to **sustainable behavior** also gave various relationships with various questions.

1. First, we have been able to determine that there is a close relationship between the perception of sustainability in our day-to-day life and gender, since women are more aware of the positive impact that a sustainable diet entails.
2. Also, women are the ones who are more inclined to make a greater economic effort to buy sustainable products and to carry out sustainable activities (such as recycling), as shown in Fig. 3.

- Finally, cross-table tests are performed between the **level of income** of the respondents and questions related to **sustainable behavior** (Fig. 4).

We have been able to determine that those people with a high level of income (between €1500 and €3500) are the ones who consume the most sustainable products. With these results we can conclude that the barriers to consumption (price being the most influential) prevent consumers from basing their diet 100% on sustainable foods, and only those with a high-income level (> €3500) reach a high of sustainable food.

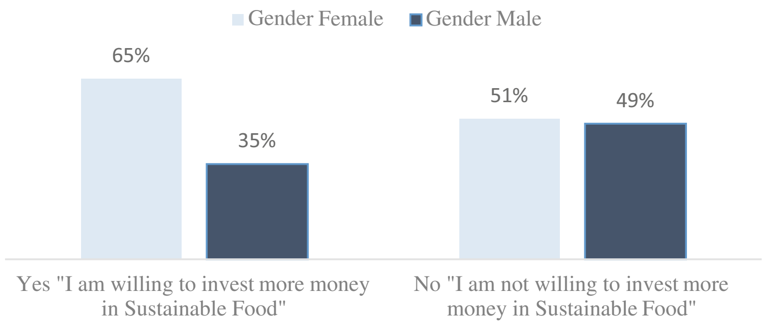


**Fig. 3** Based on: cross table "I am willing to pay more money for sustainable products" *Gender *Source*: Own elaboration

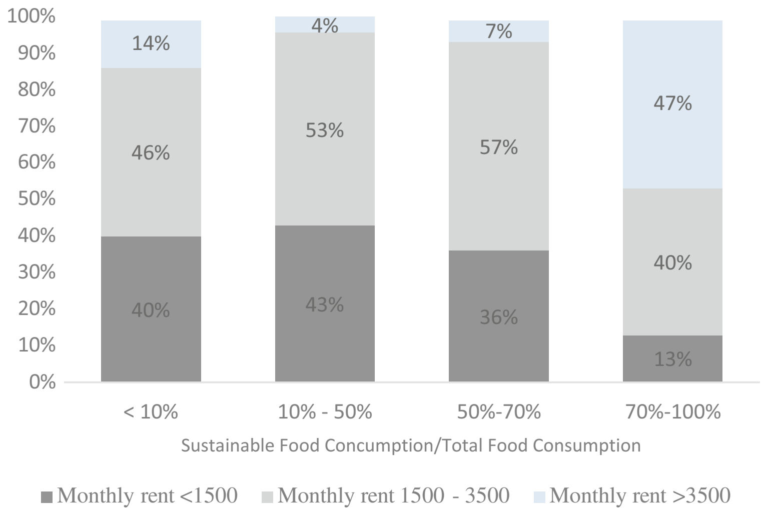


**Fig. 4** Based on cross table "Of the total food you consume, what percentage is sustainable?" *Monthly rent (€) *Source*: Own elaboration

## 4 Conclusions of the Research

The role of Sustainability is and will be crucial in the coming years, both in the development of the activities of public and private organizations, and in the day-to-day life of individuals, turning its three pillars (social, economic, and environmental) into axes of all action. To achieve this, the SDGs set out in the 2030 Agenda are used as a roadmap.

The agri-food industry is one of the most intensive in the use of natural resources and whose negative externalities (loss of terrestrial and marine biodiversity, depletion of natural resources, social inequality, and unfair economic practices, among many others) are causing irreversible damage to the Planet.

The need to change the current industry, full of failures and based on unsustainable production and consumption methods, gives rise to a new market for sustainable food and its corresponding consumers. These individuals, tired of consumerism and its disastrous externalities, develop concerns that go beyond the material, the satisfaction of their own needs.

Sustainable consumers seek the maintenance of natural resources, care for the environment, the development of vibrant local communities, as well as animal welfare and their own. They find in Sustainable Food a means to achieve a healthy and sustainable lifestyle, one that prevents us from devouring the planet.

As it is proved, sustainable food market is in constant growth, thus it is very important to know the behavior of the new sustainable consumer. In relation to the study of sustainable consumer behavior, it should be noted that, through the literature review and subsequent research on this new consumption model, numerous conclusions have been reached:

In the first place, in relation to the sociodemographic characteristics of the individuals, it is concluded that the sample is made up mostly of young students or employed individuals (between 19 and 34 years old), predominantly women (60.1%), with a high level of education (74% of individuals have training equivalent to or higher than a degree).

Regarding the behavior of the consumer of sustainable food, the following conclusions are drawn:

The most mentioned attributes to designate these products are local, healthy, fair trade, pesticide-free and NMG foods, which is consistent with the own official definition of sustainable food.

The motivational factors for the consumption of these foods are the care and improvement of the health of humans and the environment's health, the desire to support the local economy and achieve a healthy and sustainable lifestyle. Opposite to these the barriers to consumption are led by price and availability.

On the other hand, through the analysis of cross tables (in which the relationship between 2 different variables is measured) the following conclusions are reached:

A sustainable lifestyle can lead to a healthy lifestyle (through actions such as sustainable eating).

Individuals with a level of education equal to or higher than the degree have a more sustainable behavior; The higher the level of education, the greater the probability of having a sustainable behavior.

Regarding sustainable behavior, there is a difference depending on the gender of the individual; Women have a more active role in the change towards sustainable consumption, as they are willing to invest more time and money in it, in addition to being more aware of its benefits at a global level.

The level of income directly influences the amount of sustainable food consumed (it is directly proportional). It can constitute a barrier or an incentive to the consumption of sustainable food, depending on the level of income.

We are facing a time of transition towards sustainable consumption models therefore knowing the behavior and characteristics of the actors involved in the Great Challenge of Sustainability is of the utmost importance.

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# Resin Degradation of End-of-Life Wind Turbine Blades to Produce Useful Chemical Compounds in the Context of Waste to Resource Recovery

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**Abstract.** The selection of proper strategies for degradation and useful product conversion of fiber composites is driven by various environmental and economic factors. Recycling end-of-life (EOL) waste of wind turbine (WT) blade composites is a critical challenge for the renewable energy sector because of its complex composition. The focus of this study is to degrade the complex resins of wind turbine blades to produce useful chemical compounds through the oxy-liquefaction technique under subcritical water conditions. Wind turbine blades have various resins including epoxy resins, glass fibers, and carbon fibers, and they are not easy to separate so the recovery of resin as an individual component is not an easy task. The treatment of selected waste material is carried out at the temperature range of 250 to 350 °C with starting pressure of 20 to 40 bar. The effect of varying weight percentages of oxygen, waste to liquid ratio and residence time on resin degradation has also been studied. Production of various chemical compounds including volatile fatty acids and benzene, toluene and xylene (BTXs) and their dependency on the extent of resin degradation have been checked by using analysis of variance (ANOVA) analysis. Identification of the various chemical compounds against different retention times and temperatures in gas chromatography with flame ionization detection (GC-FID) has also been presented. High resin degradation is an identification of the fact that the oxi-liquefaction technique has the potential to effectively treat the wind turbine blades and support the concept of waste to resource recovery.

**Keywords:** Wind turbines · Resin degradation · Volatile fatty acid production · Oxi-liquefaction

## 1 Introduction

Wind turbines are one of the most environmentally sound technologies for producing electricity, and wind energy has very low environmental impacts. The global wind industry is growing fast, in terms of both the number of turbines and their sizes [1]. According


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to the Global Wind Energy Council (GWEC) [2], modern turbines are 100 times the size of those in 1980. Over the same period, rotor diameters have increased eight-fold, with turbine blades surpassing 60 m in length [3]. Wind turbine blades typically consist of reinforcement fibers, such as glass fibers or carbon fibers; a plastic polymer, such as polyester or epoxy; sandwich core materials such as polyvinyl chloride (PVC), polyethylene terephthalate PET, or balsa wood; and bonded joints, coating (polyurethane), and lightning conductors. Wind turbine blades are predicted to have a lifecycle of around 20–25 years [4]. The question is what to do with them afterward. There are three possible routes for dismantling wind turbine blades: landfill, incineration, or recycling. In the modern era of science, landfilling and incineration are the least acceptable methods because of the number of cons associated with them. In the case of recycling, pyrolysis has the potential to solve the problem but being a high energy-intensive process and fewer chances of resource recovery the process is also not favorable [5, 6].

On the other hand, oxi-liquefaction is the process in which organic compounds are converted to low molecular weight organic acids in the controlled atmosphere of water in presence of oxidants at moderate temperatures and pressures [7]. Oxidants are compounds that decompose at a specific temperature and provide enough oxygen required for the oxidation of organic compounds present. The presence of oxidant makes the process more effective at lower temperatures and pressures [8].

Epoxy resins and glass fiber reinforced plastics (GRP) that are a major portion of wind turbine blades can affect the health of living organisms when they come in contact with skin, or if they evaporate or form a mist or dust in the air. The main effects of overexposure are irritation of the eyes, nose, throat, and skin, skin allergies, and asthma [3]. So the objective of this study is to check the potential of the oxi-liquefaction technique to reasonably degrade the epoxy resins and GRPs, to produce intermediate molecular weight organic compounds mostly volatile fatty acids. To relate the extant of resin degradation with fatty acids yield is also the objective of the study to support the concept of waste to resource recovery. Previously, almost no efforts have been made for resin degradation and value products from this type of complex solid waste. So, the current study offered oxy-liquefaction of the wind turbine as an emerging technique to sustainably degrade the complex resins with the aim of solid waste reduction and valuable product generation.

## 2 Materials and Methods

The pieces of wind turbine blades were collected from ANMET company whose sole purpose is recycling the waste and these pieces were further cut mechanically into small pieces varying in size between 1 and 2 cm and mixed with water and hydrogen peroxide in suitable proportion according to the experimental conditions. Parr 4650 reactor was used to carry out the experiments at a set temperature and pressure conditions. Nitrogen gas played its role to provide an inert environment and maintain the required pressure inside the reactor. Experiments were performed between 250 and 350 °C, at a pressure range of 20–40 bar. The three retention times 30, 60, and 90 min, concentrations of $H_2O_2$ (15%, 30%, and 45%), and waste/liquid ratio (5%, 15%, and 25%) were also tested in these experiments. The characteristics of wind turbine blades used in these experiments have been provided in Table 1. GC-FID was used to identify the various chemical products in the solution that has been already adopted in available studies for determining the products of pyrolysis [9–11]. ANOVA analysis through statisca software has been used to identify the type of relation between total resin degradation and VFAs productions by calculating the value of correlation factor "r" whose positive values show the direct relation while negative values show the indirect relation between the tested quantities [12].

**Table 1** Results from Ultimate and proximate analysis of wind turbine blades

| Parameters | Concentration (%) | Parameters | Concentration (%) |
|---|---|---|---|
| Moisture content in the analytical state ($M_{ad}$) | 1.31 | Content of total carbon in the analytical state ($C_{ad}$) | 28.21 |
| Ash content in the analytical state ($A_{ad}$) | 56.9 | Content of total hydrogen in the dry state ($H_a$) | 2.71 |
| Volatile matter (VM) | 40.71 | Content of nitrogen in the analytical state ($N_{ad}$) | 1.20 |
| Content of total sulphur in the analytical state ($w_{S, ad}$) | $< 0.1$ | Content of oxygen | 8.0 |

# 3 Results and Discussions

## 3.1 Resin Degradation and Production of Fatty Acids

As the result of the oxy-liquefaction process, a large content of resins 48 percent of the total weight has been degraded successfully, but this degradation of resin is dependent upon applied pressure, temperature, the concentration of $H_2O_2$, and waste to liquid ratio, this dependency is in agreement with one provided by Suresh K. Bhargava while explaining wet oxidation and catalytic wet oxidation in details [7]. Experiments showed that out of all these mentioned parameters the resin degradation is highly dependent upon the waste/liquid ratio. Lower waste to liquid ratio results in higher degradation of wind turbine resins that are highly organic in nature and result in the production of volatile fatty acids (VFAs) and BTXs compounds. Oxidative degradation of organic compounds like resins results in the formation of aldehydes, ketones, and alcohols, which are further oxidized to volatile fatty acids.

The formation of VFAs is highly dependent upon the extent of degradation of solid resins, a greater extent of degradation will result in a higher concentration of various acids. The validation of this fact is also shown in Fig. 1, where the percentage of resin degradation has been plotted against the total amount of VFAs produced. Co-relation value 'r' is very close to 1 showing that the tested quantities have a strong influence on each other, and a positive sign shows there is a direct relation between them.

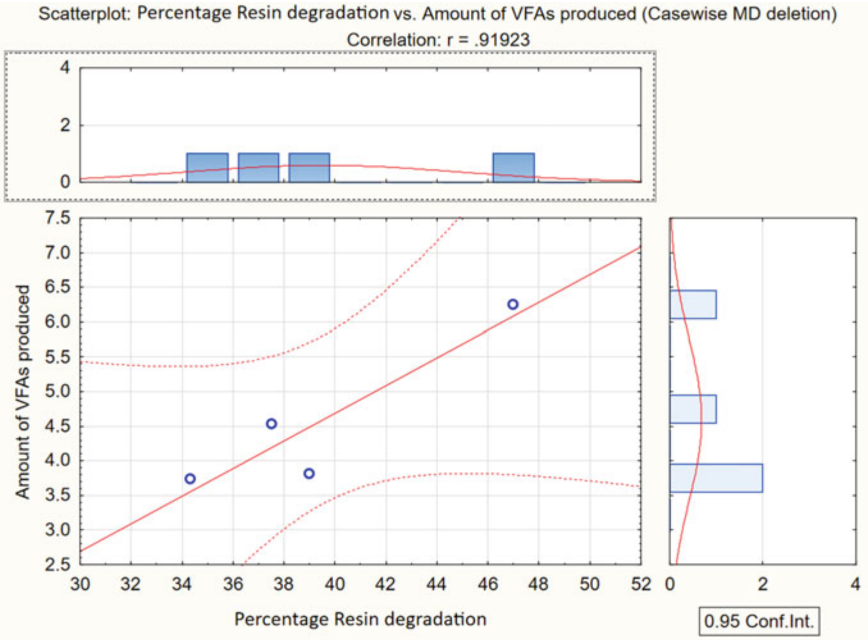


**Fig. 1** Dependency of total VFAs production on percentage resin degradation

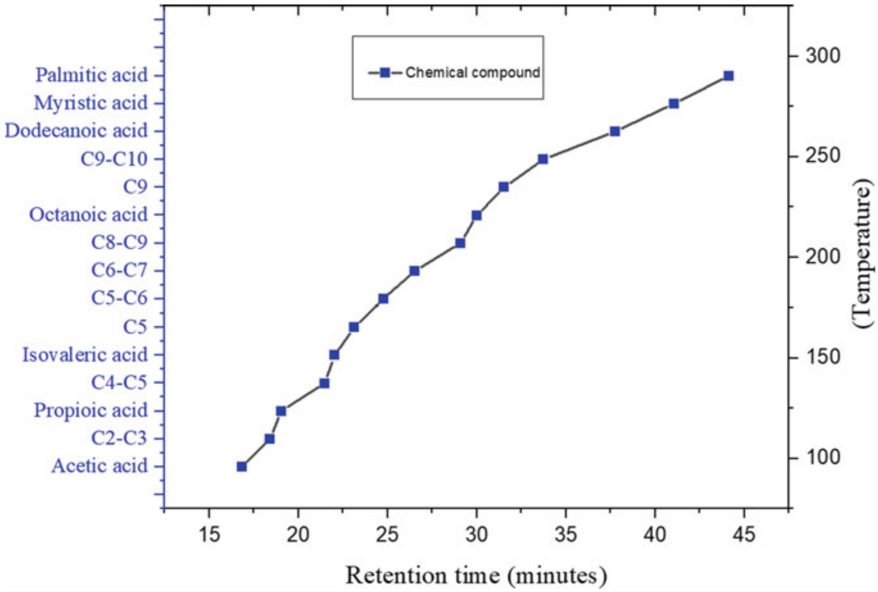


**Fig. 2** Identification of various chemical compounds against different retention time and temperature

Identification of various compounds against increasing temperature and increasing retention time in GC-FID can be seen in Fig. 2.

The first compound that appear in the results at the minimum temperature was acetic acid. That is the major concern of a number of studies reported [13, 14]. Later there are various compounds that can be seen against the different retention times and temperatures but the special compounds with carbon numbers mentioned for example $C_2$–$C_3$ are the compounds that have not been identified clearly by GC-FID analysis, but it is confirmed they have the number of atoms between 2 and 3, similarly the number of carbon atoms are between 4 and 5 for a compound mentioned with the name $C_4$–$C_5$. In the presence of peroxide, the oxidation of organic compounds is supposed to follow the mentioned scheme.

$$H_2O_2 \rightarrow HO^{\cdot} + HO^{\cdot} \quad (1)$$

$$O_2 \rightarrow O^{\cdot} + O^{\cdot} \quad (2)$$

$$H_2O + O^{\cdot} \rightarrow HO^{\cdot} + HO^{\cdot} \quad (3)$$

These three reactions are the initiation reaction that generates the free radical to decompose the long chains of organic compounds.

$$RH + HO^{\cdot} \rightarrow R^{\cdot} + H_2O \quad (4)$$

$$R^{\cdot} + O_2 \rightarrow R - O - O^{\cdot} \quad (5)$$

$$R - O - O^{\cdot} + RH \rightarrow R - O - O - H + R^{\cdot} \quad (6)$$

The organic hydroperoxide that is produced in step (7) is unstable and highly reactive which plays an important role in acid formation, hydroxyl radical cycling and secondary organic aerosol formation.

$$2R - O - O^{\cdot} \rightarrow R - O - O - R + O^2 \quad (7)$$

Steps represented by the Eq. (4) to (6) are intermediate steps of the conversion mechanism, and Eq. (7) represents the termination step. This mechanism is very similar to the one proposed by [15].

## 4 Conclusions

Oxy-liquefaction technique can effectively degrade organic resins in wind turbine blades that are dangerous to the environment. During oxi-liquefaction, resins are degraded, BTX and volatile fatty acids are produced and their concentration is widely dependent upon the temperature, pressure, weight percentages of oxygen, waste to liquid ratio, and residence time. Maximum resin degradation i.e., 48% is observed when the waste/liquid ratio was minimum. Total resin degradation is directly related to the production of VFAs, so the chances of formation of other less desirable compounds are less expectable. Obtained results suggest that the oxi-liquefaction technique has the potential for resin degradation of the WTB for value-added products generation but the further results from GC-FID analysis will help us to propose the dependency of concentration of individual components on various factors and interconversion against the increasing temperature and oxygen percentage. The future studies will be focusing on examination the effects of the size of WTB chips in sample preparation, other temperatures, residence times, and waste-to-liquid rations, and also co-liquefaction with biomass, as an oxidizer alternative to the hydrogen peroxide.

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# Ecological Risks of Post-artisanal Mining Sites and Their Sustainable Cleaning Techniques

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**Abstract.** This study assessed the residual contaminant load of three groups of artisanal gold mining (ASM) impacted lands, thereafter, phytoremediation techniques using *Jatropha curcas, Manihot esculenta* and organic amendments were used for mitigation. A total of 110 soil samples from 30 ASM sites were investigated for their total contents of Cd, As, Pb, Hg, Zn, Fe and Al. After sample digestion, ICP-MS was used for content determinations. Using activated neem seed extracts (NE) and poultry manure (PM) at different application rates, the phytoremediation potentials of *Jatropha curcas* and *Manihot esculenta* were assessed for 270 days after planting. The obtained data were analyzed with SPSS statistics 28 for the ANOVA. The results indicated mining spoils were suppliers of toxic elements in the soil however, their distributions per contaminant varied based on the properties of the ore materials mined. As a result, mine spoils created the processing of oxide and underground rock ores supplied contents of As, Fe, Al, Cd and Zn much more than alluvial mining sites and above tolerable threshold levels. Both *J. curcas* and *M. esculenta exhibited* phytostabilizing potentials as larger portions of absorbed elements were stored in their root organs. However, the application of a 25% mixture of neem seed extract and poultry manure or 25% poultry manure only (w/w) to soils reduced the uptake capacity of potentially toxic elements by *J. curcas* and *M. esculenta* by 19-38% and 10.4-45% respectively.

**Keywords:** Mine spoil · Potentially toxic elements · Phytoremediation

## 1 Introduction

Due to their presence in the food chain and related health implications, potentially toxic elements “PTEs,” in the ecosystem have drawn more attention globally [1, 2]. Even though their presence in the environment may be natural, PTEs loads in the ecosystem have been dramatically worsened by anthropogenic channels such as pharmaceutical products, untreated wastewater discharges, agrochemicals, mining, and ore processing


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[1, 3, 4]. With their binding connection with ore bodies, mine wastes have been regarded as hotspots for PTEs like Al, As, Pb, Ti, Cd, Fe, Mn, Ni, and V in the environment [5, 6]. This means the quality, safety, and integrity of environmental media including plants, air, soil, and surface and groundwater resources, near mining areas are thereby compromised because of their persistence [7, 8].

Because of historical mining and/or industrial use reasons, many areas in Southern and Central Saxony, North Rhine-Westphalia, Germany have predominantly high levels of PTEs in their soils, making some of them unsafe for use as playgrounds for kids [2, 9, 10]. Near a silver mine in Iran, different Cr, Cd, and Hg concentrations that were higher than their permissible threshold levels were discovered [4]. While the tremendous industrialization effort in China alone was responsible for approximately 2 million hectares of polluted soils at a rate of 46,600 ha/year [11]. The result is the significant contamination of terrestrial and aquatic environments, as well as of their products, which has a negative impact on health and the ability of the world to achieve environmental sustainability [4]. Because most PTEs are often not biodegradable, human exposure to levels beyond the acceptable threshold results in increased health risks as they easily get absorbed into their tissues [12].

There are many ways to clean up PTEs-filled media which may include biological, chemical, or physical [13]. However, the implementation of any choice has additional effects on price, soil quality and structure, and the viability of implementation in vast regions. Interestingly, compared to conventional treatment approaches, phytoremediation has shown to be a more economical and environmentally favourable [14–17]. There are numerous phytoremediation methods, including rhizodegradation, phytoextraction, phytostabilization, phytofiltration, phytodegradation, and phytovolatilization [13, 18]. However, their relevance depends on the intended outcome of the program for soil remediation because different plants have unique qualities for adaptability and effectiveness. However, for increased success rates the use of native hyperaccumulators that are well adapted must be ensured [15, 19]. In the Ghanaian setting, different types of ore bodies are mined and processed artisanally. However, all previous studies have treated such mine spoils as similar entities devoid of the characteristics of the parent materials mined. Additionally, investigating phytoremediation which is reasonably inexpensive and simple to implement presents a more sustainable option. However, inadequate information on the management options for potential accumulator plants exists. In most instances, native plants that had naturally colonised a site were examined for their PTE contents. In this case, background physicochemical and growth conditions were unknown or forecasted in some instances. Therefore, this investigation was carried out to ascertain the potential differences in total contents of Cd, As, Pb, Hg, Zn, Fe and Al contaminant load in different artisanal mining sites and phytoremediate them using native plants and organic amendments.

## 2 Materials and methods

### 2.1 Geology of Study Location and Sampling

This study was undertaken between January 2020 and July 2022 in Southern Ghana. The geology of the area falls within the Paleoproterozoic Tarkwaian and Birimian group formations and receives an average rainfall of about 1900 mm per annum [20]. The area is a hot spot for artisanal mining due to the presence and richness of free metallic gold dust [21]. Triplicate soil samples from 30 artisanal mining sites were further categorised into three distinct groups due to their differences in the type of ore materials mined and their resultant mine spoil characteristics. Whilst 20 independent soil samples from nearby (>1 km) forest areas were taken for control purposes. Thus, a total of 110 soil samples were analysed in this study. The digestion and analysis of processed samples were done according to the methods used by Okoroafor et al. [17].

### 2.2 Experimental Design

In a pot experiment conducted outside of a greenhouse, bulk soil from a mining site with well-determined physicochemical parameters (Average total contents of 28.52, 326.17, 30.08, 7.60, and 261.39 mg/kg of Cd, As, Pb, Hg, and Zn, respectively) was used. For the removal of PTEs from the soil by plants, nursed *Jatropha curcas* seedlings and pre-sprouted *Manihot esculenta* stem cuttings were used. Different kinds and amounts of organic amendments were added to the mine soil before curation and independent planting. These included thoroughly mixing both activated neem seed (NE) and poultry litter (PM) at application rates of 15% and 25% (w/w), or independently at the same rates. Destructive harvesting was carried out 270 days after planting (DAP) where soil samples and plant parts (shoot and root) were washed thoroughly and air-dried and milled for further analysis using the methods mentioned above. Using IBM SPSS version 28, a one-way analysis of variance (Welch test) between means was made between mine spoil types and bioaccumulation abilities of plants under the different treatments at a 95% significance level.

## 3 Results

### 3.1 Contaminants in Mine Spoil Types

The chemical distribution of target contaminants in the different mine spoils is presented in Table 1. Apart from soil As the total average contents of all PTEs in the forests were within tolerable limits whilst the Urs and OxS mine spoils were more contaminated than the Avs mine spoils.

### 3.2 Biostimulation Effects of Organic Amendments on Plant's Phytoremediation Abilities

Although both plants absorbed target PTEs mostly through their roots, distinct treatments had varying effects that were statistically different ($p < 0.05$) from one another. For instance, the application of 25% NE+PM resulted in the largest decrease in PTE uptake by both test plants. Aside from Cd uptake (in both shoot and roots) and Pb uptake (in the roots alone) in *J. curcas* (Figure 1), *M. esculenta* surpassed *J. curcas* in the uptake of Pb and Zn by 10.3 and 6.6%, respectively, whilst *J. curcas* exceeded it in the removal of soil As, Cd, and Hg by 13.4, 0.02 and 6%, respectively.

**Table 1** Chemical properties of sampled mine spoils

*Mean ± Standard Deviation*

| Sample source | Sample size (n) | Cadmium | Zinc | Lead | Mercury | Arsenic | Iron | Aluminum | pH | Electronic conductivity |
|---|---|---|---|---|---|---|---|---|---|---|
| Forest | 20 | 0.1 ± 0.2 | 19.6 ± 5.9 | 2.6 ± 2.0 | 0.1 ± 0.2 | 5.9 ± 4.3 | 5974.1 ± 1529.1 | 2644.0 ± 659.6 | 5.9 ± 0.8 | 48.5 ± 24.5 |
| Underground rock spoil (UrS) | 30 | 9.5 ± 4.8 | 226.1 ± 78.6 | 17.8 ± 4.7 | 3.8 ± 2.0 | 282.8 ± 72.9 | 14,048.1 ± 5223.6 | 6404.8 ± 2859.0 | 4.3 ± 0.6 | 1696.4 ± 241.0 |
| Oxide spoils (OxS) | 30 | 10.0 ± 3.0 | 175.7 ± 102.8 | 17.7 ± 6.9 | 2.2 ± 1.9 | 260.2 ± 115.4 | 45,100.4 ± 9567.0 | 20,589.5 ± 5616.1 | 4.9 ± 0.7 | 1786.0 ± 142.1 |
| Alluvial spoils (AvS) | 30 | 2.8 ± 1.6 | 23.0 ± 2.2 | 5.2 ± 1.0 | 1.4 ± 1.3 | 9.6 ± 2.1 | 31,360.6 ± 11,339.6 | 14,407.3 ± 5668.5 | 5.1 ± 0.7 | 104.0 ± 31.9 |

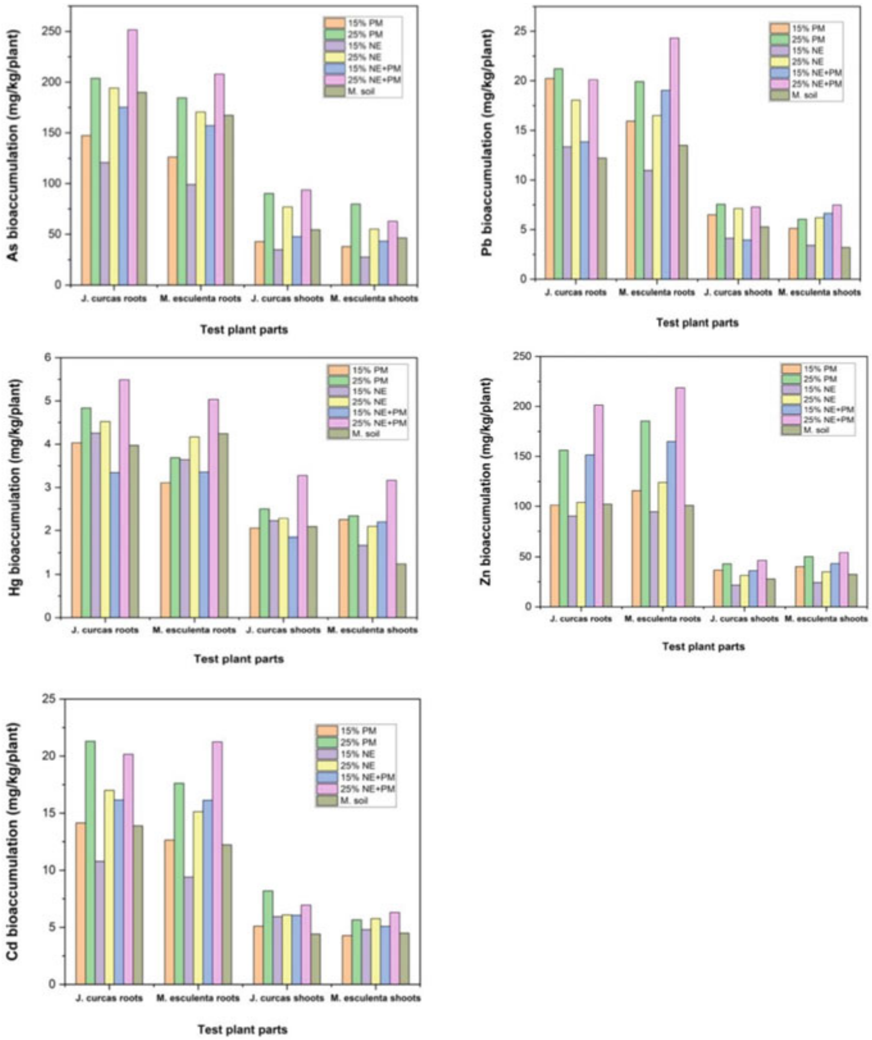


**Fig. 1** Total PTEs in soils after the application of organic amendments

Under all treatment conditions, *J. curcas* and *M. esculenta* showed output ranges (min-max) of 37.0–77.1% and 30.3–63.7% for As, 37.8–75.5% and 32.9–74.4% for Cd, 37.8–75.5% and 32.9–74.4% for Pb, 44.0-72.2% and 44.1-66.2%, for Hg and then 34.5–77.0% and 36.1–83.6% for soil Zn more than their respective controls. However, the application of 25% NE+PM followed by 25% PM caused the largest immobilization of PTEs in soils than the remaining amendment additions/ rates. Both plants' limited shoot accumulations often followed the same trend as their corresponding root accumulation as no shoot was able to absorb up to 30% of the target PTE under the various treatments. The applied organic amendments further resulted in up to 1.25 higher in dry biomass weights.

# 4 Discussions

## 4.1 Contaminants in Mine Spoil Types

The differences ($p < 0.05$) in PTE load between different types of mine soils and forest soils demonstrated the potential influence that human-induced weathering through mining and the variations in the geochemical characteristics of the ore materials mined. Thus, rocks and oxide gold ores were larger suppliers of PTEs in the mine environment than the alluvial ore forms. According to Bundschuh et al. [22], the cumulative levels of both Fe and Al, and then As in at UrS and OxS sites investigated surpassed the 20,000 and 5 mg/kg maximum background contents for natural soils, respectively as these elements have binding connections to gold. We found that the dangers of UrS and OxS mine spoils were largely due to extreme contents of As, Hg and Cd and pose serious ecological safety and human health concerns as the order of site contaminations was OxS> UrS> AvS> FS amongst sites.

## 4.2 Immobilization Effects of Organic Amendments on Plant's Phytoremediation Abilities

Whereas the test plants were able to absorb appreciable contents of soil PTEs, the decreases even though varying in plants' PTE uptake in response to applied organic amendment demonstrates their different influence on soil geochemistry and plant physiology. Thus, adding 25% NE + PM to soils may have given soils the combined advantages of biochar addition, which includes the sorption of PTE to itself and made them not readily available for uptake by plants. Whilst the delivery of nutrients and carbon to soils for plant growth through the addition of PM increased biomass production [23–25]. Therefore, compared to other treatments, this combination may have improved soil governing conditions such as soil nutrient enrichment and improved soil microbial functions. Owing to the limited capacities for shoot uptake which caused a lower transfer coefficient $< 1$, *J. curcas* and *M. esculenta* may be best used as phytostabilizers [26]. The application of 25% NE + PM followed by 25% PM can further immobilize soil PTE that might have been absorbed by plants.

## 4.3 Conclusion

To efficiently reclaim degraded mining soils, knowledge about their contaminants load is required. This study, therefore, analysed 110 soil samples from 30 artisanal mine sites which had visible disparities in their spoil characteristics due to differences in ore materials mined and processed. Laboratory analysis showed that, sites, where hard rocks and oxide gold ores were mined and processed, contained contents of PTEs far above their respective tolerable threshold limits as compared to alluvial mine spoils or forest soils. The toxicity to ecosystem fell in the order OxS > UrS > AvS > forest soils.

The use of *J. curcas* and *M. esculenta* proved to be efficient in phytostabilising multi-contaminated soils due to their high root bioaccumulation potentials than in aboveground parts. However, the addition of 25% activated neem seed extract and poultry manure was able to decrease the uptake of more toxic elements in the soil by plants than in their natural state. Using effective root cleansing plants can offer opportunities to reduce possible toxicity to primary consumers in the food web.

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# Innovative Treatment of Municipal Sewage Sludge Using Hydrothermal Carbonization and Nutrient Recovery Technologies

## Utilization Potential in the DACH Region and a Short Evaluation of the Environmental Impacts

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**Abstract.** Phosphorus (P) is an essential and at the same time critical resource, as there are barely any available reserves in the European Union, which means that there is a dependence on imports from non-EU countries. In these countries, there are critical working and environmental conditions for which social responsibility must be taken. To address these challenges, municipal sewage sludge has to be utilized since it has a huge potential to produce sustainable P- fertilizers. Hydrothermal Carbonization (HTC) is an energy-improved treatment of sewage sludge and enhances the dewatering properties. The remaining process water contains a significant nutrient content, especially nitrogen (N) and phosphorous (P). For a future project, the recovery potential of P was investigated for Germany, Austria and Switzerland (DACH region). The forecasted P recovery potential in the DACH region until 2030 covers 25% of the annual P demand and the environmental impact due to the conventional industrial production of P fertilizer could be reduced dramatically (up to 63 t of $CO_2$ emissions can be saved per year). To identify the sustainable development goals (SDGs) which are primarily addressed by the project, the following question was formulated: What effects does the technology have in terms of sustainability (social, ecological, economic)? The investigation showed that SDGs 8, 11, 12, and 13 are mainly focused. The investigations serve as a basis for a future project, which is shortly introduced in this work, where the nutrients, as well as heavy metals, will be recovered by an innovative combination of three novel processes.

**Keywords:** Wastewater treatment · Phosphorus recovery · Ion exchange · Zeolite · Sustainable consumption and production · Fertilizer

## 1 Introduction

In recent years, the utilization of sewage sludge (SS) has been heavily regulated, which currently confronts many wastewater treatment plants in Germany, Austria, and Switzerland, and thus cities and municipalities with rising wastewater disposal costs. The majority of sewage sludge is incinerated, which shows that the focus is on energy yield or


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secure disposal, but not on the waste management principles of closing the loop and creating safe sinks. Meanwhile, the Austrian Federal Environmental Agency's Waste Management Plan, for example, calls for a [*…need for action in the area of sustainable phosphorus recycling from sewage sludge and animal meal…]* and describes new technologies to condition sewage sludge and recover the phosphorus it contains [1].

Phosphorus is an irreplaceable element that is needed for plant growth and therefore plays an important role in fertilizer production. The reasons for phosphorus recycling are manifold, sometimes the declining quality of phosphate reserves plays a role, as they are increasingly contaminated by heavy metals and represent an environmental problem. There is also a case for securing supply independence since Europe itself has no significant deposits and up to 90% of the economically exploitable phosphate reserves are located in Morocco, China, the USA, Algeria, Jordan, Russia, and South Africa [2]. Since the European Union classified P as a critical raw material, especially in terms of economic importance, innovative and new technologies for P recovery must be implemented [3]. As a result, conventional sewage sludge treatment, for example, co-incineration of sewage sludge in waste incineration plants, cement, or coal-fired power plants will no longer be possible [4].

In addition, in the countries of primary P fertilizer production, there are inhumane working conditions and critical environmental impacts, such as the disposal problem of phosphate gypsum contaminated with heavy metals and radioactivity. To meet the United Nations Sustainable Development Goals (SDGs), municipal sewage sludge must be utilized since it has a huge potential to produce sustainable P fertilizers [5, 6]

### 1.1 Current Situation in Terms of Technologies for Sewage Sludge Treatment and Phosphorous Recovery

To meet recent requirements in terms of phosphorus recovery, technologies for sewage sludge conditioning and nutrient recovery are currently being promoted in industry and research, but they differ greatly in their technical concept and recovery rate, as well as in their technical readiness level. The only concrete technical measure mentioned is the mono-incineration of sewage sludge with subsequent P recovery from the incineration ash. This technology also brings aspects such as high consumption of chemicals or long transportation distances, as well as the monopoly position of waste management companies with centralized treatment plants. The problem becomes even more obvious that there is a gap between decentralized sewage sludge production and centralized sewage sludge utilization that needs to be closed [7].

The BAT (best available technology) for waste incineration plants also does not mention alternatives to P recovery from ash, while the report of the Federal Ministry (BMLFUW) proposes decentralized, on-site treatment and recovery of P, but also mentions thermal recovery in a central sewage sludge mono-incineration as a future option [8].

An alternative is the conditioning of sewage sludge using pyrolysis or hydrothermal processes. Both processes are characterized by the fact that they are coupled to wastewater treatment plants and sewage sludge with a high water content ($> 70$ vol.%) can be treated. Accordingly, conditioning and disposal costs are reduced, and the resulting process gas is lower in volume compared to conventional incineration.

However, pyrolysis entails significant disadvantages, such as the required tightness, inert gas atmosphere, operational safety (T > 600 °C), and by-products, such as coke or pyrolysis oil, whose use is severely limited due to their composition [9]. Much more efficient and operationally reliable process management is offered by the treatment of sewage sludge with HTC processes (hydrothermal carbonization), which is one of the future technologies for energetically optimized treatment [10].

### 1.2 Hydrothermal Carbonization

Hydrothermal Carbonization (HTC) is an energy-improved alternative for the treatment of sewage sludge and enhancing the dewatering properties. This novel approach treats sewage sludge with a water content of up to 75% at approx. 220 °C and 24 bar, resulting in a thermochemical conversion. Here, ‚nature's natural carbonization is recreated in a technical process. Dehydration and carboxylation processes produce a brown-to-black solid with the calorific value of peat or lignite and a lower oxygen and hydrogen content. The process significantly improves the mechanical dewatering properties and at the same time sterile the sludge. As a result, sludge volumes are significantly reduced compared to other mechanical dewatering methods [11, 12].

The filtrate after mechanical dewatering is referred to as HTC process water and has a high proportion of nitrogen and phosphorus, the residue is referred to as HTC char/coal and is characterized by a high amount of carbon. The process can be controlled by process conditions, like pressure, temperature, pH, heating rate, or time, as well as the additives in such a way that the division of the nutrients into solid and aqueous products can be adjusted. Compared to conventional drying and dewatering processes, the HTC process has advantages due to the better dewatering properties of the sewage sludge after mechanical dewatering and thus a lower total energy demand. In addition, there is a positive $CO_2$ balance and cost efficiency (on-site concept, reduction of transport, storage and disposal costs) [13].

Thus, the remaining process water contains a high concentration of organic and inorganic compounds (COD content up to 10.000 mg/L)1, but also a significant nutrient content, nitrogen (N), and especially phosphorous (P). Therefore, the challenge is to utilize the process water for nutrient recovery and both, isolate the critical components to meet the requirements for the discharge availability of the remaining process water [14].

## 2 Objectives

Within this work, the phosphorous potential for recovering from municipal sewage sludge in Germany, Austria and Switzerland (DACH region) has to be investigated and an assessment to show the impact on the environment has to be carried out. The last step is to identify those key SDGs to present them as relevant and considerable. Based[1] on the previous tasks, a future project should be outlined, which addresses the treatment

[1] Analyses of real HTC process water from a plant in Switzerland, carried out by the author Marion Andritz (01/2021).

of municipal sewage sludge and the recovery of nutrients from the process water after HTC treatment.

The project has not started yet, and it is also not part of this paper, however, it is shortly introduced by the scheme in Fig. 1 to understand the considerations in Chapter 3. The scheme demonstrates a possible process combination, where phosphorous as phosphate, nitrogen as ammonia, as well as heavy metals, are to be recovered after the hydrothermal treatment of sewage sludge. Therefore, the ion-exchange loop stripping process (ILS process) with a natural zeolite [15] and the FerroDECONT process (a redox process with zero-valent iron) were combined [16].

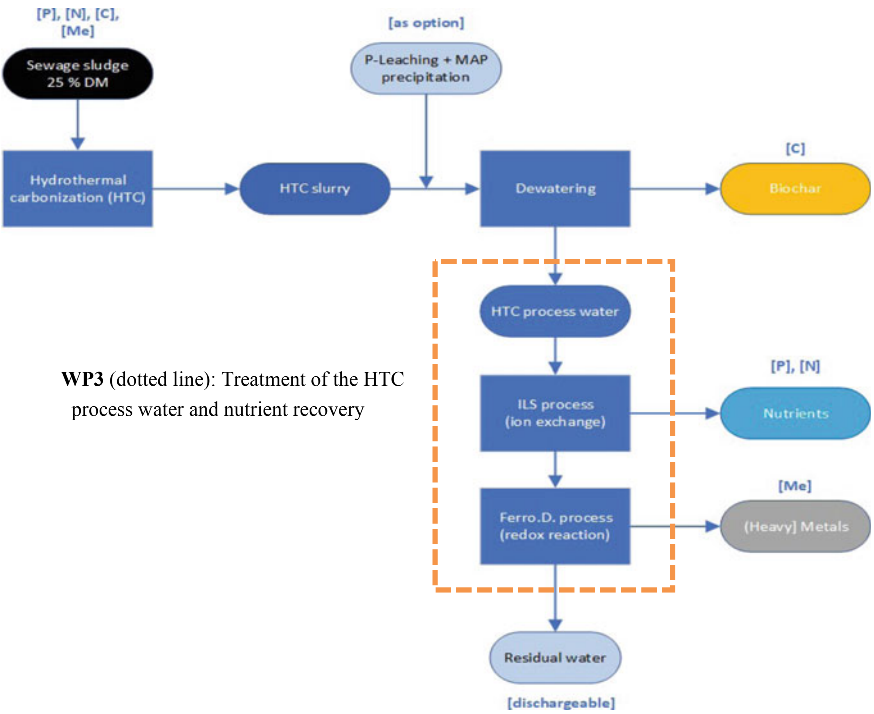


**Fig. 1** Scheme of the process: HTC process water treatment with the ion-exchange-loop- stripping process for nutrient recovery combined with the ferroDECONT process for metal isolation

The products are a nutrient-rich fertilizer solution and a low pollutant but carbon- and energy-rich biochar which can be utilized for material and energy purposes. The scope of the project is to develop an overall concept that serves as a decision-making basis for the technical implementation of these processes in an existing wastewater treatment plant in Austria. One character of the project is a life cycle analyses of the technology and the task to consider the principles of circular economy which is defined in a separate work package (WP). In total, the project consists of 5 WPs whereas the WP3 focuses on the treatment of the HTC process water and nutrient and metal recovery and the WP4 considers the sustainable perspectives, which this paper is part of it.

# 3 Methods

## 3.1 Assessment of the Phosphorous Recovery Potential for the DACH Region

To assess the benefits and impact of phosphorus recovery strategies, the potential for Germany, Austria and Switzerland (DACH region) was evaluated by the author. The forecast runs until 2030, as it is assumed that by then the strategies will be legally anchored and the technologies regarding the recovery rates will be mature. The reason for choosing these countries is the availability of meaningful data basis on previous research.

**Sewage sludge volume**: In the first step, the annual amount of sewage sludge was determined in terms of dry matter (DM) and population equivalent (PE). However, to be able to make reliable data for a current potential estimate or an estimate up to the year 2030, some assumptions were made, which are explained in the following.

In Germany, the total sewage sludge volume in 2010 was around 1.89 million [t] dry matter. In 2018, the amount of sewage sludge produced was approx. 1.74 million [t] dry matter and was thus roughly the same as in previous years. According to statistics on the development of municipal sewage sludge production in Germany from 2010 – 2019, the amount of municipal sewage sludge has not fluctuated significantly in Germany over the last 10 years [17].

The volume of municipal sewage sludge in Austria has remained in the same order of magnitude in recent years and has always been in the range of 235,000 to 238,000 [t] dry substance [18].

Compared to Austria and Germany, there are no current central statistics in Switzerland on the development of sewage sludge production or the types of treatment. These data are documented in the individual cantons, and in some cases, no distinction is made between municipal and industrial sewage sludge, or between sludge from other sources. To be able to make statements about the volume and utilization of sewage sludge, the data from 2017 were used in current publications. According to [19] the sewage sludge volume in 2017 was around 178,000 [t] dry matter.

To collect an estimate of the potential for the DACH region, the period 2017–2018 was therefore chosen as the reference period, based on extensive data for Switzerland.

**Usable amount of sewage sludge for P recovery**: For the actual usable amount of sewage sludge that can be considered for future recovery strategies, the previous recovery sectors in the DACH region were surveyed within the scope of research, whereby it was shown in summary that in all 3 countries about 80% of the sewage sludge quantities can be considered for P recovery. This includes those quantities that are already thermally utilized and will be treated in the future in a mono-incineration with P recovery from the ash. Another part is those quantities that are currently still landfilled or agriculturally utilized and, in both cases, will be prohibited and strictly regulated by 2030 and thus must also be subjected to treatment. The remaining 20% was accounted for by other disposal routes, such as co-incineration in cement plants, whereby it is assumed it will remain unchanged [20].

**The phosphorous content in municipal sewage sludge:** According to [21], sewage sludge contains between 20.0 and 25.0 g P/kg DM. It should be mentioned that the calculations are based on elemental phosphorus. For further estimation, the mean value (22.5 g P/kg DM) was used. Multiplied by the annual utilizable amount of sewage sludge in Germany, Austria and Switzerland, the theoretical amount of phosphorus that could be theoretically recovered is obtained.

**Recovery rates from sewage sludge:** According to a report by the DECHEMA [2], there are currently about 70 processes for P recycling from sewage sludge and sewage sludge ash, which vary greatly in terms of efficiency or recovery rate. The final report of the "StraPhos" study [4] showed that the rate depends not only on the respective technology status but also on the principle of recovery (from the ash after mono- incineration or wet-chemical), as well as on the input quantities. Especially whether the recovery takes place decentral at the wastewater treatment plant with lower input quantities ($< 50{,}000$ PE) or centrally in a mono-incineration plant with input quantities ($> 100{,}000$ PE). Therefore, the report shows that the efficiency for decentralized concepts is between 45 and 70% and for centralized technologies between 60 and 85%. For further calculations, the respective average values for the former with 58% (decentralized, wet-chemically) and the latter with 75% (centralized, thermochemically) are used. In further surveys, the share of wastewater treatment plants that can be considered for a decentralized or a centralized recovery strategy was estimated. According to this, a classification of the size classes in Austria and the resulting sewage sludge quantities shows that 1/3 can be used for decentralized recovery strategies and 2/3 for centralized technologies. This approach was approximated for the entire DACH region [21].

**Demand for phosphorous for fertilizer production:** The demand for phosphorus merely for agricultural use as fertilizer is based on surveys from AMA Austria [22] and was assumed to remain constant in 2030 according to the annual statistics. Not included in the data was the demand for additives in animal feed or chemicals [23].

### 3.2 Evaluation of the Environmental Impacts

For the environmental impacts, the overburden produced during phosphate mining, the phosphorus gypsum produced, and the possible $CO_2$ savings are surveyed. Existing life cycle assessments show that between 7 and 10 kg of phosphate rock is mined for every kg of pure phosphorous [kg rock/kg P]. During the production of phosphorus fertilizer, between 4 and 6 kg of phosphate gypsum is produced per kg of phosphorus, which is contaminated with heavy metals and radioactive substances and is currently landfilled. The $CO_2$ emission results from the input of fossil energy into the operation. In addition to fossil energy sources, this also includes process energy for the production and distribution of mineral fertilizers, pesticides, electricity, water, and external services and varies between 0.5 and 2.4 kg $CO_2$/kg P [24].

The yearly amount of conventional phosphorous that could be replaced is then multiplied by the previous ranges to estimate the environmental effects.

### 3.3 Relation to the Sustainable Development Goals (SDGs)

The relationship between phosphorus recovery from municipal sewage sludge and the SDGs based on the definitions by the United Nations [25] was considered and qualitatively formulated by the author. For the first approach, a stakeholder analysis was conducted to assess the benefits and impacts.

It was assumed that at a wastewater treatment plant with < 50.000 PE the sewage sludge treatment is carried out by hydrothermal carbonization (described in 1.2) followed by a wet-chemical phosphorus recovery process (for example an ion exchange process). This means that the sewage sludge is processed directly on-site. Therefore, there are no additional disposal or transport costs to other treatment companies. The phosphorus recovered is in a condition (unspecified) that it can be used as a feedstock for further fertilizer production (not on-site). The technology system is compact (container size) and can be easily installed on the existing wastewater plant. Accordingly, the plant includes conventional (existing) wastewater treatment processes, innovative sewage sludge conditioning with HTC, and a process for nutrient recovery, where the latter can be considered as an additional sales product to the fertilizer sector.

The next step is to identify the key SDGs which are relevant and considerable. In this way, it can be shown which SDGs the technology has the greatest influence. A document from [26], based on [27] was used as a guideline to conduct a simple but robust analysis. Therefore, three questions (see Table 1) were developed by the author to identify the key SDGs. The answers and ideas were then collected and compared with the contents of the SDGs. The following questions were defined:

**Table 1** Questions to answer for identifying the key SDGs (defined by the author)

| Questions |
|---|
| What effects does the technology have in terms of sustainability (social, ecological, economic)? |
| Where are points of contact with adjacent actors (e.g. municipalities)? |
| Where and in which way is an external impact generated (regionally, globally)? |

## 4 Results

### 4.1 Potential for DACH Region

In 2030, the total volume of sewage sludge will be up to 2.153 [t] per year, where 1.722 [t] can be utilized for phosphorous recovery and 39 [t] per year will be recovered, based on the assumption that the recovery technologies are on technology readiness level higher than 7 [4]. **Table 2** summarizes the results for the DACH region based on the assumptions in 3.1. The potential survey indicates that up to 25 wt% of the annual phosphorus demand to produce fertilizers in the DACH region can be replaced.

**Table 2** P-recovery potential [kt/a] from sewage sludge (SS) for the DACH region until 2030

| Parameter | Value [t/a] |
|---|---|
| Volume total of SS in DM | 2153 |
| The volume of SS in DM used for P recovery (80%) | 1722 |
| The potential amount of P (elementary) in SS (22,5 g P/kg DM SS) | 39 |
| Recovery potential (averaged rate, depending on technology and plant size) | 26 |
| The demand for P for fertilizers in agriculture (excl***animal feed, chemicals)*** | 105 |

## 4.2 Environmental Benefits

The environmental effects due to conventional phosphorus being replaced by recovering are shown in Table 3.

**Table 3** Environmental benefits by replacing conventional P fertilizer production with recovered P in the DACH region until 2030

| Parameter of environmental impact | Unit | Statistical values (range) | Total reduction/benefit (range) [t/a] |
|---|---|---|---|
| Reduction of overburden | [kg rock/kg P] | 7–10 | 185–264 |
| Reduction of harmful gypsum to\be landfilled | [kg gypsum/kg P] | 4–10 | 106–160 |
| Reduction of $CO_2$ emissions | [kg $CO_2$/kg P] | 0.5–2.4 | 13.2–63 |

Up to 264 [t] of overburden produced during phosphate mining can be reduced and 160 [t] of the harmful phosphorus gypsum can be reduced. The possible $CO_2$ savings are between 13.2 and 63 [t] per year and vary greatly since the system boundaries are not uniformly set.

## 4.3 Relation to the Sustainable Development Goals (SDGs)

Based on the previous analysis the technologies of decentralized hydrothermal carbonization of sewage sludge with subsequent recovery of phosphorus primarily address the following goals:

**SDG 6**. Clean water and sanitation: Recovery processes contribute to wastewater disposal by relieving the burden on sewage sludge recycling and creating an alternative use for valuable sewage sludge components, like nutrients. As a result, wastewater disposal become more efficient and sustainable. Further, since the sewage sludge treatment and the nutrient recovery is located on-site, it can also be implemented worldwide, especially in less developed regions.

**SDG 8**. Decent work and economic growth: On the part of the EU, economic dependencies are reduced since sewage sludge is available in large quantities and all year round. Additionally, the national added value and economic performance are increased through the creation of new technologies and thus jobs. For companies in the field of mechanical and plant engineering, the implementation of the technology also leads to the expansion of the portfolio through innovative technologies and the promotion of expertise. Consequently, jobs are also created in this area.

The majority of phosphate mining takes place in North Africa and the Middle East, with inhumane working conditions. Insufficient protective equipment leads to respiratory, and heart problems, and cancer. Phosphorus recovery can reduce phosphate degradation and in addition, new jobs will also be created in those regions if phosphorus recovery technology is expanded globally. This guarantees to take social responsibility for less developed countries.

**SDG 11**. Sustainable Cities and Communities: Growing cities will have to deal with increasing amounts of wastewater and sewage sludge. The treatment of sewage sludge with HTC processes enables the reduction of sewage sludge volumes and the recycling of previously unused side streams. Wastewater treatment plants become deliverers of sustainable nutrients and renewable energy by using biochar energetically. and reducing transport distances. Efficient and economic sewage sludge utilization is of high social relevance, as it leads to reduced odor irritation, reduced transport frequency, and noise pollution. In addition, the technology makes a significant contribution to reducing wastewater charges and municipal disposal costs. This leads to the minimization of financial burdens (sewer fees) for all affected households.

**SDG 12.** Sustainable consumption and production: The provision of nutrients and energy from residues (sewage sludge) increases resource and energy efficiency and reduces the impact of primary production. This includes the fact that the process water produced during conventional phosphate mining is discharged into the surrounding waters, and large quantities of Phosphate gypsum are landfilled as a partly radioactive by-product. The process heat generated by the HTC process can be recovered, and no chemicals are required for the process itself. The use of sewage sludge as a source of renewable energy (fuel or biogas) and nutrients leads to a simultaneous reduction of greenhouse gas emissions. This means that an environmentally damaging effect is avoided. The space requirements for both processes (HTC and nutrient recovery process) are significantly lower than for central mono- incineration plants. Since these processes are used in a decentralized manner, the surrounding region also benefits from them, as the recovered nutrients can be further processed for fertilization in local agriculture.

**SDG 13**: Climate action: By implementing the technology, it can be demonstrated that a contribution to climate protection can also be made in an existing wastewater treatment plant. In addition, education, and openness for sustainability in the region are promoted by such technologies (lighthouse project).

In a future study, which is not covered in this paper, a quantitative and measurable monitoring system will be developed to evaluate the achievement of the considered SDG goals.

## 5 Conclusions

In this paper, an estimation of the annual amount of phosphorous (P) which can be theoretically recovered, and the impact of the environmental aspects were carried out. Further, the relationship between the SDGs and the phosphorus recovery from municipal sewage sludge was evaluated and showed that SDGs 8, 11, 12, and 13 are the key goals. In a future study, a quantitative and measurable monitoring method has to be developed to evaluate the achievement of the considered SDG goals. The connection to the SDGs and following those goals thus serves as an effective orientation to ensure a positive contribution to the environment and humans.

The forecasted P recovery potential in the DACH region until 2030 replaces not more than 25% of the annual demand for elementary phosphorous [t/a], but the environmental impact could be reduced dramatically. Up to 264 [t] of overburden produced during phosphate mining can be reduced and 160 [t] of the harmful phosphorus gypsum can be avoided. The possible $CO_2$ savings are between 13.2 and 63 per year, which vary greatly and depend on the set system boundaries of the regarded process. However, the results show positive environmental effects, which are pronounced for overburden and landfilling. By avoiding overburden and phosphor gypsum, huge areas of green spaces, landscapes, and forests, thus habitat, can be protected. In addition, the input into the groundwater is reduced by the substances contained in the gypsum. Thus, today the potential is limited to the current state of the art of technologies which are mostly on a demonstration or pilot plant scale [2].

The recovery technologies must guarantee high efficiency and need further and intensive research activities, especially including wastewater treatment plants and municipalities to guarantee an overall concept that can be realized. A significant aspect is, that wastewater and sewage sludge are not only regarded as a "sink" but as a "source" of nutrients and follow the principle of the circular economy. Based on the above potential surveys and sustainability assessment, a future project will be outlined, which addresses the treatment of municipal sewage sludge and the recovery of nutrients from the process water. Therefore, in the next step, the first experiments will be carried out and the nutrient and metal recovery process will be investigated.

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# Life Cycle Assessment for the Primary Raw Materials Extraction Industry

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**Abstract.** Since August of 2019, a small team of researchers at Technische Universität Bergakademie Freiberg have been training students and young researchers on the use of Life Cycle Assessment (LCA) with several software packages called UMBERTO+, GaBi and LCA Open access for the purpose of investigating the environmental impacts of processes along their entire Life Cycle. LCA is not new, since researchers started to develop and expand the theoretical background and the methodology already in the early seventies of the last century, except that LCA studies on the extraction, treatment and management of natural resources are not very common. That is why, in Freiberg, our focus is on processes in mining and in mineral processing, especially with respect to minerals and metals with critical relevance for new technological developments, such as decarbonization, the energy transition and the circular economy.

**Keywords:** Life cycle analysis · UMBERTO+ · Training for LCA · Environmental and health impacts · Environmental and health categories

## 1 Life Cycle Assessment

**Life cycle assessment (LCA)** is a methodology for assessing the environmental impacts of a product or a service across all stages from the extraction of the required natural resources through the manufacturing steps, the use and the end-of life with recycling or final disposal. LCA can also be applied to processes leading to the manufacturing of a product or a service. In that way, it can reveal any "ecological burden" which such a product or a service carries before it enters into its use stage [1].

In the course of time, practitioners of LCA and LCIA (the "I" standing for Impact) have been given guidance after the adoption of the ISO 14040 Standard on the 'principles and framework' and of ISO 14044 on the 'requirements and guidelines' [2]. In general, any LCA study according to ISO 14040 consists of four stages as illustrated in Fig. 1.

Many literature sources explain the meaning of the stages and the relevant tasks which they require and readers are referred to them [1, 3–5]. In this contribution, it suffices to point out that LCA studies related to mining as the extraction and processing of primary raw materials are not (yet) very numerous [6–9]. For mining operators, LCA studies do not yet constitute a common practice in the design of feasibility studies on the development and the construction of mineral deposits. Currently, such studies require an


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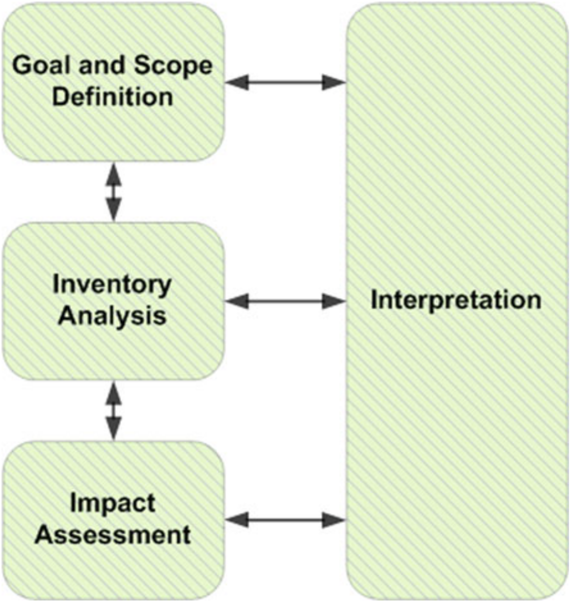


**Fig. 1** The four stages of an LCA study according to ISO 14040

Environmental Impact Assessment (EIA) of the mining activity itself which, however, constitutes only a part of all environmental impacts which can be identified through an LCA.

As a result, as of 2019, the Institute of Surface Mining of Technische Universität Bergakademie Freiberg initiated an educational training of students and researchers in the theory and the practice of LCA related to specific aspects of the extraction and processing of primary raw materials. The following sections report on this initiative, its methodology, its progress and the outcomes so far.

## 2 Training of Life Cycle Assessment for the Primary Raw Materials Sector

Training students and young researchers on LCA for strategic and critical minerals and metals enables them to gain insights in the environmental and health impacts of mining through practical studies and projects. They are trained to develop and complete a full LCA study in all its four stages according to the ISO 14040 standard. In the first stage, they are confronted with the collection of the required input data for the start-up of the study. For the second stage, they learn how to model a process with (i) all inputs from stage one, (ii) the modelling of all technical steps of the process under investigation, (iii) the identification of all environmental and health of these technical steps and their allocation to meaningful environmental and health categories and (iv) finally, the interpretation of the results in respect of their relevance and their application to the set-up of mineral resources projects.

Training is done on ad ad-hoc basis as soon as a small group of researchers and students have registered. Using a case study with given input data, they learn how to design the relevant process for the product of the case study. It is visualized with a technique called Petri Nets combining "places" of inputs and outputs, represented by circles with" transitions" of materials and energy, shown as boxes. All input and intermediate output circles and the boxes are connected by arrows. Backward leading arrows represent returns of circular outputs into the system. Usually, students and researchers receive the required competences in five online or in-person sessions.

Figure 2 shows an example of a process modelling with circles showing inputs or outputs and boxes depicting transformations. All of them are connected by arrows illustrating materials flows.

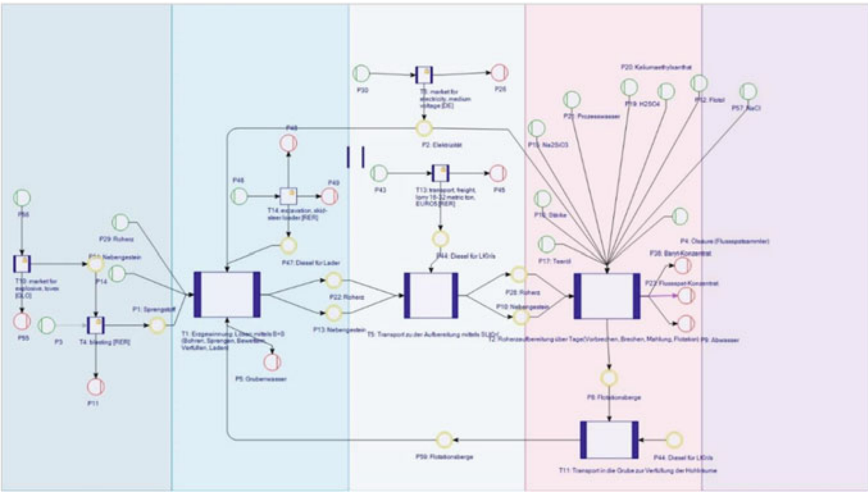

**Fig. 2** A process diagramme [confidential student thesis]

With the help of the software (in our case it is UMBERTO+) [10], the input data of the process model are transformed into environmental and health outputs. These outputs, or, better, impacts, are generated from a large database named Ecoinvent which is managed and regularly updated by a Swiss Consortium of five leading research organizations. Ecoinvent collects such impacts for a large amount of materials, types of energy and a multitude of basic processes, all of that of a per unit bases. By way of example, Ecoinvent lists all relevant environmental and health outputs related to the production of one kg of steel or the transportation of one tonne of cargo by a specified truck on one km of distance. Using the process model designed by the researcher, the software calculates the relevant environmental and health impacts through simple multiplications. Processes not available in Ecoinvent must be modelled by the researcher. This is often the case for mining equipment. As a result, feasibility studies of mining projects and product data sheets by OEMs of mining equipment constitute useful providers of information.

Usually, Ecoinvent delivers long lists of environmental and health impacts for all intermediate and, of course, all final outputs of the process. This inventory, in line with stage two of the LCA study (as shown in Fig. 1), needs to be made transparent to the researcher and any audiences through an assessment, as suggested in stage three of Fig. 1. For that purpose, on the basis of scientific studies, the impacts are allocated to environmental and health categories, as shown in Fig. 3. At this stage, the researcher can select those categories which she or he considers relevant for the research at hand.

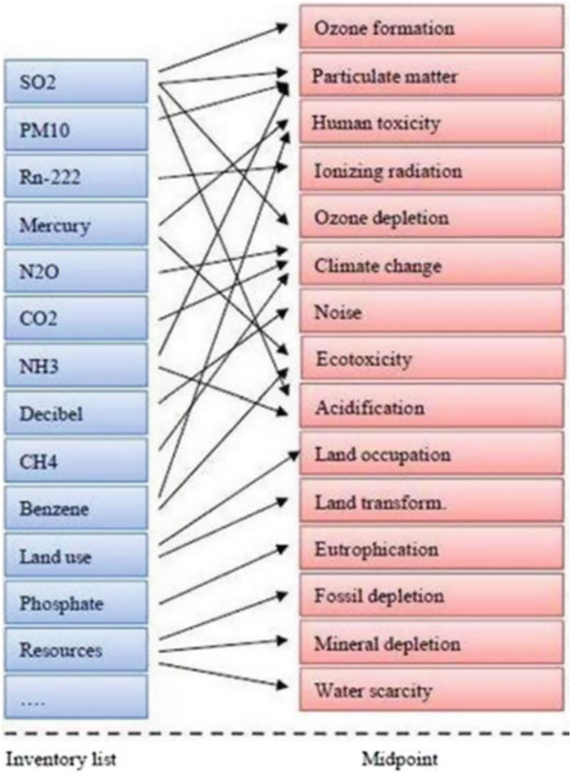


**Fig. 3** Allocation of environmental and health impacts to categories [5]

The final result of any LCA study is a detailed overview of environmental impacts for all steps of a process by category. An example is shown in Fig. 4, taken from a confidential study on Technical Solutions (TS) for flooding a closed open pit mine.

Depending on the complexity of the process and the number of selected categories, the final result is composed of many quantitative tables (not shown in this paper) and many graphs as in Fig. 4. This implies a need for further interpretations (stage 4 of Fig. 1), such as the identification of hot spots, (un)important categories and process stages and the comparison of results of similar studies, if any.

More detailed interpretations relate to a test on the reliability of the final results. For that purpose, some or all input data can be enlarged or reduced by certain percentages (e.g. 2% or 5% up to 10%) and all calculations are repeated to achieve a so-called sensitivity

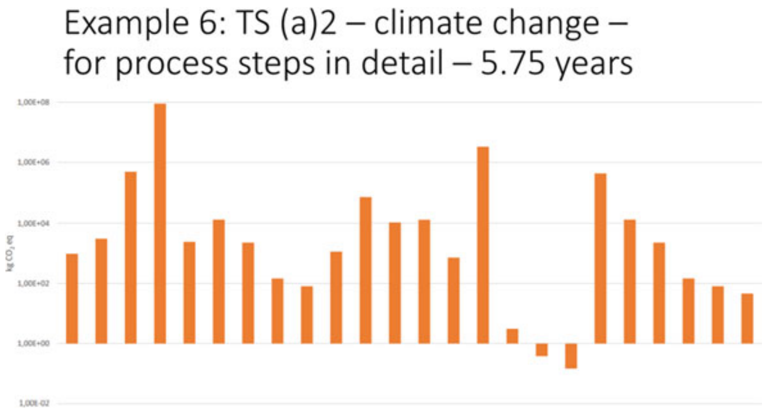


**Fig. 4** Final outcome of an LCA study—excerpt of a report on technical solutions for flooding and open pit mine [confidential student thesis]

analysis. Such additional studies may indicate and suggest potential improvements in the process in order to reduce environmental and health impacts.

## 3 Benefits of Life Cycle Assessment for Research and Practical Applications

Training students and young researchers on LCA for the mining and minerals processing sector and especially for strategic and critical minerals and metals enables to gain insights in the environmental and health impacts. This is relevant, since these minerals and metals carry an environmental burden prior to their use in a large variety of applications.

In as much as Europe is committed to a new Green Deal, awareness should be raised for these ecological rucksacks and strategies need to be developed for their "depreciation" over time within a decarbonized and circular economy. This knowledge also contributes to a better understanding of the significance of SDG 12.

The Institute of Surface Mining of Technische Universität Bergakademie Freiberg is open for co-operation in this area with partner universities, especially of members of the EURECA-PRO European University Alliance.

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# Improving Sustainability in Industrial Plant Construction-Available Tools and Methods

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**Abstract.** In the current scenario, sustainability is a factor that is becoming indispensable in the engineering and construction industry as a basis for decision-making during the life cycle of projects, from the engineering phase, to the construction management phase and finally for asset life management. To achieve the desired impact, which is the drastic reduction of pollutant emissions, a holistic vision needs to consider all the different elements of an engineering and construction of an industrial project. Among the currently available options to include the concept of sustainability in industrial plant construction projects, this work explores the contributions of Virtual Design and Construction (VDC), Integrated Project Delivery (IPD), Lean Construction, DfMA and Modular Construction. VDC, one of its best known elements is BIM (Building Information Management), provides a collaborative work environment, hence contributing to the creation of synergies and the early resolution of interferences between different systems, what links perfectly with contractual strategies such as IPD. VDC provides also the tools to design entire industrial plants in 3D and to combine such 3D models with the execution program to create virtual construction sequences (4D). Such simulations enable the coordination of different activities and the application of Lean Construction techniques, such as Lean planning or Just in Time to name a few. With regard to the prefabrication and industrialisation of components and their effect on the sustainability of construction, the possibilities and interactions between DfMA and VDC are enormous.

**Keywords:** BIM · DfMA · Lean construction · Modular construction · VDC

## 1 Introduction

The European Green Deal sets the blueprint for a transformational change, with the commitment of all EU 27 Member States to turn the EU into the first climate neutral continent by 2050, reducing emissions by at least 55% by 2030, compared to 1990 levels [1].

The green transition will create new opportunities for innovation and investment, developing markets for clean new technologies and products and providing sustainable, local and skilled jobs across the EU. The "Fit for 55" package, further boosted by the REPowerEU Plan [2], includes new requirements for industry to decarbonise production processes, but also supports mechanisms for the uptake of new technologies [3]. Such


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technologies will disrupt current practices in many of the processes that are commonly used to produce a wide range of goods of common use.

There are no simple ways to achieve the decarbonisation of the economy, and several technologies will be used to support the thriving of a new kind of industrial plants. Technologies such as Carbon Capture Use and Storage (CCUS), Green fuels (Hydrogen, Ammonia) together with new techniques and processes (i.e. Direct Iron Reduction (DRI) using Hydrogen instead of coke as reduction agent) will play a crucial role. Such technologies, jointly or combined together, will be key to decarbonise sectors like cement, steel, ammonia or ethylene production. New investment plans for new green facilities are announced every week, often at a gigawatt scale. Few of them fall under the European Union category of "Project of Common Interested (PCI)" for which detailed information and location can be found in [4]. Focusing in CCUS technology, which can be considered a driver to decarbonize existing facilities, over 50 projects are announced or planned across Europe [5]. In this framework, it cannot be ignored that, according to the data from the International Energy Agency [6], the construction industry contributed nearly 36% of final energy use and 39% of energy- and process-related emissions in 2018. In addition, it is well known that the infrastructure sector is an integral part of the global economy. According to the World Economic Forum [7], engineering and construction activities—which form the central part of this sector—generate approximately $10 trillion in annual revenue, equivalent to about 6% of global GDP. In recent years, however, the construction industry has failed to keep up with productivity and sustainability gains achieved in other industries.

Among the causes that contributed to this historically low productivity of the construction sector, the following ones can be highlighted:

Activities are organised around a project structure distinguished by extreme complexity and customisation [8] with a large amount of Engineering-to-Order components [9], low repeatability and a fragmented supply chain [10]. Projects are most of the time executed far away from the company's headquarters, which creates the need of deploying a large multidisciplinary team [11] that can deal with the site conditions which makes each project, even maintaining the design, unique [12]. This organisation makes it difficult to capture knowledge and to transmit it from one project and one team to the next.
Construction sector has been traditionally a conservative sector in terms of innovation, ranking in 2020 among the European industries with lesser investments in R&D [13]. In addition to that, the construction sector presents a low permittivity to the integration of technological advances [10, 14], with lack of real collaboration, poor communication [15] and a big resistance to the change.
Construction projects generally face cost overruns and generate a big amount of waste. Even though it is difficult to measure this waste, some authors found that it represents the 30% of the materials employed in the construction [10].
Construction is a cyclic labour intensive industry and very resource dependent [16].

Improving the productivity of the construction industry while using more sustainable construction methods would generate a positive impact in all the parts of the triple bottom line, social, environmental and financial [10, 17]. Sustainability can be also used as a project management tool, contributing to the decision making process [18, 19].

The aim of this paper is to identify the available techniques and methods that can support the deployment of sustainable construction in the construction of industrial projects. From this in the conclusion section, the main findings, the limitations of the study and issues for future research are presented.

## 2 Objectives

In the new scenario of the Green Deal, the definition of sustainable engineering and construction methods applicable to the industrial plants construction sector will become a critical factor for the success of the decarbonisation strategies. To improve the efficiency of the construction processes, removing extra costs, wastes, and delivering on time, new approaches that support a sustainable construction are needed [20]. The expected end result of the deployment of the sustainable construction technologies is to contribute to the mitigation and reduction of the emissions of the construction. Concepts and techniques like Virtual Design and Construction (VDC), Integrated Project Delivery (IPC), Lean Construction, DfMA and Modular Construction can support sustainable construction management. This article will explore how best practices of each one of these techniques, jointly or separately, can contribute to sustainable construction management.

## 3 Methods

This article was built from a review of literature of Scopus, IGLC and scholar.google.com databases. Several other sources of publications, like the Singapore's Building and Construction Authority, The American Institute of Architects, The Royal Institution of Chartered Surveyors (RICS), Construction Owners Association of Alberta (COAA), The Royal Institute of British Architects (RIBA) were also consulted.

The period analysed comprise the last 10 years, that was considered sufficient to observe the effects of the newly developed approaches in the construction projects. In the mentioned period, 162 publications with the keywords "Lean Construction", "Virtual Design and Construction", "VDC", "BIM", "DfMA", "Modular Construction", "Integrated Project Delivery" and "Sustainable Construction" were selected for further analysis. For the purpose of this paper, 43 of them were included.

## 4 Results

This research has found that there are numerous options currently available to include the concept of sustainability in industrial plant construction projects. Thus, Virtual Design and Construction, one of whose best-known elements is BIM (Building Information Management), provides a collaborative work environment, in which different companies can work in parallel on the same model, as a consequence contributing to the creation of synergies and the early resolution of interferences between different systems. This mode of collaborative work links perfectly with contractual strategies such as Integrated Project Delivery (IPD) [21]. In this methodology—which relies on the creation of a contractual framework on which all the main stakeholders of the project, and in particular the contractors, work together since the earliest stages of the project—BIM can be used as the perfect platform to enable collaboration [22, 23]. When IPD and BIM are implemented together benefits in terms of better project performance and collaboration can be appreciated [21].

The potential of BIM as an engineering coordination tool was widely highlighted in the literature [24]. The importance of the use of collaborative practices and their direct impact on good performance of industrial construction projects was underlined in [25, 26].The relation between an effective design coordination using BIM and the reduction of inefficiencies, cost overruns, schedule impacts and waste was highlighted in [27, 28].

Virtual Design and Construction also provides the tools not only to design entire industrial plants using 3D, but also to bring benefits in terms of visualisation and communication. The combination of the 3D models with the project planning allows the creation of virtual construction sequences, the so called 4D, that allows different simulations of construction sequences, the coordination of different activities and the application of Lean Construction techniques, such as Lean planning or Just in Time, to name a few. These 3D and 4D Models, when combined with an early contractor engagement, can be enriched with the contractor's experience in regard to material selection, schedule, crew compositions and installation methods [22]. The development of this strategy, that has been called by some practitioners as 'build it twice' [29], allows the simulation of the construction process and helps in the identification of some of the potential risks that can later affect the project in the non-virtual construction phase [30].

Several authors have highlighted the benefits of the joint application of VDC/BIM and Lean Construction. Synergy between both BIM and Lean Construction and their ability to improve company culture, create value, increase quality while reducing project delivery time and cost was explored in [20, 31]. Value creation in relation with BIM was explored also in [32, 33]. In addition to highlight positive effects in efficiency, productivity and sustainability when VDC/BIM and Lean Construction are jointly applied, the positive effects in sustainability are also highlighted in [24].

In the same sense, the effects of a combined approach using Lean and BIM on a safer, quicker and better quality project delivery were explored in [34], measuring benefits in the reduction of work at height ($< 75\%$), reduction of defects ($< 60\%$) and reduction in the labour spend ($< 45\%$). Other studies had also explored the relation between the use of BIM and the Design for Safety practices, highlighting satisfactory results. The possibility to use BIM during the design phase to identify the HSE risks during the evolution of a construction project was discussed in [35]. Benefits from applying BIM as a tool for prevention were examined in [36, 37], bringing to the attention the importance of integrated and collaborative approaches to substantially improve safety performance. The benefits that BIM brings to the workers in terms of familiarization with the working environment, the construction methods and sequences and their effect in the hazard reduction were highlighted in [38, 39].

Using a series of techniques that have been called 5D, there is also the possibility of combining cost analysis with 3D and 4D models, hence obtaining detailed cost estimates, as well as detailed measurements throughout the project period. As cost overrun represents one of the major risks of a project [39], having the ability to control it could contribute to enhance project performance.

Prefabrication and industrialisation of components has been highlighted as other of the pillars of sustainable construction. Their effect on the sustainability of construction and the possibilities and interactions between Modular Construction techniques and Virtual Design and Construction are enormous. Starting from the models developed by engineering, manufacturing models can be developed, which will allow efficient construction and installation. The size of the components to be prefabricated off-site (increasing productivity and minimising environmental impact) could be defined using not only purely design criteria, but taking the advantage of the use of 3D and 4D, considering also the sequence of assembly, work needs or the availability of on-site storage. Again, a direct relation between VDC and Lean Construction can be appreciated here, as improving the flow of materials on site and consequently avoiding the deterioration of components due to incorrect or prolonged storage connect with Just in Time and waste elimination principles. In a case study by [40], the positive effect of the use of BIM in reducing the design time and the support prefabrication and related installation ($\leq 50\%$) is presented. Several authors have underlined the benefits and opportunities that combining BIM and Design for Manufacturing and Assembly (DfMA) techniques brings to the multi-trade prefabrication, in particular in improving the safety of the workers, overall quality [41], reducing the project schedule [42], cost [43] and reducing waste [30]. When developing modular construction for industrial plants, BIM and VDC can support on the definition of the module size and in the definition of the cranes to be used [44].

## 5 Discussion

Even though there is enough scientific evidence in the literature that the methods mentioned above (Lean Construction, VDC&BIM, DfMA, IPD) have positive effects in the sustainability and productivity improvements on the construction sector, their effective implementation is far from being widespread among the majority of the companies. According the "European Construction Sector Observatory" [45], even being the most used digital technology in the construction sector, only 29% of the construction companies uses BIM 3D. Figures further reduced to 6% when considering BIM 4D. Lean Construction implementation policies are scarcely accessible, and even when available are found in conjunction with BIM [46]. DfMA is a still maturing technology and its application in the construction industry is still limited [47].

One of the reason for this could be the tradition of resistance to the change of the sector and the fact that the construction industry is at the bottom in terms of investment on R&D. There is also a controversy if the application of the above-mentioned methods will create the desired effect in terms of productivity and sustainability when applied to the construction project. One of the most common thoughts is that the application of such methods will only introduce another additional cost that will impact the already tight margins of the sector, or on the contrary will reduce cost, risks and improve sustainability. The application of BIM&VDC requires an increase of the engineering effort in the initial phases of the projects, but this initial additional effort can be lately compensated by the improvement on the construction sequence, the reducing of waste and inefficiencies. To solve this extra effort in the initial stages, The Singapore's Building and Construction

Authority considers in their guidelines that overall project cost remains unchanged and proposes a 5% increase of the cost of the Design phase and the same amount of cost decrease of the construction phase, maintaining the total project budget from a non-BIM to a BIM project unchanged.

Modularisation also increases the complexity on the design [48], and this, together with the requirement of an early freezing of scope and design, leads to increased initial costs, due to more extensive design and engineering, as well as the requirement of coordination between disciplines. This initial effort can be lately compensated, among others, by shorter project duration, reduction of manpower deployed in the construction site.

The benefits of the use of BIM as a Lean project management tool was also explored by [40], finding that BIM could help to decrease the total contract price ($< 11\%$) and the project time ($< 25\%$). When compared with traditional design methods, BIM results in a faster ($> 10\%$) and more accurate ($> 80\%$) design method with a positive effect on the time needed for the preparation of the documentation ($< 30\%$) [11]. However, the same study highlighted also the limitations of its implementation, like lack of enough trained resources and their higher cost when compared with traditional ones. The authors also highlight the fact that only a completed model is useful. This findings matches with the ones of other research [49], that reveals that in average 3D models only contain 50% of the required information for the developing of the cost estimates. Correction of the models requires investing large amounts of time to transform the 3D model in a valid input. The completeness and accuracy of the models becomes also one crucial point when used as a base for the development of prefabrication, as prefabrication for its own nature is very sensitive to the design changes and all the potential benefits can be easily ruined due to late design changes [50].

## 6 Conclusion

This work provides the basis for a fast understanding of the potential benefits of the application of the practices considered as the three pillars of the Sustainable Construction [10], Lean Construction, Virtual Design and Construction and Manufacturing. Despite its potential, such practices are not fully embraced by the industry and should be a common target of the academia and research community to continue to highlight its benefits and to find effective ways to transfer such knowledge to the construction industry.

For its role as contributor to the negative effects on sustainability, the construction industry has now the opportunity to take advantage, in full or partially, of sustainable practices that will support the objective of a more sustainable society.

From a research point of view, the relations and interactions between Lean Construction, Virtual Design and Construction and Manufacturing should be further explored, and a more comprehensive framework for its effective implementation should be created. Transition from VDC&BIM and Lean Construction to digital delivery systems, like Integrated Digital Delivery, and its potential effects in sustainability should be further explored.

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# Industrial Applications of the Internet of Things

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**Abstract.** In the age of Industry 4.0, a substantial concern for modern manufacturing organizations in optimizing production processes under an Internet of Things (IoT) framework is noted. Moreover, given the significant volume of production, energy efficiency is an inevitable issue. To a great extent, improving production performance depends on the development of new technologies. As a result, this research targets to conduct a research review for the implementation of industry 4.0 technologies in continuous manufacturing. While there is a significant amount of research on batch manufacturing and industry 4.0, continuous manufacturing is less addressed in these scientific works. In an attempt to fill this gap, we try to understand the transition from batch processing manufacturing to continuous processing manufacturing within certain industries, emphasizing the benefits of industry 4.0 relevant to the industry and sustainability. Another crucial part of this study is identifying open issues and challenges of industry 4.0 infrastructure in continuous manufacturing. For such reason, we developed two research questions that we will try to answer during this work. The first one is which are the technologies being implemented as part of industry 4.0 in continuous manufacturing and the second one, does the implementation of such technologies in continuous manufacturing led to energy efficiency improvement.

**Keywords:** Continuous process · Energy efficiency · Industry 4.0 · Research review · Continuous manufacturing

## 1 Introduction

With the increasing development of new technology solutions through the internet of things, big data and data mining there is a need to dig deeper into the interdisciplinary areas of manufacturing cooperation with these advanced technological solutions. Internet of Things (IoT) is identified as an emerging technology used in the manufacturing domain in monitoring and controlling processes and operations [1]. Different studies emphasize the relationship of industry 4.0 with manufacturing in general without concretely studying continuous manufacturing [2]. While there is a significant amount of research on batch manufacturing and industry 4.0, continuous manufacturing is less addressed in these scientific works. In an attempt to fill this gap, we try to understand the transition from batch processing manufacturing to continuous processing manufacturing within certain industries, emphasizing the benefits of industry 4.0 relevant to the industry and sustainability. Another crucial part of this study is identifying open issues and challenges of industry 4.0 infrastructure in continuous manufacturing. However,


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these last years have noticed considerable extension in the application of advanced analytics through IoT in continuous process manufacturing. In addition to that, in many manufacturing industries, there is an increasing awareness of energy savings and energy efficiency considered green manufacturing [3, 4]. Also, manufacturers are aiming at identifying best practices that lead to less and less energy consumption. Many industries have traditionally operated in batch mode. Recently can be noticed an increasing trend for switching from batch operations to continuous operations, especially in the pharmaceutical manufacturing which is considerably gaining momentum. Continuous manufacturing in pharmaceutical industry has been researched for more than two decades. Moreover, Muzzio at Rutgers University started the first research program for continuous manufacturing of pharmaceuticals in the early 1990s. However, the concept of continuous processing has been introduced in different industries such as oil, paper, fertilizers, foods, automotive, etc. On the other side, continuous manufacturing in the pharmaceutical industry's first publication by Imperial Chemical Industries (ICI) made headlines in 1984. Academia and industry are cooperating closely in the matter to outline insights output that can revolutionize the manufacturing production environment. The main contribution of this paper is to identify and categorize current practices and technologies of industry 4.0 implemented in continuous manufacturing industries. Moreover, another focus is trying to address sustainability in terms of energy efficiency in matter in continuous industrial production. For such reason, we developed two research questions that we will try to answer during this work. The first one is which are the technologies being implemented as part of industry 4.0 in continuous manufacturing and the second one, does the implementation of such technologies in continuous manufacturing led to energy efficiency improvement.

## 2 Methods

"The systematic literature review in this paper is conducted through mixed methods proposed by PRISMA statement and guidelines advocated by Webster and Watson 2002 [5]". As result, the review process consists of three main phases: the planning phase, the acting phase, and reporting of results. In the planning phase is discussed the planning part of conducting a review focusing on the available literature, in the acting phase are being discussed the actual steps to conduct the review and in the reporting of results part are included in the results, discussion, and conclusion this study.

We developed a query to search in our database of choice Scopus which provides indexed only peer-reviewed reputable journals [6]. Due to the diversity of content in technical areas we started our query using "continuous manufacturing", "production continuous manufacturing", "Industry 4.0″. Due to the low number of papers identified and for the sake of the robustness of the search we extended our search in areas we were concerned about such as „continuous process*", "continuous manufacturing system", "data-driven", "industrial big data", "analytics", integrating digital environment with the production environment. We build the query employing Boolean operators OR, AND and wild cards with respective variations of keywords:

*Query defined*:

((“continuous manufacturing” OR “production continuous manufacturing” OR “continuous process*” OR “continuous manufacturing system”) AND (“data driven” OR “industry 4.0” OR “industrial big data” OR “analytics”)).

To conduct a qualitative review in this paper we adopt the PRISMA methodology. Using the query defined we searched the literature in the scientific database Scopus. The review is entirely on the research objectives introduced in the above section. Hence articles that did not address those objectives are not considered for further review. The initial total number of the identified records is 1949. Only English-written papers were selected. After limiting the query to all open access papers, the number of retrieved studies was further reduced to 629. Moving forward, a careful title-abstract-keyword screening was made conforming to our research scope that aims to cover industrial applications of the Internet of Things in continuous manufacturing. There were 603 articles excluded at this step. The majority is not focused on continuous manufacturing, not covering technologies implemented, not focused on industrial application, or repeated theoretical cycles on the topic. In the last step, the full-text paper is studied with a thorough assessment resulting in 26 articles. The detailed schema is in Fig. 1.

We also followed some quality assessment review for the screened articles an approach based on the Kitchenham SLR model.

**QA1.** Are the goals and objectives of each article clearly stated?
**QA2**. Is the methodology and scope of the article clearly defined?
**QA3**. Does the research have an industrial application?
**QA4**. Does the article comply and answers our pre-defined research questions in our study?

This quality assessment is a sort of customized protocol that helped us to enforce the PRISMA methodology findings. It is worth mentioning that the excluded papers in Fig. 1 did not fulfill the QA mentioned above. All questions should be answered in the paper’s literature otherwise the paper is not valid for further review. The final papers taken into consideration did answer all these questions in their literature and have major contributions on this work.

## 3 Results

In the majority of the studies process analytical technology (PAT) is highlighted as a rapidly evolving technology for process industries. Beside that Digital Twin, Quality-by-Design (QbD), Data Mining and Machine Learning implemented through the Internet of things are considered innovative technologies. Although, the integration of one or more technology can be translated as a very challenging task due to implementation. Extensive research is conducted in the pharmaceutical industry as a form of continuous manufacturing. Other industries studied are steel, energy, pulp and paper, automotive, chemical, agrochemical, and biopharmaceutical. The research tries to emphasize the advantages of continuous manufacturing over batch manufacturing in terms of economic, energy efficiency, energy costs, scale-up flexibility, failures, and environmental load.

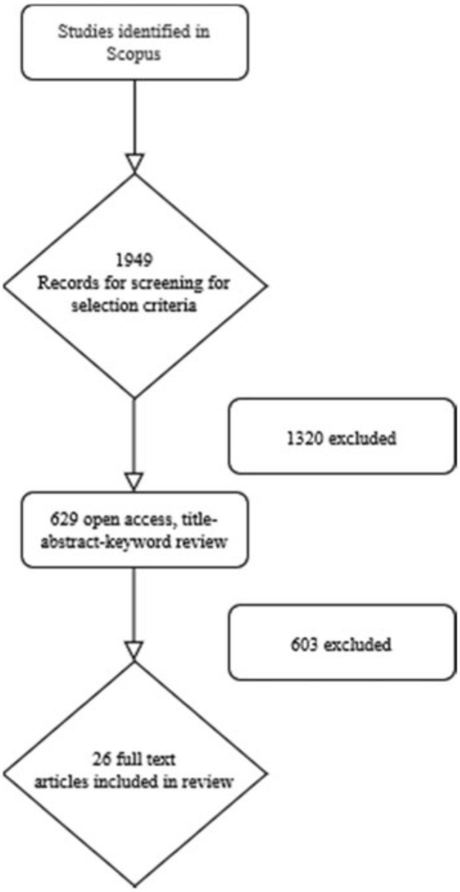


**Fig. 1** PRISMA guideline literature review

### 3.1 Process Analytical Technology (PAT)

This technology is gaining momentum in many industries, especially in pharmaceutical one [7–14]. One aspect of including PAT in Freeze-drying manufacturing can provide additional information on the Critical Process Parameters (CPPs) and Critical Quality Attributes (CQAs) during biopharmaceutical processing. It is proven that this technology reduces time, operational costs, and energy consumption. However, is stated that besides many benefits of using this technology, feasibility at commercial sale requires further exploration [9]. PAT plays a crucial role in continuous flow processing providing real-time monitoring and analysis for a range of applications within the pharmaceutical industry. Continuous manufacturing processes ensure safety and quality of a product. This paper has demonstrated the synergy between different PAT tools, their predictive power to detect and monitor process deviations [15]. The paper "Pat for continuous chromatography integrated into continuous manufacturing of biologics towards autonomous operation" [13] is proven potential for inline measurement. It proposes a reliable inline

PAT concept for the simultaneous monitoring of different product components after chromatography. Moreover, is highlighted that Biologic manufacturing moves toward high-throughput continuous process alternatives. It is suggested for standard batch chromatography or integrated counter-current chromatography (iCCC), an inline measurement of multiple components (e.g., the main component and side components) would be promising to simplify process control. PAT technology has been integrated with emerging technologies such as machine learning attempting to give promising insights. This paper aims to assess the potential of ANNs within the PAT concept to aid the modernization of pharmaceutical manufacturing [7]. It concludes that real-time application for PAT is still scarce. Possible future direction and research gaps as the real-time training capabilities of NNs for continually increasing volume of data should be further studied, as well as the role of time-series ANNs could be investigated in much more detail.

### 3.2 Data Mining

The paper "Challenges and opportunities in modelling wet granulation in the pharmaceutical industry—A critical review" has been discussed how data-driven models based on neural networks have been indicated to be used for application in continuous granulation with great accuracy compared to other approaches, which can also be implemented for process control. This data-driven modelling can play an important role in future process design, optimization, and control of pharmaceutical wet granulation processes [16]. Different studies rely on data mining techniques mostly in continuous production in the pharmaceutical industry. Many challenges need to be addressed in the industrial environment such as scaling, high data volume, data security, and the risk of using Blackbox models. Many industries are focused in applying analytics and automation to their production environment. For that purpose, different data mining techniques are performed and evaluated in an industrial context solving complex challenges. Nowadays the overall trend is comparing classical machine learning algorithms with ensemble methods. In this paper in the steel industry, they experimented with different techniques for fault detection and diagnosis. The result of their study is that machine learning methods can be used and applied to the steel manufacturing process which relies on monitoring strategies such as fault detection to reduce the number of errors that can lead to huge losses. Future research needs to evaluate techniques for fault diagnostics in real time using predictive maintenance. Future research is crucial as sensors record huge amounts of data that need Big Data Analytics to help with analysis for better decision-making. The real-time manufacturing process is compromised due to a lack of proper monitoring techniques for identifying faults [17].

### 3.3 Digital Twin and Quality-by-Design

Most of the studies identify digital twins and quality by design as correlated terms which represent powerful emerging technologies, especially in the pharmaceutical context. "Quality-by-Design (QbD) is demanded by regulatory authorities in biopharmaceutical production. Within the QbD frame advanced process control (APC), facilitated through process analytical technology (PAT) and digital twins (DT), plays an increasingly important role as it can help to assure to stay within the predefined proven acceptable range (PAR). This ensures high product quality, minimizes failure and is an important step towards a real-time-release testing (RTRT) that could help to accelerate the time-to-market of drug substances [18]". Several recent studies tend to present a thorough description of the digital twin development for a continuous pharmaceutical by the Process Analytical Technologies (PAT) and Quality by Design (QbD) guidelines emphasizing that reduced material costs and limited development timeframe manifest the digital twin an efficient tool in technological development [19–22]. Future research is needed to address the integration of Digital Twin technology in a data-driven environment which has its complex challenges presented in the above section.

Below we give a summary of our final customized dataset (Table 1).

**Table 1** Summary results according to final studies

| Title | Technology | References |
|---|---|---|
| Application of artificial neural networks in the process analytical technology of pharmaceutical manufacturing—a review | Neural Network + PAT | [7] |
| Improving the load flexibility of industrial air separation units using a pressure-driven digital twin | ASU (air separation units) | [15] |
| Simulation for predictive maintenance using weighted training algorithms in machine learning | Data mining | [23] |
| Digital twin for HIV-Gag VLP production in HEK293 cells | DigitalTwin, PAT, QbD | [8] |
| Digital twins for scFv production in *Escherichia coli* | Quality-by-Design (QbD), digital twin, pat | [18] |
| Challenges and opportunities in modelling wet granulation in pharmaceutical industry—a critical review | Data mining | [16] |
| A data mining approach for continuous battery cell manufacturing processes from development towards production | Datadriven, data mining | [24] |
| Investigating the trade-off between design and operational flexibility in continuous manufacturing of pharmaceutical tablets: a case study of the fluid bed dryer | Datamining, blackbox model | [25] |
| A review on data-driven process monitoring methods: characterization and mining of industrial data | Fault detection and diagnosis (FDD), data-driven process monitoringtechnology | [26] |
| Digital twin of low dosage continuous powder blending—artificial neural networks and residence time distribution models | ANN, DigitalTwin, PAT, QbD | [19] |
| Innovative drying technologies for biopharmaceuticals | PAT | [9] |
| Energy strategies in the pulp and paper industry in Sweden: Interactions between efficient resource utilisation and increased product diversification | Energy management systems | [27] |
| Optimally managing chemical plant operations: an example oriented by industry 4.0 paradigms | RTO system(digital twin, industry 4.0) | [28] |

(*continued*)

**Table 1** (*continued*)

| Title | Technology | References |
|---|---|---|
| Integrated continuous pharmaceutical technologies—a review | Electrospinning (ES), PAT | [10] |
| A comment on continuous flow technologies within the agrochemical industry | PAT | [11] |
| Advanced real-time process analytics for multistep synthesis in continuous flow** | PAT, machine learning | [12] |
| Pat for continuous chromatography integrated into continuous manufacturing of biologics towards autonomous operation | PAT | [13] |
| Process analytical technology as key-enabler for digital twins in continuous biomanufacturing | PAT, digital twin | [20] |
| Why is batch processing still dominating the biologics landscape? Towards an integrated continuous bioprocessing alternative | PAT, process modeling and simulation | [29] |
| Application of machine learning tools for energy efficiency in industry: a review | Machine learning | [30] |
| Process analytical technologies and data analytics for the manufacture of monoclonal antibodies | PAT | [14] |
| Digital twins in pharmaceutical and biopharmaceutical manufacturing: a literature review | PAT, digital twin | [21] |
| Towards implementation of big data concepts in a pharmaceutical company | Big data | [31] |
| An efficient genetic method for multi-objective continuous production scheduling in Industrial Internet of Things | Industrial internet of things | [32] |
| Accelerating biologics manufacturing by modeling or: Is Approval under the QbD and PAT approaches demanded by authorities acceptable without a digital-twin? | PAT, QbD, digital twin | [22] |
| Performance evaluation of data mining techniques in steel manufacturing industry | Data mining | [17] |

Below we are presenting the Ishikawa diagram of cause-effect for the transition from batch to continuous that we have customized based on our needs on the literature we have taken into consideration. It is considered a powerful tool for brainstorming and generating new ideas for a problem. It is widely believed that identifying the causes of a problem leads to potential solution.

Concretely while studying the literature, it is noted that the transition from batch to continuous manufacturing has many advantages but also brings on the table many challenges. An attempt of ours is to display our main findings in the cause-effect diagram in Fig. 2. In terms of resources, the most challenges identified are lack of continuous manufacturing expert's domain, lack of motivation, management, and human errors. For advantages and challenges from a technical point of view, the digitalization process is crucial for production using real-time analytics, PAT technology, internet of things with a huge techno-economic impact. Data mining can enable accurate insights with data modelling but comes with many challenges of handling high volume and variety of data.

The transition process is recognized as very important the quality assurance component. Last but not least, continuous manufacturing using IoT identified energy usage and foot print reduction as two leading goals in terms of energy efficiency.

## 4 Discussion

Nowadays still most manufacturers rely on batch production. The reasons are different, but mostly due to the historical prevalence of batch operations, and a lack of motivation to make changes to operating practices because of the minimal cost of production relative to the profit margins expected in these industries. Much of the resistance to change arises from the fear of the impact on product quality.

Many researchers studied batch processing or batch production systems. In their study, the authors combined different techniques such as OEE analysis, Internet of Things (IoT), and cyber-physical production system (CPPSs) that lead to energy savings. They focused on the process cycle time and energy consumption in the batch production. Another crucial component to achieving overall productivity in the batch process is production scheduling. It plays a huge role in heat integration and represents a tool that could help to reduce energy consumption in batch processing. The manufacturing industry has been one of the biggest energy consumers.

As a consequence, energy efficiency has become a very significant factor for manufacturing enterprises to reduce energy consumption for minimizing costs and environmental impact, finding new solutions to produce "more with less". The main findings of this study are that energy efficiency has to be defined separately for each manufacturing level, and process-level energy efficiency is successfully defined for all manufacturing processes. Energy efficiency at the production line and factory levels can be significantly improved with better scheduling and the inclusion of shutdown or eco-modes in the work

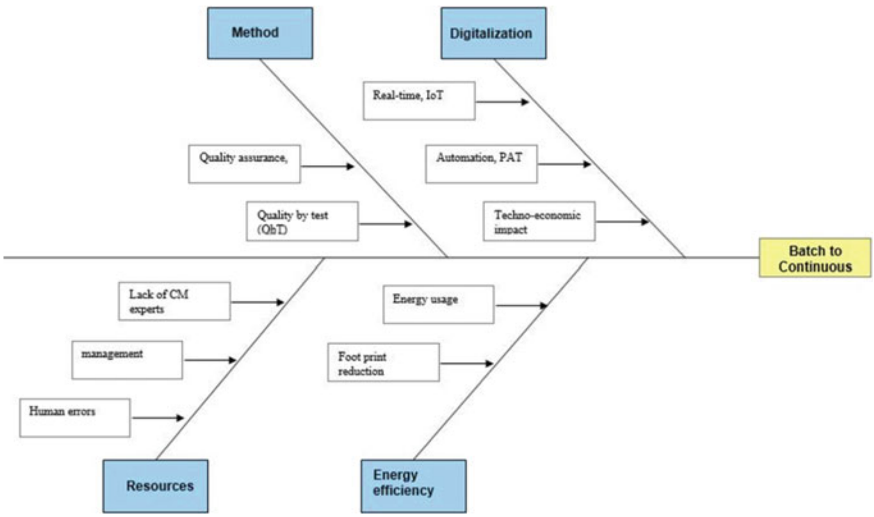


**Fig. 2** Ishikawa diagram cause-effect-problem

planning of the machines. However, the main industry that has mostly switched from batch processing to continuous one is the pharmaceutical industry. Another interesting article [33] that writes about the transition from batches to continuous and generally for continuous processing or continuous manufacturing, presents some interesting questions such as how to ensure quality and regulatory compliance. How to maintain consistent process control and quality when there are no checkpoints between batches?

To answer this question is needed real-time monitoring and advanced analytics are.

Another article [10] in support of the transition from batches to continuous manufacturing in the pharmaceutical industry, confirms that the continuation of production means companies can minimize waste and energy usage, reduce changeover costs, and better monitor drug quality on a continuously through data analytics and real-time checks. Moreover, US Federal Drug Administration (FDA) confirms this switch due to flexibility, the positive effects on the production side, and the minimization of human errors. On the other side is pointed out many risks that come with the implementation of continuous production. In the end, they come up with a case study; the global Biotech company that leverages real-time monitoring and advanced data analytics through automation excellence to achieve continuous manufacturing in a new digital manufacturing facility. Internet of things (IoT), predictive technologies are said to rely on one common core: process analytical technology (PAT). In continuous manufacturing environments, many industries (mostly pharmaceutical) are relying on in-line PAT.) However, this study has supported the idea that pharmaceutical continuous manufacturing does not yet coordinate with PAT technology in terms of control framework. Further research and collaboration from academia and industry is more than needed and praised regarding the matter of discussion.

## 5 Conclusion

Reviewing the recent literature, the following has been noticed:

Only a small number of papers present energy efficiency in continuous manufacturing through the internet of things (IoT). Their research is mostly focused on footprint reduction and energy usage in cycle times. There are many challenges in the implementation of continuous manufacturing and also from the transition between batch and continuous manufacturing which are also discussed in the Ishikawa diagram, most of which are related to digitalization, automation, lack of expert domain, human errors, and lack of motivation.

The biggest part of the research emphasizes PAT technology in the pharmaceutical industry. More research is needed in the implementation of continuous manufacturing in other industries besides pharmaceutical industry.

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# Introduction of Integrated Resource Management for Sustainable Development of Industries

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**Abstract.** The transformation of the energy market towards a decarbonized economy as well as the increased dynamization of the corporate environment in combination with easier accessible information on company-internal processes as a result of digitalization require a holistic view of a firm's resources. This paper presents the approach of Integrated Resource Management (IRM) as an instrument of strategic corporate alignment using the practical example of carbon neutrality. After a review of the development of the concept of resources in context of corporate management systems, a potential matrix is applied to structure substitution alternatives for gas supply. In addition, the subprocesses of bundling and leveraging a firm's resources are described in the context of gaining a competitive advantage as a result of an Integrated Resource Management approach.

**Keywords:** Carbon neutrality · Energy management · Substitution potential · Resource-based view · Strategic management

## 1 Introduction

Due to increasing interconnectedness and the resulting dynamization of the firm's environment, as well as rising complexity in processes within companies, management faces ever greater challenges caused by the multitude of interdependencies. The transformation of the energy market and the associated topics such as carbon neutrality or security of supply demonstrate how quickly those changes become crucial factors for success. The approach of resource-oriented management, which has gained importance in economic practice since the 1980s, is examined in more detail in the following article, whereby the added value of an integrated view of resources from the aspect of carbon neutrality is to be demonstrated.

Since the goal of this article is to suggest an integrated resource management perspective for sustainable development in industries, it will first provide a historical overview of the development of management literature focusing on company internal and external perspectives. This provided overview shall help to embed the term "resource" within this field of research.

As a result of the increased dynamization of the business environment towards the end of the last century, it became increasingly difficult for large, divisional-organized


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companies (e.g. General Electrics, ABB) to keep up with small, less hierarchically structured competitors. In many cases, this resulted in a restructuring of the established large corporations [1].

The management approach that prevailed until then focused mainly on external incentives and requirements, which also became known as the Market-Based View (MBV). In this growth-oriented, strategic alignment of companies, less attention was paid to the systematic recording of the equally important internal influences [2].

In order to meet the increasing dynamization of the market, many management systems focused on the internal company perspective, whereby various management philosophies were pursued. Examples of this are "In Search of Excellence" by Peters and Waterman from 1982, Total Quality Management as a corporate strategy as well as the "Learning Organization". Each of these approaches contributed to improved understanding, but lacked effective linkage to the previously prevailing, established management strategy based on the external point of view [1].

In 1984 Wernerfelt published the article "A Resource-based View of the Firm" (RBV), which stated that the optimal orientation on the product market can be found by recording the resource profile of a company. In his definition, the concept of resources encompassed all internal aspects which can be seen as either strengths or weaknesses of the respective company. For this purpose, methods and concepts were developed in order to be able to map the resource profile of a company and to derive a strategic company orientation from it [3].

Teece et al. [4] analyzed that well-known companies such as IBM or Texas Instruments, have apparently pursued such a resource-based corporate strategy. This was done by accumulating valuable, idiosyncratic and difficult-to-imitate technological assets. However, it should be noted that this strategy does not result in a significant competitive advantage in all branches of industries. The alignment of corporate competencies to the dynamics of the market, as well as the effective strategic management in terms of adaptation, integration and reconfiguration of internal and external skills, resources and functional competencies of the organization has been summarized by the authors under the term "Dynamic Capabilities". This is intended to give companies a sustainable competitive advantage by effectively combining the internal (RBV) and external (MBV) views.

A well-known publication entitled "Competing for the Future" by Hamel and Prahalat [5] published in the Harvard Business Review also justifies the necessity for resource-oriented corporate management arguing that competitive positioning could be lost by focusing solely on present-oriented, operative process optimization. In order to substantiate this position, questions were posed along the core aspects of the theory (customers, competitors, competencies) to enable an active comparison between the present and possible future developments. According to the authors Hamel and Prahalat [5], it is not possible to generate a long-term competitive advantage with the management models established up to that point, which focused on increasing cost efficiency as well as quality and productivity. For companies aiming to improve their market position, management must integrate both internal processes and external factors into a holistic view to lay the foundation for a sustainable and future-oriented corporate orientation. This approach is also reflected by the concept of core competences, which include the external view by looking on the market side as well as the internal view by including difficult to imitate competences [6].

After placing the need for an integrated resource management by providing a qualitative overview on literature focusing on this area of research, the article highlights the objectives of the given research and outlines the methods used for conducting the qualitative literature review. Furthermore, the results of the research are presented and applied in a use case enabling diversification of energy supply for carbon neutrality, while increasing security of supply. Finally, the limitations and future research objectives are described.

## 2 Objectives

In this paper, the authors propose an integrated view of the company's resources, which offers a viable solution by combining both perspectives and allowing to gain a sustainable competitive advantage by combining a firm's resources in the most effective way through qualitative and quantitative evaluation. Therefore, a qualitative literature review on the term "resource" in the context of the field of economics has been conducted to derive a better understanding of the current state of research. Furthermore, the idea of an Integrated Resource Management (IRM) to combine a firm's resources in the most effective way through qualitative and quantitative evaluation is introduced. This is exemplified by applying instruments of the proposed IRM framework, which are used for decreasing the carbon footprint of energy supply while increasing resilience in the face of power supply shortages.

## 3 Methods

Part of this research was conducted through a structured literature review using constrained snowball sampling in order to set the theoretical framework centered around the economic view of the resource definition and understanding. By using the snowball sampling technique, a seed article was used from which other relevant articles were identified until the historic origin of the resource-based perspective was found. This proceeding was meant to ensure a comprehensive analysis of the research topic regarding the classification of the term "resource" in the field of economic literature.

The need for future research in the described field was not only shown by the results of the comprehensive literature study, but also by Hitt et al. [7], who highlighted the necessity of resource classification.

An application for the practical use of instruments of the integrated resource management is provided through the example of evaluation of energy supply options. Therefore, a potential matrix has been applied to assess options for decarbonization.

For the example of evaluation of diversification of energy supply options, the considered alternatives as well as the circumstances taken into consideration are based on information available as of June 2022.

## 4 Results

The resources available to a company can be classified according to their characteristics. The term “strategic resources” describes those resources which are integrated in corporate planning and whose market development is therefore followed more closely. Valuable, rare, inimitable and non-substitutable are the characteristics that are summarized under the acronym “VRIN” and represent strategic resources [5]. This term results from their contribution to the successful implementation of the corporate strategy. However, the successful implementation of a strategy depends not only on VRIN resources, but also on complementary or non-strategic resources (non-VRIN). With the “Factor-Market Rivalry” (FMR) theory, the main focus is on these non-strategic resources, which by themselves do not provide a sustainable competitive advantage [8, 9]. The circumstance that non-strategic resources are necessary to develop the contribution of strategic resources to the execution of the corporate strategy reflects the fact that the value of resources is dynamic [10]. An important influencing factor in the dynamic shaping of the value of resources is their availability, independent of the allocation or classification of the resource. As a consequence, it follows that a clear distinction between strategic and non-strategic resources cannot always be made [9]. Bergen and Peteraf (2002) state the necessity for enterprises to concentrate not only on the sales market, but also on the procurement market, due to the fact that enterprises face (indirect) competition on both markets. This is also a conclusion of the work of Dyer et al. [8], who examined the supplier markets of the automotive industry, where the strategy of co-operation could provide an advantage in the competition for resources [8].

Since the energy transition has a major impact on production companies, a change in the design of the resources used for manufacturing represents a significant challenge. This results in the need to enable an effective classification and efficient use of corporate resources through an integrated consideration of those in order to generate a sustainable competitive advantage through these core competencies.

According to Scheuss [11], the concept of resources is further subdivided into tangible, intangible, financial, and organizational resources. While tangible resources include all current and fixed asset items, intangible resources include rights of disposal such as patents, licenses, trade secrets, etc., as well as the image of a company. Financial resources, on the other hand, describe, for example, liquidity or the composition of the company’s capital. Organizational resources include information, communication and controlling systems. From the author’s point of view, material resources do not permit any differentiation in competition, but merely indicate the available capacities.

However, based on the current situation, it can be argued that due to rising energy prices, caused by limited availability and the challenges of the energy transition, an optimization of the asset and energy management strategy in terms of material resource management can enable a competitive advantage. In this context, it is worth mentioning that due to the dynamics in the value creation of resources, as well as the temporal component of the impact of strategic decisions, material resources can provide a competitive advantage at least in the medium-term time horizon and contribute significantly to the company’s success. This interaction contributes to the fact that non-strategic resources can become strategic resources and vice versa, illustrating the need for effective evaluation and allocation of corporate resources, which can lead to a core competence. To some degree uncertainty about the market value of a firm's resources is incorporated in the resource based-view. However, the inclusion of transaction cost economics is missing, e.g., when the behavior of market participants is unpredictable [12].

A further important consideration, which is necessary to prevent unintended loss of competitive advantages, is the coordination of internal resources. This is due to the fact that individual efforts to organize resources may result in decreased complementarity among the resources within a firm [13].

Restrictions in the infrastructure or uncertainties due to political events intensify the competition at the procurement market for production factors [9]. In addition to the above-mentioned dynamics, environmental challenges are increasingly putting carbon neutrality at the center of business strategy. In order to meet these challenges, the coordination of various corporate departments through integrated resource management is necessary.

Sirmon et al. [15] divides the resource management of enterprises into the subprocesses structuring of the resource portfolio, bundling resources to create capabilities and leveraging capabilities to exploit market opportunities to create an advantage for the enterprise. The process of structuring deals with the management of a company's resource portfolio and features the process steps of acquisition, accumulation and divesting of resources. The importance of giving attention to the identification of company internal resources has also been highlighted by Chen et al. [14]. In the case of resource bundling, which describes the combination of corporate resources to modify existing or create new capabilities, the sub-aspects of stabilization, enrichment and pioneering can be mentioned. Leveraging of corporate resources describes the use of available capabilities in the form of mobilization, coordination and deployment in order to create a benefit for the customer or create value for the shareholders of the company (Fig. 1).

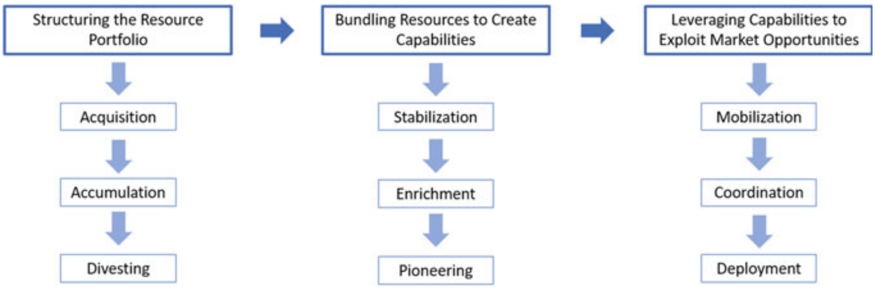


**Fig. 1** Subprocesses and steps of resource management (Own representation based on [15])

In order to meet challenges such as the firm's carbon neutrality, it is necessary to effectively structure, bundle and leverage, besides others, tangible and intangible respectively strategic and non-strategic resources.

## 4.1 Structuring

Due to the dynamic value structure of resources and the interdependence with strategic decisions, the creation of a resource portfolio can be a possible way of meeting the challenge of sustainable development in a forward-looking manner. This is applied in the process step of resource acquisition, as part of the structuring process. In this paper, the instrument of the potential matrix is explained in more detail as one possible instrument applicable within the IRM framework.

Figure 2 illustrates the application of a potential matrix for the objective of substituting energy supply based on natural gas with more sustainable alternatives. For this purpose, the options of substituting gas with electricity, heat from thermal utilization of residual materials, and geothermal energy have been used. The diameter of the circles represent an estimate of the investment costs for a new installation of the aforementioned technologies.

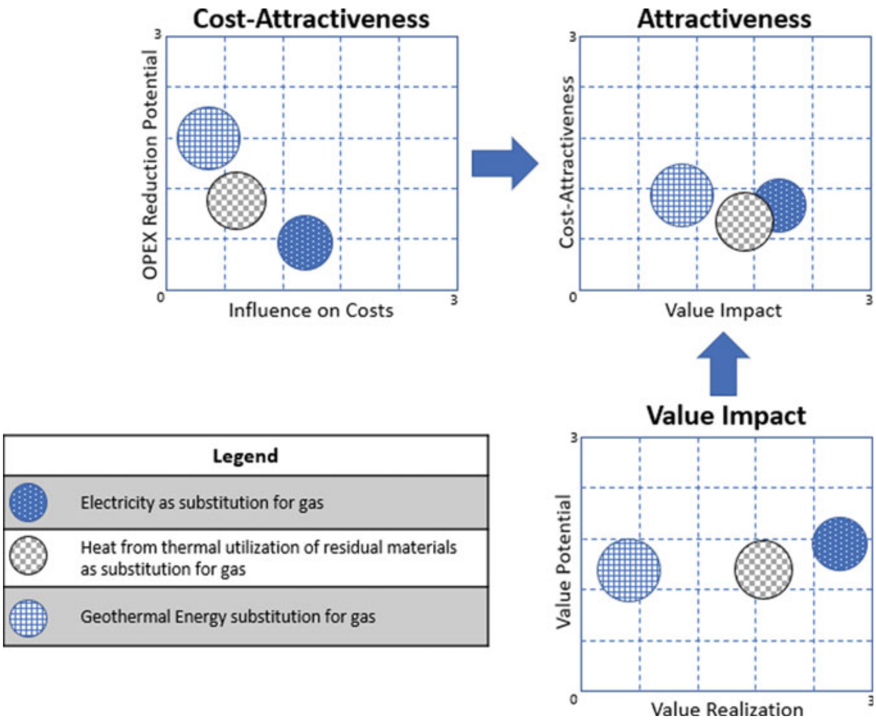


**Fig. 2** Exemplary dimensions of the potential matrix displaying attractiveness of the energy carriers (Own representation based on [16])

The diagram of cost-attractiveness in Fig. 2 consists of the reduction potential of operational costs (OPEX) and the influenceability of these costs. The OPEX reduction potential sets the operational expenses of options for substitution in relation to the alternative of staying with the status quo. The OPEX can consist of expenses for maintenance as well as expenditures for CO2-certificates, energy for operation and others. The abscissa of the diagram measures the influenceability of operational expenses such as choosing an alternative energy supplier.

For example, the operational expenses for a geothermal energy well are assumed to be lower than those for the alternative of gas heating. Thus, the OPEX reduction potential shows a high value for the option of geothermal energy. On the other side, the option of using electricity instead of gas allows for a higher influence of costs, due to a greater number of suppliers compared to the gas market as well as the option of an, at least partially decentralized, production and therefore self-supply. The OPEX reduction potential is estimated lower, because of the interconnectedness of the electricity price from grid supply with the gas price if the demand cannot be covered solemnly by alternative energy sources.

The value impact of an option for substitution is described by the dimensions of value potential and value realization. The value potential is based on different aspects inherent to the energy carrier. With respect to carbon neutrality a factor for the value potential is the impact on the carbon footprint generated by the firm. Another aspect of value potential might be the quality of energy supply enabled by the energy carrier. Depending on a company's strategy different emphasis can be laid upon the considered aspects adding to the value potential. The dimension of value realization is characterized by the ability to communicate an added value to the customer or to utilize the advantage in competence gained by the switch in technologies. For the example at hand, a move to geothermal energy supply allows for carbon neutrality, which can be a market barrier and is therefore seen as a value potential. Due to the complexity of the geothermal energy solutions, the communication of the added value to the customer can prove itself more difficult compared to other solutions. The arithmetic average of both charts, cost-attractiveness, and value impact, is depicted in the diagram of attractiveness.

To estimate and classify the substitution potential of alternatives, the security of supply must be taken into consideration in addition to the dimension of attractiveness of the solution. The security of supply consists of the price security and the availability of the respective options. In the given example, the geothermal energy solution grants rather stable prices, while at the same time an economic profitable operation is restricted to certain geological areas, as shown in Fig. 3.

Consequently, the substitution potential matrix is derived by combining the attractiveness and the security of supply. A high substitution potential for a given technology indicates the most favorable option for fulfilling a sustainable development strategy. With the exemplary parameters underlying the use case depicted in Fig. 3, the geothermal energy solution does not show the greatest potential for substituting the required energy demand. This is partly due to the small influenceability on operational expenses as well as the low number for value realization. Aiming for the highest impact on carbon neutrality, the option for electrification shows the highest potential as indicated by the position in the substitution potential matrix.

## 4.2 Bundling

In order to address the issue of carbon neutrality in an increasingly dynamic environment, it is necessary to bundle the company's resources effectively and efficiently with a special focus on energy supply. The classification of the various supply options previously carried out as an example for structuring the energy supply, can be used to gain an effective compilation of the resources available in the company.

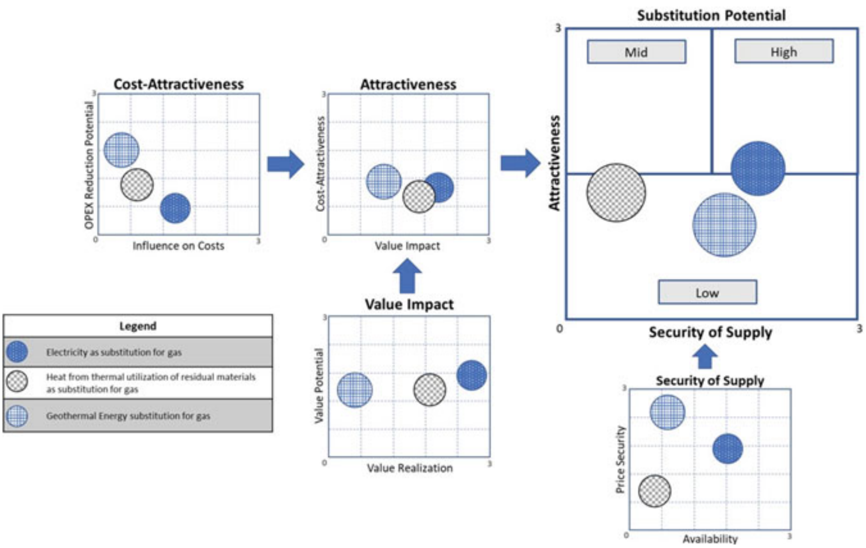


**Fig. 3** Exemplary energy potential matrix for different energy carriers (Own representation based on [16])

Due to the different lifetimes and periods of use of resources, the interaction requires not only bundling but also the constant dissolving and reassembling of resources [17].

### 4.3 Leveraging

The resulting ability of the company to combine the classification of energy sources in the potential matrix with the existing strategic and non-strategic resources represents a core competence with regard to carbon neutrality. In addition, synergy effects can arise due to the flexibilization in the design of the energy supply, as well as the resilience to failures and security of supply. The exploitation of this capability to the competitive advantage of the company in form of leveraging, i.e. the use of the resource bundles, represents the linking of the acquisition process of resource management with the orientation of energy management in the company.

## 5 Discussion

The goal of this article was to review the development of the concept of resources in the context of corporate management systems. Recent developments in the business environment such as increased dynamization of the markets, as well as the energy transition lead to new challenges in terms of managerial decisions. Additionally, an increased amount of information regarding the development of a firm's internal resources has become available for decision makers due to the advancements in the field of digitalization. The aforementioned progresses do not only enable a more holistic view on the resources, but also strongly improves the capability of this integrated management view to gain a competitive advantage.

Future research is needed to provide and test the necessary instruments and tools to effectively and efficiently structure, bundle, and leverage a firm's resources. This is exemplified by structuring the energy carriers through assessment against the energy potential matrix and needs to be further developed in bundling and eventually leveraging the resources to use those in the most effective and efficient way possible.

## 6 Conclusion

The progress in digitalization in combination with increased competitiveness due to an ever faster changing business environment, results in the necessity to further develop a holistic view of resources for management systems. This is due to the fact that current challenges like carbon neutrality and resilience against specific energy sources together with easier access to information, require coordination of decisions on internal as well as external perspectives. As the development of the term "resource" over time has shown, an extension and adaption to today's market conditions is necessary, since major transformations, such as the energy transition or digitalization, influence all parts of modern industry. The Integrated Resource Management view offers a viable solution by combining both views and allowing to gain a sustainable competitive advantage by connecting a firm's resources in the most effective way through qualitative and quantitative evaluation.

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# Text Classification of Users Claiming to Have ASD Using Traditional Machine Learning Techniques

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**Abstract.** Autism spectrum disorders (ASD) are developmental disabilities caused by differences in the brain. According to the WHO, ASD affects 1% of the population. However, many people are still undiagnosed. Thanks to artificial intelligence, more and more research is being carried out with the aim of obtaining early diagnoses that help to reduce the negative impact of the diseases or even prevent them. For all these reasons, this research has been carried out by collecting and tagging data through the social network Twitter. These tweets were obtained from users who, in their biography, indicated that they suffered from ASD or were relatives of someone with ASD. Subsequently, the set of tweets obtained was preprocessed, generating a set of 404,627 tweets, thanks to which text classification techniques, Random Forest and Support Vector Classifications, were applied. The results show predictive models with an accuracy of over 74% when classifying texts that may come from people with ASD. The research, despite its limitations, opens up a new line of research that may improve the diagnosis of this disease.

**Keywords:** NLP · SVC · Text classification · ASD · Autism spectrum disorders


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## 1 Introduction

Autism spectrum disorders (ASD) are developmental disabilities caused by differences in the brain [1]. According to the World Health Organisation (WHO), ASD affects approximately 1% of children, although this figure may be higher because there are many undiagnosed cases of ASD [2].

The early diagnosis of this disease is one of the challenges facing medicine today. It is important to note that early diagnosis of ASD cannot help prevent the disease. However, it does help directly in the quality of life of the patient and his or her relatives, since the treatment that an ASD patient must receive for even everyday tasks is different from that of a person who does not suffer from this disease. Among the different diagnostic methods are the CARS (Childhood Autism Rating Scale), ASD-OC (Autism Spectrum Disorder-Observation for Children) and ASD-DA (Autism Spectrum Disorder-Diagnosis Scale for Intellectually Disabled Adults), the ADI-R (Autism Diagnostic Interview-Revised), 3di (developmental, dimensional, and diagnostic interview), ASDI (Asperger Syndrome (and high-functioning autism) Diagnostic Interview), DISCO (Diagnostic Interview for Social and Communication Disorders) and, nowadays, diagnoses using artificial intelligence techniques such as those combined with eye-tracking techniques [3].

The use of artificial intelligence techniques in the field of medicine and health in general is becoming increasingly important [4–6]. Thanks to this branch of knowledge, systems for COVID-19 diagnosis [7] and also in the field of mental illnesses such as schizophrenia [8] have been generated. Furthermore, in the field of natural language processing, studies have been obtained that have helped, for example, to detect people suffering from eating disorders [9]. Natural language processing techniques together with data from social networks, such as Twitter, are helping to generate artificial intelligence models capable of classifying or detecting patients suffering from some kind of pathology, especially in the field of mental illness.

Taking into account the advances achieved through artificial intelligence techniques and, more specifically, the application of natural language processing to texts in the field of health, this research proposes to make use of texts obtained from a social network by applying these techniques to obtain different models capable of identifying ASD in the network's users. In the literature that has been reviewed, studies have been found that analyse the discourse of people who talk about autism and other articles that talk about the possibilities offered by artificial intelligence in the diagnosis of ASD [10]. But no studies have been found that cover the problem presented in this research.

In view of the above, the main objective of this study is to generate predictive models of natural language processing capable of detecting people who may suffer from ASD in texts through traditional machine learning techniques. In the future, comparisons will be made with other more advanced models and semantic enrichment techniques will be added to generate new approaches that can be extrapolated to other problems.

## 2 Material and Methods

### 2.1 Dataset

A dataset was generated for which a Twitter developer account was used by requesting researcher access. In order to collect this set of tweets, the following steps were followed:

- **Search for ASD-related Twitter profiles**: First, a manual search was performed for Twitter profiles whose users included ASD-related terms in their biography: ASD, autism, Asperger, aspie, autistic. 252 profiles were obtained.
- **Twitter profile labelling**: once the 252 profiles were obtained, each one of them was accessed by analyzing whether it was a person who claimed to have ASD, finding profiles of relatives and associations that corresponded to the category of Twitter accounts that do not suffer from ASD.
- **Collection and labelling of tweets**: After having the set of users labelled as users who suffer from ASD, or who do not suffer from it, the tweets written in English by each of the users were collected.
- **Data preprocessing**: after preprocessing the tweets, eliminating duplicate tweets, retweets and others, a total of 404,627 tweets were obtained, of which 358,841 (88.68%) belonged to people with ASD and 45,786 (11.32%) belonged to users who did not suffer from ASD.

### 2.2 Models, Hyperparameter Tuning and Evaluation Metrics

Among the traditional artificial intelligence techniques most used in the field of NLP is Random Forest (RF) and Support Vector Classification (SVC). Some studies like [9] performed on similar problems have shown to give good precision and accuracy results. For this reason, it was decided to use this technique, which will be extended in the future, to obtain automatic classification models.

On this type of classification techniques, GridSearchCV was used to find the best hyperparameters for RF & SVC, configuring the tuning with the settings showed in Table 1.

In order to apply these classification models, NLP techniques were applied to vectorise the texts through the Tokenizer function of the Keras Python library.

### 2.3 Metrics to Evaluate Results

To evaluate the results obtained in each of the models developed, 3 different metrics have been used: Precision (P), Recall (R) and F1-score (F1). **Precision** thanks to this metric it is possible to know the relative number of positive samples that have been correctly classified. In the present case study, it allows knowing the percentage of data labelled as ASD that are indeed ASD cases. In the following formula presented, c represents the class, where 0 are the Non-ASD cases, 1 are the ASD cases and, the abbreviations correspond to TP = True Positive, FP = False Positive and FN = False Negative:

**Table 1.** Hyperparameter settings for fine-tuning via GridSearchCV

| Model | Hyperparameter | Values |
|---|---|---|
| Random forest | Bootstrap | [True, false] |
| | Max_depth | [10, 20, 30, 40, 50, None] |
| | Max_features | ['sqrt', 'log2'] |
| | Min_samples_leaf | [1, 2, 4] |
| | Min_samples_split | [2, 5, 10] |
| | n_estimators | [30, 97, 165, 232, 300] |
| SVC | C | [0.1, 1, 10, 100, 1000] |
| | Gamma | [1, 0.1, 0.01, 0.001] |

$$P(c) = \frac{TP}{TP + FP} \tag{1}$$

**Recall**, this metric provides somewhat different information than the previous one. This metric also makes use of how many samples are correctly classified as positive, but the denominator is different. This metric is represented by the next formula:

$$R(c) = \frac{TP}{TP + FN} \tag{2}$$

**F1-score**, is a metric that makes use of the above two values. Thanks to it, it is possible to better differentiate how effective the model is in correctly classifying the samples. In this case, the formula is composed of precision (P) and recall (R) as shown in the equation below:

$$F_1 = \frac{2 * P * R}{P + R} \tag{3}$$

# 3 Experiments and Results

## 3.1 Experimental Setup

Due to the large number of tweets available, 45,000 tweets tagged in each of the categories were selected, resulting in a balanced dataset composed of 50% of tweets tagged as written by users with ASD and 50% of tweets written by people without ASD.

For these experiments, the data were divided into a training set (70%) and a test set for model validation (30%).

**Table 2.** The best hyperparameters using GridSearchCV

| Model | Hyperparameter | Values |
|---|---|---|
| Random forest | Bootstrap | False |
| | Max_depth | None |
| | Max_features | log2 |
| | Min_samples_leaf | 1 |
| | Min_samples_split | 5 |
| | n_estimators | 300 |
| SVC | C | 10 |
| | gamma | 0.001 |

**Table 3.** Results obtained for all models

| Model | Precision | Recall | F1 |
|---|---|---|---|
| Random forest | 74.9% | **85.0** % | **79.7**% |
| SVC | **77.9**% | 78.8% | 78.4% |

The programming language used was Python version 3.10. A Random Forest classification model (RandomForestClassifier) was generated using the sklearn library. The input hyperparameters used for training were those obtained after the hyperparameter tuning explained in the previous section. These values are described in Table 2.

### 3.2 Results

Table 3 shows the results obtained after numerous runs of the various predictive models.

Figure 1 shows matrices of the RF and SVC models.

## 4 Discussion and Conclusions

The results show that it has been possible to generate machine learning models capable of predicting whether or not a text has been written by a person with ASD with a fairly high accuracy (74.9% and 77.9% respectively).

Analysing the values of the metrics used, Random Forest offers a higher recall and f1-score, while SVC has a higher accuracy. This difference occurs because the precision metric is higher the fewer false positives there are, while the recall is higher the fewer false negatives there are. In this case, it is decisive to value the F1-score, as it takes into account the relationship between both measures (precision and recall). Thus, it is possible to say that Random Forest offers, in this case, a better result in terms of the problem that has been posed.

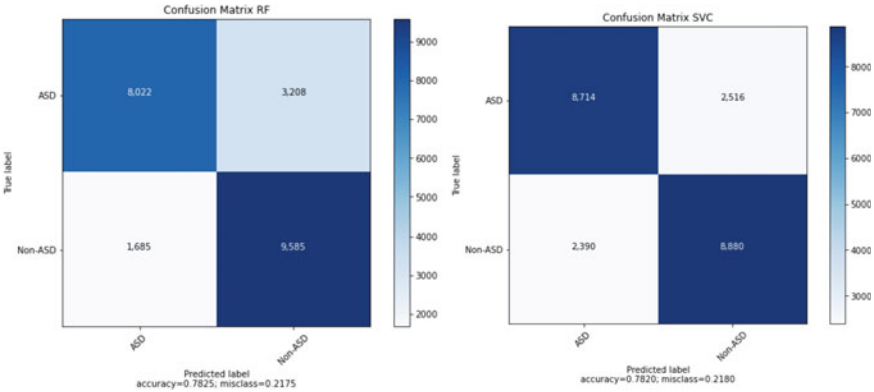


**Fig. 1.** Confusion matrices of the RF and SVC models

It should be noted that, thanks to the information available in social networks, it has been possible to generate a dataset with which to train text classification models capable of deducing whether or not a person has written a text with ASD. It is also important to note that one of the limitations of this study, making use of this dataset, is the fact that there may be a bias in the classification of the texts taking into account that users may lie in their biography. These results are still preliminary and do not allow us to draw solid conclusions, but they do generate an interesting line of research. In the future, new machine learning and deep learning models will be tested and semantic enrichment techniques will be added to the problem, in an attempt to find solutions of interest in the field of ASD and other diseases.

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# Responsible Heritage Protection Actions

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**Abstract.** In recent decades, interest in maintaining and conserving cultural assets has grown and there has been greater investment in the conservation of historical heritage. Developing a good methodology for action is key to guaranteeing adequate preservation of cultural assets. With this in mind, the Spanish Historical Heritage Institute convened a conference in 2002 to try to define basic criteria to guide the different phases of the intervention process in stone materials in all stages of stone conservation: cleaning, consolidation and protection. Carrying out efficient protection of monuments in the traditional way focuses efforts only on how it affects the property, but not on the collateral impact it may have on the environment, or how the effects of climate change may alter its functionality. Thus, a more multidisciplinary test design is needed, with a mandatory laboratory simulation phase under simulated rainfall that represents the increased environmental aggressiveness expected in the near future due to climate change. Hence, water becomes a means to simulate these future conditions, but also a way to explore the effects on rivers and groundwater near the points where the monuments will be treated. Since fresh water is one of the resources that is expected to become scarce in the short term, we intend to carry out responsible tests that take into account both aspects: saving water use and water pollution. Combining the conservation of monuments and environmental responsibility, it will be shown how it is possible to carry out research to achieve a natural product that serves as a sustainable coating for monuments of stone material that is durable but that reduces the environmental impact both in the selection of the product and in the experimental phase, as well as in its operation after application.

**Keywords:** Local resources · Heritage preservation · Environmental-friendly · Climatic-change · Sustainable research

## 1 Introduction

Due to the great impact that industry has on the environment and on natural resources, environmental responsibility has begun to be acquired over the years, which has changed the way of working. Nowadays, all aspects of the industry that harm the environment


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are taken into account and we act in a cleaner and more efficient way in line with the objectives of sustainable development, specifically 6 and 12: clean water and sanitation and responsible consumption and production.

As modern industry is advancing, maintaining and conserving cultural and heritage assets is also an important aspect of society and developing a good methodology, guaranteeing adequate preservation taking into account the more aggressive climatic changes that we are experiencing, requires detailed studies of the effects of each product on the monument and on the climate. In heritage restauration, the different phases of the intervention process cleaning, consolidation and protection need to be followed under a criterium of environmental respect [1], trying to protect the scarce water available [2] by avoiding pollution of groundwater or restricting the use of other resources or the transportation of materials and people by using treatments of longer duration.

But nature and stone heritage influence each other in more ways than one. Ornamental stone materials, normally used in the construction of monuments all over the world and especially in Castilla y León, the study area (Fig. 1), are severely exposed to different environmental conditions (heat, cold, rain) leading to erosion in their structures. Fighting against this climatic wear requires constant economic expenses, as there is no solution available yet offering long-term protection [3]. Additionally, it is essential that such protective treatments would not alter in any way the aesthetics and functionality of our heritage, limiting the possibility to find a suitable protector, so the only way forward so far is to rely on restoration. Achieving this while reducing the environmental impact at each stage is one of the most important challenges facing research. Every year large amounts of money are invested in the restoration of historical monuments worldwide. There are many methods for the restoration and cleaning of limestones and dolomites, but none of them are easily or rapidly applied, nor have durable effects [3] or has not been design under environmental-friendly perspective [4].

The prolonged effect of inclement weather is very harmful for particular stone materials such as limestone and dolomite, to which a truly effective and durable protective agent has not yet been found. Our research group is working on coatings from natural materials that are clean and durable, and that resist the effects that climate change has on the erosion processes that affect stone materials. Abrupt changes in temperature and the aggressiveness of rain make water a fundamental element for testing the developed products. Water is involved in every phase: product design, experimental stage, and treatment impact, so it is of vital importance to use it responsibly and maintain control over its use.

## 2 Objectives

The main objective of this study is to design a protection coating under an environmental friendly vision, not only the cultural and economic vision. We are developing a process of a sustainable product and a methodology for its use that provides an effective coating on stone materials that slows their erosion and can preserve them without intervention for longer periods of time, taking into account the environmental impact in every step of the process.

By using sustainable materials and reducing the amount of water used in the periodic washing of the facades of cultural heritage monuments, the aim is to take a further

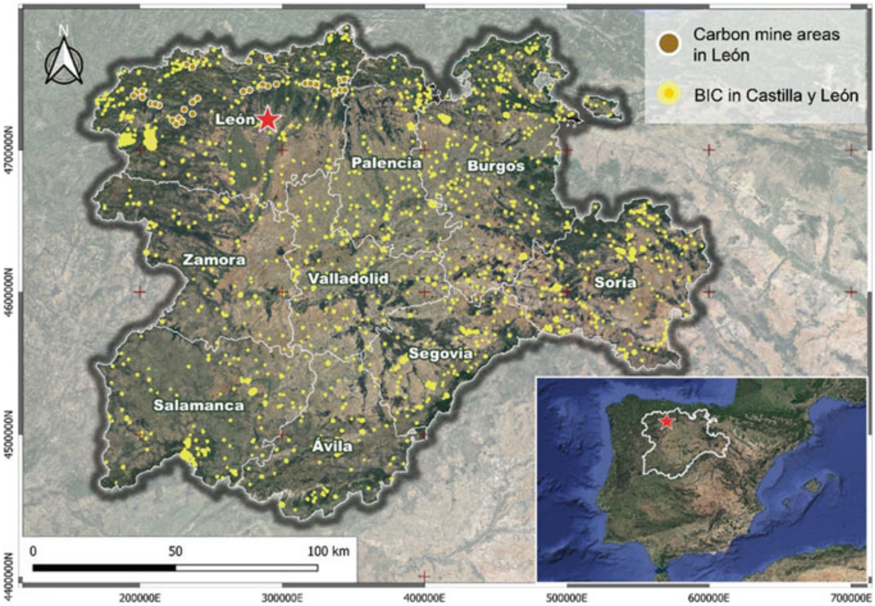


**Fig. 1** Map of cultural assets (yellow), known as BIC, in Castilla y León, NW Spain [5]. Inset map shows Castilla y León with respect to the Iberian Peninsula. In both maps, red star indicates the location of the simulator in León province

step towards a more efficient and sustainable use of water, in line with the sustainable development objectives of the United Nations.

## 3 Methods

In order to control water consumption, it is necessary to control each step of the process and to know to what extent its use is necessary or essential and to what extent it can affect the surrounding waters.

The impact study from product development to product performance is done in phases:

### 3.1 Product Design

The product developed is a graphene composite [6], which is a substance composed of pure carbon, which is one of the local resources of León [7] (area of research, minimizing transport) and it is an alternative way of use of carbon reducing $CO_2$ emission (Fig. 1). The resulting product is presented in a state of additive-free aqueous colloidal suspension. As it is a natural product, it does not generate by-products harmful to the environment or health.

Currently, our group is developing another protective coating to stone heritage derived from cellulose and chitin biopolymers from recycled organic waste.

### 3.2 Experimental Stage

The prolonged effect of inclement weather is very harmful for particular stone materials such as limestone and dolomite. Even if the greatest climate change impact is usually ascribed to temperature, different reports from European projects (e.g. Noah's Ark [8]) have concluded that the main threat to heritage is actually water [9].

In view of the reports, to test the effects of the coating, it is necessary to subject rock samples to controlled temperature changes and rainfall simulations. The rain simulator has been built in a courtyard under controlled conditions (Fig. 2) and the rainfall generated is a fully automated process by which the control the duration of the rainfall is possible.

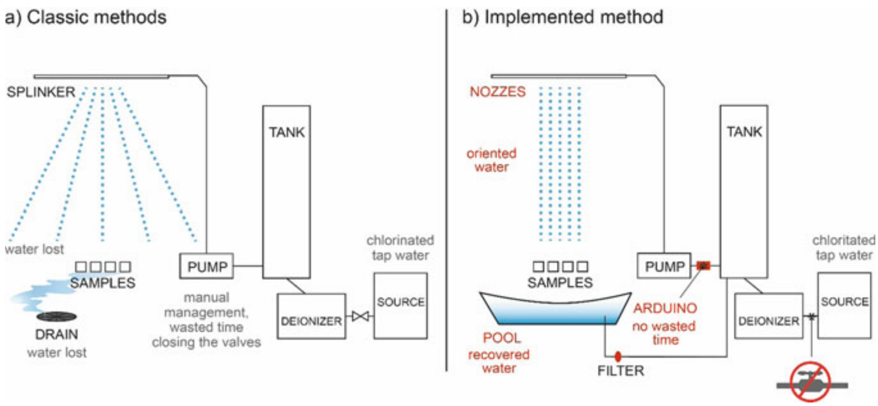


**Fig. 2** Scheme of the rainfall simulator: **a** classic methos and **b** implemented method indicating improvements to save water in the process (red)

In addition to these tests, mechanical strength tests are performed. These are typically destructive tests, but non-destructive alternatives that provide equally accurate data are being tested.

### 3.3 Treatment Impact Analysis

The method of choice to deposit the water-based suspensions of graphene oxide over the stones surface will be the spraying technique because on one hand is easy to apply, and on the other hand can be done in situ. By this way, a fine and homogeneous coverage of the coating will be pursued.

This method avoids the need for some parts to be transported to the laboratory to be treated, saving the $CO_2$ emission.

## 4 Results

During the product development and laboratory testing phases, improvements have been made that have resulted in a more responsible use of resources, adjusting its use to the strictly necessary.

- Product design: tasks selection has been made taking always into account the environment impact.

  - The chosen products come always from natural elements, such as carbon or paper or organic waste, which does not generate harmful by-products.
  - The raw material is local, therefore, kilometer 0.
  - Water saving by reducing the cleaning walls or floors of the monuments or eroded material.
  - Prevention of the lixiviation of polluted water to groundwater.

- Experimental stage: The most representative laboratory tests to evaluate the effectiveness of the product as a coating are temperature changes and rain simulation. The experimental phase had several stages since it is necessary to continuously evaluate water consumption and act on critical processes (Table 1).

**Table 1** Aspect of the design of the rainfall simulator that represents a significant saving of water resources. *l/h = liters per hour

| Applied technology | Modifying aspect | Benefit | Quantity of water saved (l/h)* |
|---|---|---|---|
| Use of nozzles in enclosed patio | · Oriented water<br>· Water not dispersed by wind | No water loss over an unsampled area | – |
| Programming with arduino | · Simulator running time | Reduce the lost time closing valves | 20 |
| Pool water collection | · Water recirculation | Reduces the use of tap water | 1080 |

  - The rain simulation test is set up in such a way that its operation is fully automated, and times are controlled. The amount of water simulated by minute is 20 L approximately, and estimated time spent on turning valves on and off is one minute per hour in total, thus water savings in one hour is 20 L.
  - In classic methods, the rainwater acting on the rock samples was washed away, but after assessing the impact, the water began to be recovered after each cycle and recirculated. In this way no water is lost if the simulator (Fig. 2) and 180 L of water are saved each hour. On the other hand, the use of directed nozzles instead of traditional sprinklers ensures that most of the water falls on the samples.
  - In addition, the small size of the courtyard and its 10-m-high walls prevent the entry of wind that could disperse the water droplets.
  - In addition, search for non-destructive testing involving the cleaning of fractured material and the use of new raw material and everything involved in its extraction.

- Treatment impact analysis: The treatment of the product on the cultural property, once applied, is expected to last for 20 years, while current treatments last between 5 and 10 years. During that time, the coating will prevent water from entering the pores or crevices of the stone material and will prevent the proliferation of biological material. After application of the product, the reduction in water consumption will be the greatest of the three phases:

  – Durable protection will reduce the frequency of facade cleaning. The most common cleaning methods are water-based such as water jetting, water spray that needs several applications and rinsing, water mist, water vapor or water in dressings [10]. Sometimes chemical, water-based agents are also used, which can also reach the soil infiltrating and contaminating the groundwater.
  – By protecting the cracks from water ingress, mechanical erosion due to the effect of cryogenic water is prevented [11]. The coating also protects against mechanical wind erosion, which causes the grains of stone material to fall to the ground and the loss of volume of the rocks that form the wall. The grains fallen to the ground by mechanical erosion are often removed with pressurized water corrosion, so that with the application of the coating the cleaning of soils with water would diminish notably.
  – At the same time, preventing the loss of volume and the degradation of the rocks avoids their replacement, which means higher consumption of raw material, its transportation and treatment for its placement.
  – In addition, preventing the formation of biological material reduces the use of biocides, which in turn are potential contaminants for soil, groundwater, and animals.

## 5 Discussion and Conclusion

The product and methodology shown here have been developed following innovative processes to obtain sustainable coatings with an environmental care perspective, contributing the research experience to the circular economy.

This research offers a truly durable protective coating for carbonated stone monuments, able to endure any weather inclemency with the best efficacy and protection validity. The impact of this product will be environmental as well as economic and operational.

The product and methodology have been developed working in an environmentally friendly and fully sustainable scenario, being affordable, non-contaminating, and without posing any kind of risk for the citizenship or nature.

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# The Inextricable Link Among Climate Change, Pandemic, Migrations, and Geopolitics: How Artificial Intelligence Can Help Us

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**Abstract.** The theme of sustainability transition has been the subject of an increasing number of research in recent years. This contribution aims to highlight the close links existing between several issues (that are apparently distant from each other, but all related to sustainability) and Artificial Intelligence (AI). In particular, we want to underline the interdependencies—and possible developments—mong climate change, pandemics, migration, and geopolitics, in light of the new discoveries of AI.

**Keywords:** Sustainability · Climate change · Pandemic · Migration · Geopolitics · Artificial Intelligence

## 1 Introduction

Today the concept of sustainability transition has several areas of application. Considering the necessity to stop the transmission of diseases as well as the evolution of COronaVIrus Disease 19 (COVID-19), digital technology is a useful resource, specifically, Machine Learning (ML) and Artificial Intelligence (AI). In particular, innovative Artificial Neural Networks (ANNs) experiments have been constructed to determine the concentration of particulate matter linked to COVID-19-related deaths, establishing new threshold values. Deep Learning (DL) techniques can forecast features of protein structures in addition to helping image-based diagnosis of COVID-19 through tomography scans. Indeed, quarantining, social distancing, and tapering tactics can all be simulated and better understood using AI [1].

The purpose of this short article is to give an overview of the potential of AI and its applications in various sectors.

## 2 Artificial Intelligence and Climate Change

Climate change has the potential to allow zoonotic spillovers while also affecting transmission chains. These factors, as well as human behaviour and awareness, must be taken into account when developing pandemic forecasting models [2]. Temperature, atmospheric carbon dioxide ($CO_2$), and cloud cover are all changing as a result of climate


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change. Therefore, climate change has an impact on natural habitats and ecosystems. In energy, AI can use deep predictive capabilities and intelligent grid systems to manage the demand and supply of renewable energy [3].

Mitigation is a concept that explains how adopting solutions to combat climate change might help slow down an alarming trend. It is a technique for selecting measures with effects that can be seen in the long-run as well as activities that can make a difference in the medium-run. Moreover, ML-based algorithms can be used to predict the course of tropical cyclones or very intense rainfall that hit specific geographic areas. Meteorologists have been utilizing AI to predict the duration of storms and estimate their potential damage [4]. However, AI's strength resides in its capacity to conduct meta-analyses to determine whether the models currently in use are appropriate. In addition, AI can supplement and improve human knowledge in interpreting satellite imagery to detect internal displacement or infrastructure damage during natural disasters [5].

Besides, AI applications in chemistry and physics can speed up the development of novel chemical and synthetic structures to make low-impact materials easier to recycle and emit less polluting substances. AI can optimize and arrange commodities routes while also considering traffic. The fewer journeys taken and the shorter the route, the fewer emissions are generated. AI findings in industrial processes help to reduce waste and mistakes in the workplace. The emerging smart industries utilize robots and intelligent control systems to minimize warehousing costs, transit delays, and environmental effects from raw materials to final products [6, 7].

In the fight against climate change, AI can have a huge impact: more energy-efficient buildings, creating new low-carbon materials, better monitoring of deforestation, and greener transportation [8]; enabling low-carbon electricity; accelerating materials science; reducing current-system impacts; reducing transport activity [9]; improving vehicle efficiency; optimizing supply chains [10]; forecasting extreme events: monitoring ecosystems and biodiversity; understanding personal carbon footprint [11]; facilitating behavioural change [12, 13]. Moreover, ANNs have recently attracted significant attention in environmental areas because of their great self-learning capability and good accuracy in mapping complex nonlinear relationships. These properties of ANNs benefit their application in solving different solid waste-related issues. Indeed, due to the ability of ANNs to model nonlinear time series, this approach is useful in a wide range of applications such as in waste management [14–16].

## 3 Artificial Intelligence and Pandemics

Moreover, AI can help predict potential changes that might affect a virus's ability to spread, the severity of the disease, and even how it will respond to currently developed treatments and vaccinations. There is a constant battle going on in the world between scientists predicting what the next mutations will be and finding the best method to combat them. Since pandemics spread rapidly, they require rapid medical resource allocation and drug development, in addition to requiring a quick response on many fronts.

With the use of big data, AI has a major advantage in a pandemic situation like COVID-19. The prognostic staging of diseases can also be aided by AI [17]. In the event of a pandemic, AI could potentially help triage patients based on the likelihood of needing more intensive care [18].

The use of AI for detecting infected people, or those with elevated temperatures, in crowds is similar to facial recognition algorithms. Additionally, AI-powered robots can clean public venues like hospitals.

Several papers demonstrated how the combustion of fossil fuels for transport purposes might cause health implications [19], confirmed the capability of polluting variables ($CO_2$, $PM_{2.5}$, $NO_2$) to accelerate COVID-19 deaths [20–22], or found new threshold levels of pollutants connected to COVID-19 cases [23]; while other studies inspected the effectiveness of the vaccination campaigns [24].

In these turbulent times, AI provides improved public safety solutions, speeds up research, and may represent a valuable asset for organizations and governments.

## 4 Artificial Intelligence and Migrations

Furthermore, big data could be particularly beneficial for studying transient or cyclic migration patterns that are difficult to measure using standard techniques and methodologies, as well as forecasting migration trends. In fact, AI has the ability to transform the way countries and international organizations manage migration flows. In the near future, AI will be utilized to undertake several activities like identification verification, border security and control, and data analysis on visa and asylum applicants over time. To sum up, the growth of AI technologies may have an impact on international migration management at least in three major areas: (1) key actor connections, (2) their practices, and (3) discourses governing international migration management [25]. Nevertheless, it would be worth highlighting the potential dangers that this technology—in the hands of governments, agencies, and institutions with authoritarian and quasi-democratic tendencies—may have for the respect of basic human rights, including the right to migrate. Indeed, technology is far from being free of ideological and geopolitical elements.

However, in recent years, the development-migration nexus is becoming more complicated: how, where, and when migration occurs is also determined by the political, social, and economic processes of possible destination nations. Migration can have a detrimental impact on development if it is not properly managed. Migrants may be jeopardized, and communities may be strained. Further, climate-induced migration is one of the most highly debated topics in the current discourse on global warming and its consequences. There is a burgeoning field in economics and other social sciences linking climatic factors or climate-related natural disasters to migration. Empirical studies use different measures to quantify migration flows and climatic factors and apply a variety of methodologies to different data sets and samples of countries. Migration provoked by climate change is one of the most contentious issues in today's discussion on the effects of global warming [26]. Thus, climate-driven migrations are now a reality, and environmental displaced individuals or climate refugees' categories have been established [27].

## 5 Artificial Intelligence and Geopolitics

Countries across the globe are grappling to comprehend the benefits and threats that AI technologies may pose to national security, economic, and political stability as they grow increasingly powerful and thoroughly integrated into human systems. However, the AI geopolitical landscape is increasingly a tangled web of state rivalry, multinational monopoly expansion, and public fear. In an effort to provide their armed forces a tactical advantage on the battlefield, governments are also hurrying to develop AI military technologies like autonomous lethal weapons and swarming technology. They are also enhancing their surveillance, communications, and data-exploitation capabilities [28–30].

Concerns regarding privacy and human rights have been raised by the complexity and widespread use of AI and digital surveillance technology. These technologies are then applied in a variety of contexts. Higher-quality data can aid firms in enhancing the precision of their facial recognition systems. These more powerful technologies may eventually be applied abroad for totalitarian purposes [31].

## 6 Concluding Remarks

In this paper, we tried to highlight the potential of AI in various fields of knowledge (environment, health, demography, political science). However, it is possible to isolate the connection of each of these topics with the others. For instance, through climatic variables like temperature, wind speed, and humidity, several underlying causes of climate change are also connected to a rise in pandemics [32]. Climate change can be regarded as a specific environmental factor leading to migration [33]. In addition, the green revolution and the nexus between weather and crop yields are strictly linked with geopolitical considerations [34]. The pandemic border closures left many migrants trapped in destination countries, at their countries of origin, or even, for some, while in route. They also created significant issues regarding membership [35]. Furthermore, as a result of the COVID-19 epidemic, many leaders lost their credibility and came out as flimsy failures during times of crisis, revealing the true need of the people for decisive leadership [36].

Obviously, the ethical questions on the boundaries of AI as well as on its legal regulation remain open (Fig. 1).

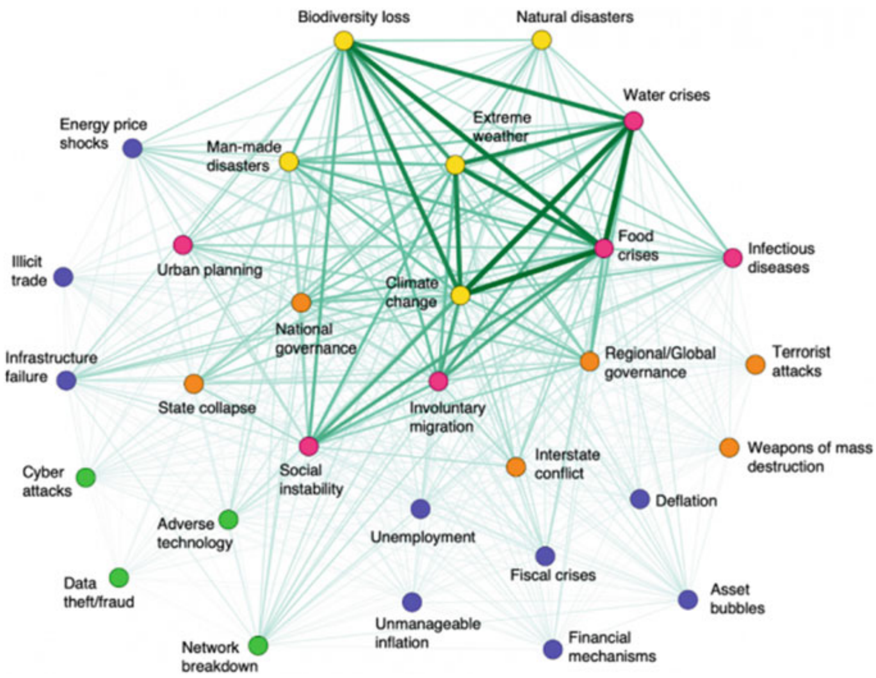


**Fig. 1** The network of potentially synergistic risks with the potential to lead to a global systemic crisis. *Notes* The colour of the node indicates the category of risk (yellow = environmental; pink = societal; orange = geopolitical; green = technological; blue = economic). The thickness of the lines connecting two risks represents the frequency of responses identifying a synergistic interconnection between them. *Source* Risks Perceptions Report 2020, Future Earth

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# Fair Trade and the Sustainable Development Goals: An Opportunity for Sustainable Production and Consumption

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**Abstract.** The chapter presents what has been labeled Fair Trade certification and how it can aid in the economic growth of communities. The aim of this chapter is twofold: On the one hand, to assess the impact of Fair Trade on developing countries and its relationship with the Sustainable Development Goals. This shall be done through a review of the literature, using as a representative example the NGO Fairtrade L.O. International. On the other hand, to try to understand the perception of this certification among consumers, since trust in the effectiveness of Fair-Trade Standards is key to the purchase of its products. The conclusion presents evidence arguing that Fair Trade dynamics can indeed foster sustainable and fairer production, more consistent with the dignity of every human being. Thus, it has the potential to impact positively developing countries, firms seeking to fulfill CSR standards and -given the necessary trust in these organizations- address the niche for consumers in developed economies seeking sustainable and humane production.

**Keywords:** Fair Trade · SDGs · Sustainable production

## 1 Introduction

The main hypothesis of this paper is that Fair Trade initiatives can contribute to the economic development of communities. The objectives are to present empirical evidence on the matter, reviewing relevant contributions in the literature. As an important complement to this claim, a study of the perceived reliability of FT products will be conducted through primary data.

In recent years, the number of producers seeking fair trade certifications has increased, as well as consumers' demand for products that guarantee sustainably and humanely produced goods [1]. The increase both in consumer awareness and certified producers highlights the importance of these matters. It has particular significance in the light of the Sustainable Development Goals (SDG) presented by the United Nations. Fair Trade initiatives are an acknowledgment of the need for the "promotion of sustainable production and consumption" (SDG XII), "decent work and economic growth" (SDG VIII), "poverty reduction" (SDG I) and "greater gender equality" (SDG V) [2].

Fair trade also evidences that it is possible for a company to focus simultaneously in "doing good and doing well".


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## 2 Methodology

The main methodology used is qualitative, examining relevant publications in the field. For the shake of clarity, the analysis first focuses on providing a brief definition of what is to be understood by "Fair Trade (FT) products" throughout the chapter. Then, the NGO Fairtrade L.O. International (FTI) -one of the most prominent institutions certifying Fair Trade standards—will be described. To assess the contribution both of FT certifications and of FTI, the next section analyzes its connection to the United Nations SDGs. Finally, the effectiveness of Fair Trade will be examined, based on the literature on the matter.

To complement the assessment of the perceived reliability of FT products, some quantitative primary data has been collected and analyzed.

Lastly, the conclusions for both the reviewed literature and the quantitative study will be presented.

## 3 What Is Fair Trade?

### 3.1 Fair Trade Initiatives and Fairtrade L.O. International (FTI)

Fair Trade has been defined as "an initiative that aims to improve the living conditions of producers in developing nations" [3].

Among the objectives which FT organizations seek to accomplish, are the following: ensuring a higher price paid to producers, greater availability of financing, investing in community development, ensuring more stable relationships between buyers and sellers and fostering small producers' associations and sustainable production. Different organizations have undertaken the responsibility of setting standards that help achieve these objectives.

Their origin can be traced back to the 1950s, when the European Alternative Trade Organization began offering products which had been bought directly from producers in need from developing countries. This first model operated mainly with volunteers. In 1988, the first Fair Trade label was created from a Dutch NGO with religious inspiration. They ensured that producers and workers had received "sufficient wages" throughout the process and used as a label "Max Havelaar", a fictional character who fought against unfair working conditions. In fact, in the novel by Eduard Douwes Dekker, Max Havelaar defended coffee workers in Java, a Dutch colony.

Various initiatives in Europe and the United States followed this example and in 2002, the Fairtrade Certification was launched by FTI. This became what Harvard economists Dragusanu et al. have described as "the most widely recognized ethical label globally" [3]. Its growth has been exponential and it nowadays comprises more than 1.3 million farmers and operates in over 70 countries. Even though the organization was at first focused on the labor conditions of small coffee producers, it has expanded to a wide range of other categories. Coffee is still the product they are most involved in, but they also certify products like tea, cocoa, wine, flowers, herbs and spices, sugar, honey, nuts and apparel [4].

### 3.2 Requirements for the FT Label

There are a series of conditions FT products must fulfill to achieve the Fairtrade certification, aimed at improving the living conditions of both workers and small farmers in developing countries.

To begin with, producers are guaranteed a minimum price for the goods they produce and a FT premium. This is the main distinguishing feature of FT. Prices are set to ensure a decent quality of life for producers and to cover the average costs of sustainable production. FTI works with other entities like the International Coffee Organization to guarantee a sufficient wage. If the world market price is above this minimum price, the FT buyer agrees to pay the world price. Otherwise, he shall at least pay the minimum price. If needed, he is still free to negotiate with producers a higher price. This could be done to foster higher quality or other production requirements. This price floor substantially reduces the variability and risk faced by small producers.

The FT premium is a quantity payed in addition to the sales price and devoted to improving the producers' community. The aim of this premium is twofold. On the one hand, it promotes small producers' associations. These associations have to choose the project to finance with the premium in a democratic manner. On the other hand, the benefits stem beyond producers, helping their communities through these projects. Some examples of initiatives that can be funded with this premium are investments in infrastructure, schooling, hospitals, education, water systems and security or sustainable production standards [3].

The second requirement addresses the situation of workers. They must have freedom of association, wages equal to—at least—the national average and labor conditions consistent with the legal requirements. Child labor is strictly prohibited, and FTI is one of the few organizations that not only de-certificates any producer who is discovered using child labor but actively targets the problem in the region and seeks a solution.

The third requirement is the structure of the institutions. Farmers must be organized as Cooperatives and comply with the standards of accountability and democratic decision making. Most of the producers with FT labels are small farms and local producers. However, larger companies must also ensure joint associations of workers have a democratic structure. One of the many positive spillovers of this requirement is what has been labeled "the FT Theory of Change". It suggests that farmer associations -which take collective, democratic decisions-will feel more empowered and able to contribute towards the good of their communities.

The fourth requirement is sustainability. There is a list of forbidden chemicals and other requirements that ensure FT practices are not only consistent with human dignity but also with care for our common home. Natural methods are used whenever possible, health and working conditions must be complied with and producers must issue an environmental report on their methods [5].

Last, but not least, FT standards ensure the access to credit and stability, FT buyers have to agree to long term contracts and, if needed, provide financing to the farmers that request it. All these strategies contribute to the FT theory of change, by promoting better working conditions and fostering the well-being of local communities. A final requirement is monitoring, evaluating and learning from the application of these strategies. This ensures external accountability and a correct assess of its impact.

To obtain FT certifications, producers, buyers and all stakeholders across the supply chain have to comply with the standards. An independent certification company, FLO CERT performs the inspections and certification of producers. Given all these requirements, the organization FTI has as its official mission to "connect disadvantaged producers and consumers, promote fairer trading conditions and empower producers to combat poverty, strengthen their position and take more control over their lives" [6].

### 3.3 Requirements for the FT Label

Having explained what is to be understood as Fair Trade, we turn to the question of why is it of such great importance. As mentioned in the introduction, FT standards offer a new production model and, thus, a new alternative for consumers. In fact, it aims to have a positive impact for three main groups of stakeholders (producers, consumers and companies) and positive spillovers that reach many others.

**An Opportunity for Small Producers**

FT is an approach that is producer-centered, being focused on these small farms and firms who get involved in an alternative way of production. This new production processes are not only more sustainable, but also more consistent with human dignity [5]. Workers are guaranteed an adequate wage, are able to access credit—which provides them with a greater degree of stability—and should not face discrimination. The latter is especially important to reduce gender gaps in access to credit. In many developing countries, this gap is a considerable problem. Indeed, even though the percentage of women in agriculture has increased, they have lower access to resources (including credit, land, information and education) [4].

Furthermore, FT protects children by ensuring that no child labor is used in any of the farms it certifies. The International Labour Organization estimated that "152 million children are still in child labor" and that 70% of this occurs in agriculture [7]. This impacts their living conditions in various way: hindering their possibilities to attend school, decreasing playtime and contributing to lower average nutrition levels. They also understand that "poverty remains the key driver of child labor" together with lower access to education, armed conflict, natural disasters or discrimination [8]. To assess this problem, FTI has decided to address the causes rather than only the consequences to truly prevent abuse and child exploitation. In the cases when they discover child labor being employed, they take immediate action and work with the national child protection agencies and NGOs to ensure both their short-term and longer-term wellbeing. Some examples of the mechanisms it uses is the voluntary best practices of FT Trade Standards, the investment of FT premiums in their communities (for example, in education) and the design of preventive projects to address the risks children themselves identify for their wellbeing. An example of the latter was undertaken in Belize, with the BSCFA sugar cane association.

As can be seen, FT does not only rise living standards for farmers -thus, making it more likely that they will be able to send their children to school—but actively seeks the end of child labor and addresses its root causes.

FT also fosters association among small farmers, which makes them a more organized and, thus, less vulnerable group. The current average size of fields cultivated by FT farmers is 1.5 ha. Thus, as stated in its mission statement, the organization is focused on small producers who are most in need. The positive effect of FT on producers (the majority of whom are small producers, but also hired labor organizations) is also shown by the significant increase of FT certified producer organizations over the past years [5]. This does not only represent an improvement in the living conditions of producers from all over the world but also an opportunity for their communities. Indeed, the total FT premium distributed has increased sharply in the last years, reaching 191 million in 2020 [5]. Understandably, such an amount will probably contribute to the betterment of their local communities [9].

**An Alternative for Consumers**

Economists Hainmueller et al. from Stanford University, Harvard and the London School of Economics, found evidence for increasing consumer demand of ethical products [10]. They also discovered that consumers have "differential levels of price sensitivity" towards FT labels. For higher-priced products, consumer price elasticity was much lower than for lower-priced coffee.

Their final results indicated that there was substantial consumer support for FT, even though those consumers who were more price sensitive might be less willing to pay a higher amount for a FT labeled product. Similarly, there was evidence of a growing demand for more sustainably produced goods [1]. This pattern was particularly strong for millennials. The Financial Times also found that young consumers were more prone to shifting towards ethical products [11]. This points to the fact that sustainable and ethical production is not only growing, but -if this younger generations maintain such traits—may continue to grow overtime, parallel to their increase in purchasing power.

It seems that consumers do indeed value sustainable and ethical production. Andorfer and Liebe assert that "social features of products—such as decent living and working conditions for producers in developing countries—are important ethical criteria in their (consumers') shopping strategies" [12]. These concerns have led FT sales to almost triple in just three years [13].

**A Contribution to Corporate Social Responsibility**

The remarkable contribution of FT to producers and the fact that it addresses a growing demand from consumers has led many companies to engage in CSR by promoting the use of FT products or restricting their production to FT companies and producers. Giovannucci et al. highlight how the growth of credible product certifications addresses these opportunities to fulfill CSR commitments. Among them, the labels "Voluntary Sustainability Standards", "Ethical Tea Partnership" or "Marine Stewardship Council" [14]. They argue that FT has a positive impact on producers and their communities, addresses a growing demand for ethical and sustainable production and allows companies to fulfill their CSR commitments. This explains the growing interest in FT labels and on the effects these certifications have for producers.

## 4 Fair Trade and the Sustainable Development Goals

The Fair-trade initiative is related to many of the Sustainable Development Goals established by the United Nations [2]. However, there are four goals where the connection is especially remarkable. To assess the contribution of FT to each of them, the data from the organization Fairtrade International (FTI) is used. The reason why this institution was chosen is because it was found to be “the most widely recognized ethical label globally” in the field of FT [3].

### 4.1 First SDG: No Poverty. End Poverty in All Its Forms

The first goal is to “end poverty in all its forms, everywhere”. The World Bank highlighted that close to 10% of the world’s poor population “live on rural areas and work mainly in farming” (where poverty was measured as people living with less than $1.9 a day) [15]. Therefore, they recognize agricultural development as “one of the most powerful tools to end extreme poverty”.

The first important contribution of the Fairtrade initiative to this goal is to help by defining a minimum price (protected from market fluctuations). They also encourage democratic associations and partnerships to foster small farms in rural areas. These act both as a means of protection (rising their bargaining power) and improves the accessibility of those farmers to credit and affordable production.

Secondly, the Fairtrade Premium grants money which is to be democratically invested in the improvement of their local communities (be it in schools, water access, road infrastructure, clinics or their farms and agricultural methods).

The Fairtrade standards also reduce discrimination, promoting an equitable distribution of benefits among its members and guaranteeing the exclusion of child labor. Finally, they establish standards for environmentally responsible production.

### 4.2 SDG: Zero Hunger. End Hunger, Achieve Food Security and Sustainable Agriculture

The main target of the Fairtrade Programs is small farmers. According to FTI, farmers with territories of less than two hectares provide 70% of the world population with food [5]. Like in the case of the former SDG, food security is promoted through the minimum price (guaranteeing the ability to cover basic expenses), the Fairtrade Premium (fostering the development of their communities) and access to credit. Furthermore, FT standards help achieve more sustainable agricultural practices.

One of the projects developed by FTI is the diversification of income, thus reducing the risk for small farmers. As an example, this was the objective of one of the projects this NGO undertook in Ghana, where they helped 270 cocoa farmers diversify their earnings. As a result of the program, their revenue increased by 22% [16].

### 4.3 Fifth SDG: Achieve Gender Equality

The Food and Agriculture Organization of the United Nations stated that women constitute 43% of agriculture workers in developing regions [17]. This rate has increased in recent years. Despite this increase, women have a significantly lower access to productive resources. The so called “gender gap” in agriculture comprises differences in the access to land, information (correlated as well with lower access to education) and technical assistance [17, 18].

FTI is committed to reduce this gap and foster an equitable access to the benefits of FT production. Among the requirements of FT producers are non-discrimination based on race, color, sex or religion. It also requires producers to terminate any abusive or sexually intimidating behavior, forbids the possibility to test for pregnancy when recruiting women as workers and has special programs to help women and other minority or underprivileged groups [8].

Furthermore, they have established the Women's School of Leadership in Central Asia and will replicate it in India and Indonesia, across over 100 FT producers [19]. Many of the FT premium projects are directed towards increasing opportunities for women (as an example, the Del Campo cooperative in Nicaragua, in the FT Nuts business devotes the premium to women entrepreneurs). Finally, FT also coordinates its programs with those of producer organizations', trade unions and NGOs to achieve a more equitable framework.

### 4.4 Eighth SDG: Decent work and Economic Growth

The International Labour Organization estimates in 1.1 billion the number of people engaged in agriculture. It also highlights that a large proportion of these workers are employed with sub-par work conditions, especially in developing countries [2, 8].

Among the main challenges they identify are the lack of recognition for female workers, of the adequate training, of protective labor laws, the prevalence of low wages, hazardous working conditions and the high persistence of forced and child labor. It estimates that 152 million children were engaged in child labor and over 73 million of those were in hazardous work conditions [20]. The regions where it is more prevalent are Africa (nearly one fifth of child labor takes place there), Asia and the Pacific (7.8% of world totals) and, then, the Americas, Europe, Central Asia and the Arab States. Over 70% of child labor is employed in the field of agriculture, an issue that FT international seeks to address. They understand that low prices imply higher risk of child and adult exploitation. This, in turn, increases the emigration of young people from rural areas to large cities, often in precarious conditions.

Therefore, an important step towards achieving the Eighth SDG is to ensure that farmers are able to obtain a reasonable price. Similarly, workers in agriculture need to be provided with secure working conditions, fair wages and protection from the volatility and prohibitive interests of speculative lenders.

These reasons led FTI to ensure that workers have better working conditions, access to credit and longer-term contracts. As an example, banana plantations in Colombia had 16% of the workers in non-FT firms with stable and indefinite-term contracts. In FT companies and plantations, 100% of the workers had such contracts. FTI also assists workers in negotiations for better wages and improved working conditions. The organization is also aware that precarious working conditions are often symptomatic of deeper problems and, thus, tries to address directly root causes rather than only their consequences. For example, the minimum price ensures that workers have price protection against market fluctuations or oligopolistic buyers. Finally, the FT premium provides additional funds both for workers and farmers and allows them to devote it to the most pressing issues in their communities. Like the UN stresses, for the Eighth SDG goal to be truly achieved, not only producers and workers, but also traders and consumers need to achieve and strive for ethical working standards [2].

## 5 Is Fair Trade Effective?

To address the effectiveness of FT, the literature in this area will be briefly reviewed. While a systematic and complete literature review would be beneficial, it is well beyond the scope of this chapter. Therefore, this section will compile insights from more complete assessments of the literature to provide an overview on the effectiveness of FT. One of such comprehensive analysis is performed by Loconto et al., who provide an overview of the effect of the FT premium. This topic has been increasingly studied in recent years, but they argue that the studies undertaken have usually been performed independently, with little collaboration or scholarly discussion among researchers [21]. Nevertheless, several valuable conclusions have been established and there is sufficient ground to state the positive effect of FT in the following fields: the access to FT markets and FT prices, environmental protection, investment of the FT premium in worker and small producer organizations and communities, producer and worker organizational democracy and strength, decent work conditions, household income, well-being and resilience and gender equality [4]. Each of them is discussed in further detail below.

To begin with, access to FT markets and prices contributes—among other factors—to provide price security during category-wide crisis and fluctuations (such as the 2004 Coffee crisis). Indeed, differences on price security are strongly correlated with access to FT markets. The latter have been growing in recent years, but in some categories—particularly coffee—sometimes supply exceeds current demand, hindering those workers from benefitting from FT prices and standards. Darko et al. review over 45 papers showing similar results [4]. Among others, Nelson et al., Vagneron and Roquigny and Valkila and Nygren, who explore the benefits of minimum price regulations for FT certified coffee producers in Nicaragua during the 2000–2004 coffee crisis [22–24].

The results also highlighted the positive effect of FT standards on more sustainable practices and, thus, higher environmental protection. As an example, Raynolds examined the Ecuatorian flower market and found that FT producers were much more sustainable than the national legislation required [25]. Especially, on the use of pesticides and storage. The same results were found for water and soil use, fertilizers, biodiversity conservation and the fulfillment of environment standards [4].

With respect to the FT premium, the literature highlights three main benefits from its application. The first concerns the community as a whole (such as improvements in schools, local infrastructure and health services). The second refers to benefits for producers or workers with a FT certification (like training or access to safer and more stable loans). Finally, it also helps non-FT producer organizations. For example, devoting the FT premium to cover the costs of certification for new producers. Darko, Lynch, & Smith find over fourteen papers providing evidence on these positive impacts [4]. One prominent case is the one studied by Nelson and Smith, who document the use of FT premiums in the cotton industry of India, Mali, Cameroon and Senegal [22]. They provide evidence on the positive effects steaming from projects financed through FT premiums. Among them, new schools, uniforms and scholarships, as well as investments in infrastructure, like water supply or rural electrification.

Another positive effect of Fair Trade practices is workers' democratic association and organizational strength. Management practices were found to be significantly better than for non-FT cooperatives. Similarly, workers showed higher identification with the producing entity than those that had not participated in FT programs [24, 26, 27]. An other interesting consequence is reported by Elder et al., who document the impact of FT certifications on trust using data from Rwanda coffee cooperatives [28]. They find a significant increase in trust arising from greater interaction between producers.

Further positive effects were found regarding decent work conditions, household income, wellbeing, worker empowerment, state protection and resilience [4]. Other authors have provided further support for these connections for countries like Ethiopia, Uganda and Ecuador, which is infamous for worker abuse in its flower markets [25, 29].

Finally, in the field of gender equality, FT certifications are also associated with an increase in women protection in countries like Mexico and Guatemala [30]. Other positive effects of FT are increased food security and higher educational attainments (which is a potential determinant of higher incomes), as well as reductions in the use of child labor [31].

## 6 Qualitative Inquiry on the Perception of Fair Trade

The previous section has been concerned with the positive effects of Fair Trade certifications. As stated above, the benefits of FT are not limited to producers and their communities. In fact, it has a great potential for firms wishing to improve their CSR practices and for consumers seeking more sustainably and humanely produced items. However, the literature has emphasized a key prerequisite to address these demand niches: reliability of FT standards [10]. The following section illustrates the perception of FT products with primary data. Given the limited number of responses and concerns regarding possible biases, it cannot be interpreted as a causal demonstration or as a representative cross-national sample. Rather, this survey simply intends to provide an example of FT perception. Despite these limitations, results from the analysis seem largely consistent with other studies in this area. The design of both the survey and the analysis will be covered in greater detail in the following sections.

### 6.1 The Problem: Assessing Consumer's Perception of Fair Trade Products

As stated above, the reliability of Fair Trade standards is critical for consumers. In order to accept a higher price for FT products, customers need to perceive that they are effectively contributing towards social change [32]. To assess their perception of these products—and of FTI as a prominent example—a survey has been conducted. The structure of the survey follows that of similar studies [10]. In particular, we use a modified version of the model proposed by Taylor and Boasson [33], incorporating some variables that other authors have found to be extremely relevant.

Using primary data from the responses, the subsequent analysis aims to assess the level of trust with which respondents regard FT products. To do so, we incorporate a number of measures which have been proven to affect significantly customer perception. Some of the independent variables used to measure the level of trust were the willingness to pay a higher price for a product certified as FT [34], the reliability they believe FT certifications have [32], whether they believe they are effective in fostering economic development [35] and what their behavior would be if they were sure the price premium would indeed reach the countries in need [33]. Thus, the last variable reports information on whether consumers value that their goods have been produced in a sustainable and humane way.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon \quad (1)$$

The variables have been chosen due to their prominence across the literature.

Y is consumers' perception of FT standards. This is a similar variable to the one proposed by Taylor and Boasson [33].

$X_1$ is the concern about producers' working conditions and sustainability. This would no doubt be correlated with the willingness to purchase a FT product if the certification is considered reliable, as shown by Giovannucci et al. [14].

$X_2$ describes the trust they place in the Certifications (performed by independent bodies) of FT standards. Authors such as Saenz and Zuniga-Arias or Ruben and Fort highlight the importance of this variable [36, 37].

$X_3$ accounts for whether they believe FT is an effective way to help producers in developing countries. This addresses the main question in a study performed by Harvard economists Dragusanu etal. [3]: "Does Fair Trade work?" [3].

$X_4$ represents the willingness to pay a higher price for FT products. The correlation among this and FT perception is self-evident and widely stablished across the literature [34, 38].

$\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$ and $\beta_4$ are the coefficient for these variables. A study of more magnitude would be needed to perform a complete regression and assess the importance of each of the coefficients. Especially, taking into account potential endogeneity concerns. Given the limitations of our sample, only relationships among the variables will be provided.

Finally, $\varepsilon$ represents the error term of the facts not captured with the current model. The hypothesis tested would be that an increase in any of these variables would correlate with an increase in the level of trust. A larger-scale study would be needed to assess causation instead of correlation. Nevertheless, this causal relationship has repeatedly been established across the literature, as referred above.

The operational objectives of the experimental project were:

1. Test if when the concern about producers work conditions and sustainability ($X_1$) is large, Perception of FT products (Y) is large.
2. Test if there is a positive correlation between Certification reliability ($X_2$) and Perception of FT products (Y).
3. Test if whether they believe FT is an effective way to help producers in developing countries ($X_3$) is positively correlated with Perception of FT products (Y).
4. Test if when the willingness to pay a higher price for FT products ($X_4$) is large, Perception of FT products (Y) is large.

### 6.2 Methodology and Limitations of the Survey

Regarding the structure of the survey, the data for the variables was compiled from self-administered internet questionnaires. This entails a series of concerns that make a causal analysis impossible. The respondents were mainly young professionals with international experience who responded to the survey between 2019 and 2022. The survey was performed with snowball sampling. Tough no concrete questions about income were included in the questionnaire, the fact that we employed snowball sampling probably skews our distribution towards young middle-class workers with a university degree (similar to the first respondents). In particular, the survey includes individuals from the United States, Mexico, Ecuador, Spain and Taiwan (as shown in Fig. 1). A number of variables could potentially bias our results, since consumers more prone to using electronic devices might be younger and, thus, have higher environmental or societal concerns [11]. Similarly, there are studies showing that the level of education may influence attitudes towards fair trade products [35]. This could affect our results, since most of our respondents had a university degree. A further limitation of our data was that we had no information on political beliefs, gender or personal values [34, 35]. Thereby, we acknowledge the limitation that customers in our sample may be more inclined to buy FT products than those in the general population. As a final concern, given that the number of respondents was below 200, the results may lack external validity. A larger study would have been no doubt more successful addressing these questions, but the results obtained were consistent with the ones from the literature [10].


**Fig. 1** Origin of respondents to the survey. *Source* Self-made from primary data (2022)

Regarding the design of the survey, ordinal scales displaying different prices and varying levels of trust (for example, to assess perceived reliability of certifications) were used throughout the survey. The Likert scale was used to measure ordinal data. As for the timing, the pilot testing lasted for the initial week, followed start of the data collection in 2019. The sampling frame only included adult consumers, to ensure a minimum purchasing power.

## 6.3 Analysis and Results

Regarding consumers' desire for sustainable and ethical production ($X_1$), the results indicate a strong concern for such matters for the surveyed customers. 84% of the respondents would be willing to pay a higher price and all of them would buy it if a FT product had a similar price to other products. To assess this variable, the following question was included in the survey: "If you were sure that the proceeds from this product are indeed going to reach producers in developing countries, would you buy it?". Thus, the question measures whether someone would be indifferent towards a FT product (they would only buy it if it is priced at the same rate as other products), the degree of involvement (either being willing to pay a higher price or one that almost doubles the initial price) and whether they would actively dislike a FT product (Fig. 2).

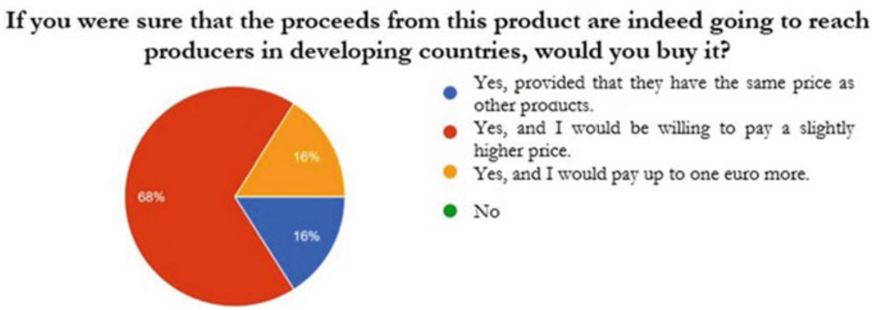


**Fig. 2** Willingness to pay for FT products. *Source* Self-made from primary data (2022)

Our study found a positive correlation. To see if it is statistically significant, further study and data volume would be needed. The results seem to understate the effect of this variable. Nevertheless, the positive effect is consistent with other studies on the matter such as Harvard economists' Dragusanu et al. [3].

For the variable measuring certification reliability ($X_2$) the negative correlation points towards a worse perception of FT products for consumers less confident that the certifications are indeed measuring compliance with FT requirements. Again, further testing would be needed to assess if such a result is statistically significant. Most respondents reported a confidence for such certifications ranging from seven to eight out of ten.

Concerning the variable measuring whether consumers perceive FT to be an effective way to help producers in developing countries ($X_3$), it is positively correlated with Perception of FT standards (Y). Only 16% of the respondents reported believing that FT had no positive effect on the economic development of producers in third world countries. This is consistent with the results from Becchetti et al. [39]. To assess this fact, a question in the survey asked, "Do you believe that products labelled as "Fair Trade" help in the economic development of producers?". It is apparent that consumers that believe that FT is an efficient way to help producers in developing countries will be more willing to accept a higher price than those that believe FT has no positive effect (Fig. 3).

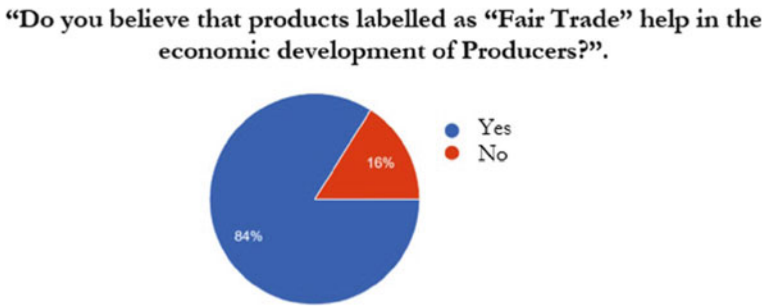


**Fig. 3** Reliability of FT certifiers. *Source* Self-made from primary data (2022)

Finally, there is a positive correlation between the willingness to pay a higher price for FT products ($X_4$) and the Perception of FT products (Y). 56% of respondents reported being willing to pay a slightly higher price (1.50 € instead of 1.20 €), 16% would be willing to pay up to 2 € and 8% would pay even a higher price (which would imply doubling the price of a non-FT product). This correlation is also consistent with the literature on the subject [38] (Fig. 4).

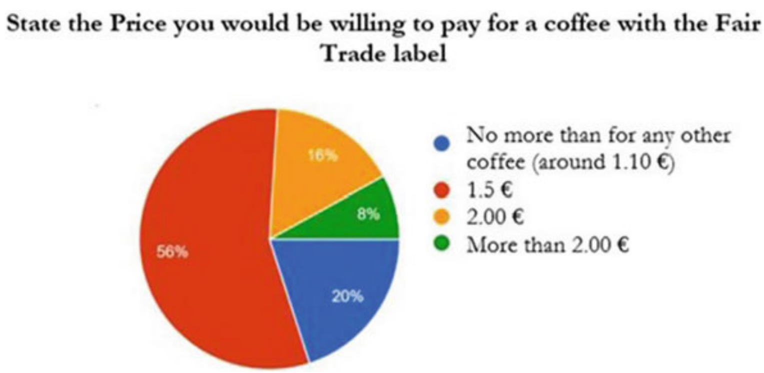


**Fig. 4** Amount respondents are willing to pay for a FT coffee. *Source* Self-made from primary data (2022)

To measure the dependent variable, Y, the following question was included as a control in the survey: "How much would you trust a product certified as "Fair Trade"?". Thus, a double Likert scale was used to measure the ordinal data on the dependent variable and assess the correlation with the other variables included in the model (Fig. 5).

An interesting insight concerns trust in FT certifications. As can be seen in the table below, those respondents that did not trust these certificates were less inclined to trust FT products or to believe in the effectiveness of FT initiatives (Table 1).


**Fig. 5** Trust in FT certification. *Source* Self-made from primary data (2022)

As discussed above, a study with a greater length, scope and use of panel data would probably be able to achieve more significant results. Nevertheless, the analysis indicates a pattern consistent with the literature on this topic. It would, thus, be reasonable to infer that the results are directionally correct.

## 7 Discussion and Conclusion

This analysis provides an overview of the literature on Fair Trade, its connection to the Sustainable Development Goals and analyzes -using primary data-consumer's perceptions of the label. The results of the study are consistent with prior literature on the matter.

The articles included in the first section provide evidence suggesting that Fair Trade does indeed aid the economic development of communities. This line of research also reports substantial evidence of the relationship of FT with a number of variables: access

**Table 1** Correlation matrix

| Variables | Trust in FT products | Ethical production | Effectiveness of FT | Reliability of certificates |
|---|---|---|---|---|
| Trust in FT products | 1 | | | |
| Concern for ethical production | 0.09895 | 1 | | |
| Effectiveness of FT | 0.30004 | 0.00586 | 1 | |
| Reliability of FT certificates | −0.1987 | 0.70342 | −0.2336 | 1 |

to FT markets and prices, environmental protection, investment of the FT premium in producer's communities, organizational strength, decent work conditions, household income, wellbeing, resilience and gender equality.

Similarly, there is evidence across the literature to support the statement that FT helps towards the attainment of the Sustainable Development Goals. Particularly, for the first, second, fifth and eighth SDGs.

The second part of the chapter provides an analysis of consumer perception of FT products, using a survey with primary data. Perception of these standards is key, since Fair Trade products provide an alternative for conscious consumers. This alternative would be unattractive if customers were to distrust either Fair Trade certifications (not believing that the extra money paid for a product truly ends up benefitting rural producers) or the efficiency of Fair Trade in general. The subsequent analysis suggests correlations consistent with those prevalent on the literature and points to a relationship between the dependent and independent variables analyzed. In the case of our analysis, further study would be needed to assess the significance of the correlations and to infer causality rather than only correlation, as well as to address the issue of selection bias, since our sample was probably not representative of the larger population. Nevertheless, results showing a positive perception of FT standards seem consistent with those of more comprehensive studies.

As can be seen, there is evidence supporting the fact that Fair Trade contributes to economic development, corporate social responsibility and -given a positive consumer perception of FT standards—FT products can provide an alternative for customers. It would, then, be possible to "do well doing good" for the three groups of stakeholders involved in Fair Trade: producers and their communities, customers and companies.

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# About *Responsibility* in Production and Consumption

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**Abstract.** This paper aims at bringing out the complexities of Sustainable Development Goal 12, Responsible Consumption and Production. This is done in the context of the EURECA-PRO initiative, the European University on Responsible Consumption and Production. The author argues that the official description of SDG 12 takes responsibility and sustainability to have the same meaning, as well as producers and consumers to be enlightened and behaving voluntarily in a responsible manner. In a more differentiated approach, responsibility means taking concrete actions towards strategic sustainability goals. Producers take on this responsibility only in a voluntary manner, when it pays off for them not to keep externalizing the socio-ecological costs of their actions. Consumers do not automatically act responsibly either, since many of them do not have the capabilities or economic possibilities to take part in responsible consumption. Concluding, the author argues that collective agency can be a way towards holding corporations accountable for their actions, as well as towards creating possibilities for consumers to participate in responsible consumption practices.

**Keywords:** Sustainable development goal 12 · Corporate social responsibility · Consumer types

## 1 Introduction

The European University Alliance EURECA-PRO works on responsible consumption and production, towards the Sustainable Development Goal number 12.

This Sustainable Development Goal is called “Responsible consumption and production”. In the short description of SDG12, it is stated that the aim of this goal is to achieve sustainable consumption and production patterns. Overall, action within SDG12 should aim at shifting consumption and production towards a more sustainable course [1].

When reading through the definition of SDG12, it becomes clear that sustainability and responsibility are used interchangeably. The authors do not make a distinction between the two terms.

Reading on, what is envisioned as sustainable consumption within SDG 12 is for consumers to be informed and thoughtful in their choices. Also, businesses should have a social conscience and look into their wider socio-environmental impacts. This means


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that SDG 12 envisions a society consisting of informed and thoughtful consumers and producers [1]. Yet, in reality, most people and businesses do not act in such ways.

The fact that sustainability and responsibility are taken to have the same meaning is problematic, since it obscures the complexity of the debates surrounding these terms. Furthermore, envisioning ideal-type consumers and producers does not take into account how consumers and producers behave in real-world conditions.

Thus, this paper takes up the following research questions:

1. What are the complexities of *responsibility* in the context of consumption and production?
2. What can be learned from these complexities for working towards SDG 12?

## 2 Objectives

The overall aim of this paper is to provide a basis for debating the meaning of responsibility in the context of the EURECA-PRO initiative.

In a first step, the author discusses the distinction between sustainability and responsibility. In a second step, the author brings out the nuances in the debate surrounding responsibility. A particular focus lies on responsibility in terms of production and consumption behaviour. In the end, the author outlines possible pathways towards fulfilling SDG 12.

## 3 Methods

This paper is based upon a selection of texts debating responsible production and consumption. The selection includes the most frequently-cited papers in this area, in German and English language. These papers are brought into a dialogue with each other. Some papers add details to other texts. Other papers bring some doubts to texts presented by their peers.

## 4 Results

Following the account of responsibility and sustainability in tourism brought forward by Mihalic [2], the two terms are linked yet separable. While sustainability is about determining a certain strategic orientation, responsibility comprises the concrete actions taken to achieve these strategic goals. Mihalic also argues that sustainability is more frequently used in the public sector, while responsibility is more often used by corporations in the private sector. This is because responsibility fits well with the societal goals of corporations, such as their orientation towards Corporate Social Responsibility (CSR).

Heidbrink [3] adds that responsibility often has a passive connotation, in the sense of "being held responsible" for something. Sustainability, on the other hand, means actively designing an agenda for the future. Responsibility also has an "aura of importance" [3, p. 25] created by its religious and legal roots.

Responsibility can be seen as response-ability, thus the ability to respond in a meaningful manner to external situations. Such responsiveness also entails entering into a dialogue with other societal actors [2].

Mihalic [2, p. 467] also puts forward the "Triple A Model" (see Fig. 1) for responsible and sustainable agency. The first "A" is awareness—the stage at which actors become aware of socio-environmental problems, yet are still driven by mainly economic concerns. In the second stage, "agenda", a sustainability agenda is set that goes beyond economic considerations. The last "A" stands for action—this is the stage where responsibility enters the picture, in taking action to step by step implement the sustainability agenda.


**Fig. 1** The three A's from awareness to action (Drawn based on [2, p. 467])

Following Heidbrink [3] and Suchanek et al. [4], responsibility entails that *someone* (the acting subject) takes responsibility towards *someone* or something (the object) according to a ruling *instance* and its rules. In contemporary society, such an instance can be the legal system or the expectations of society as a whole (see Fig. 2).

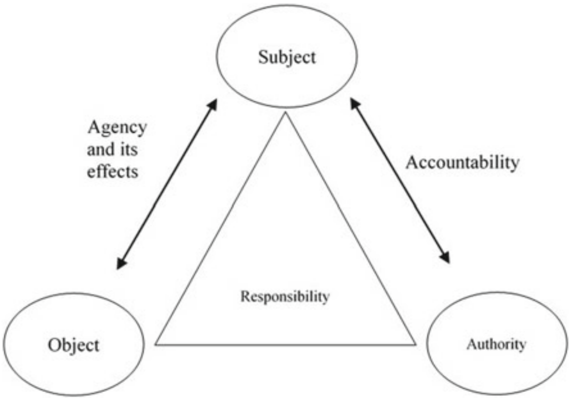


**Fig. 2** The three aspects of responsibility (Drawn based on [4])

There are preconditions for someone to be held accountable for their actions: That they act freely and with intent, and that causality can be ascribed [3]. As Williams [5] adds, rationality and normativity are also important aspects. Holding someone responsible for their actions implies that this actor has the ability to account for their actions. It also implies the existence of societal norms that provide the normative "compass" for judging actions as acceptable or unacceptable.

While this sounds quite straightforward, we live in a highly complex world, which makes it difficult to assign responsibility for something to an individual actor [3]. Agents are linked through complex networks, and so are humans and nature [6]. This also means that individual and collective actions have far-reaching consequences which cannot be easily accounted for. Furthermore, these consequences can, as Müller-Christ [7] puts forward, be intended or unintended.

Scientifically speaking, we face cognitive uncertainty about the impacts of our actions in many cases [3]. Climate change, for instance, is a well-researched topic, yet there is still some uncertainty about the concrete impacts. Such uncertainty can, as we see in the instance of climate change, lead to a situation where actors avoid taking responsibility [8].

When it comes to the production side of taking responsibility, Corporate Social Responsibility (CSR) is an important concept. Following Müller-Christ [7], CSR is very popular, yet not well-defined. Taking responsibility for social and ecological consequences is still voluntary. The author even claims that, for corporations, establishing respectful relationships with human beings and nature must be voluntary.

Firms routinely externalize the costs accumulated by their socio-ecological impacts (see Fig. 3). There needs to be a specific motivation to internalize these costs and, thus, take responsibility for the impacts caused. Quoting Müller-Christ [7, p. 44]: "If costs incurred through stakeholder reactions are greater than the cost of the commitment to social goals, businesses will choose the latter." Thus, from a business management perspective, the stakeholders' demands for more responsible production must impact the cost structure of the firm.

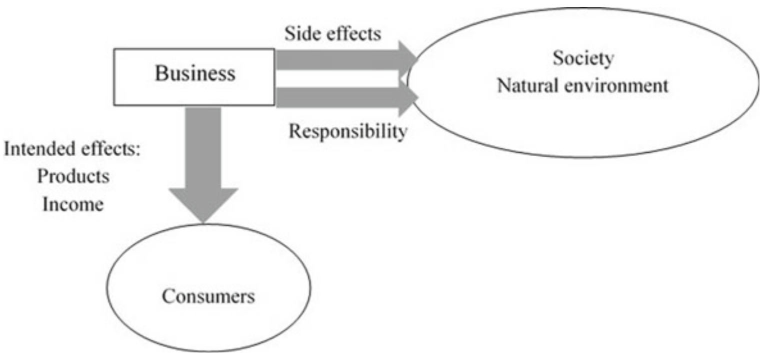


**Fig. 3** The intended and side effects of businesses (Drawn based on [7, p. 39])

Taking responsibility as a corporation amounts to an act of voluntary self-restriction, and Müller-Christ [7, p. 47] distinguishes between three possible motivations for such self-restriction:

1. Fear of negative consequences
2. The virtuous perspective that others should not be harmed
3. An expectation of possible changes in the long-term conditions and requirements of production

Thus, there can be different motivations for taking on a greater responsibility for one's actions. Yet, CSR and related schemes remain voluntary for corporations.

When it comes to the consumers' side of responsibility, it is often assumed that, as free and sovereign human beings, consumers will take informed decisions about what to consume. Still, as Micklitz et al. [9] argue, in reality, consumers are often over-burdened, over-booked, low on time, less competent, less interested, and not as disciplined as expected in theory. Micklitz and colleagues argue that there are three types of consumers: The confident, the vulnerable, and the responsible consumer.

The confident consumer has little time to collect information about products and services. Thus, this consumer relies on minimum standards set by the policy-makers regarding the quality of products and their side-effects. This also means that providing more information will have little effect on these consumers and their behaviour.

The vulnerable consumer does not have the economic and/or personal capabilities to fully take part in todays' consumer society. This consumer is at risk of being socially excluded since they do not have access to infrastructure that enables responsible consumption practices. Such basic infrastructure could be a good internet connection, but also simply access to shops that offer fresh and healthy food. It is necessary in this case that policies are created to protect these vulnerable consumers.

The responsible consumer has the possibilities and capabilities to take well-informed decisions. This consumer also has the economic possibilities to buy products that cause less socio-ecological damage. Only for this type of consumer, providing information will have an effect on consumption behaviour.

This typology of consumers also implies that taking responsibility through consumption is not an option for everyone. Consumers are not entirely free; the options they have are shaped by their socio-economic environment, such as the jobs they have access to and the infrastructure in their neighbourhood [10].

## 5 Discussion

We live in complex times. It is not becoming easier, but more difficult to assign responsibility to a specific agent.

When working towards SDG 12, it is important to differentiate between strategic sustainability goals and concrete responsible agency towards these goals. It is also important to realize that businesses only take voluntary action towards SDG 12 when it fits their cost structure. As long as the costs of acting in more responsible ways are bigger than the costs incurred by "business as usual", corporations will not take responsible action. They will keep externalizing the socio-ecological costs of their business processes, meaning that the public will have to bear these costs.

When it comes to responsible consumption, it needs to be clarified that not all consumers can act in responsible ways. Only the most privileged consumers have the time, the access to infrastructure, and the money to consume responsibly. For many others, this remains unattainable.

This means that, in working towards SDG 12, the different motivations of firms as well as the different capabilities of consumers need to be taken into account in order to act responsibly.

## 6 Conclusion

The pathway towards responsible consumption and production needs to be put into a wider social context, considering different motivations, capabilities, and the general complexity of the world we live in.

One way to navigate this challenge is to look towards collective agency. Collectively, producers and consumers can take responsibility for the consequences of their actions. This collective agency exists in a bottom-up manner as social action, but also in a top-down manner as legal regulations guiding collective agency [3].

Responsibility, "response-ability", entails entering into a dialogue with other social actors regarding the consequences of one's actions. This dialogue is best led against the backdrop of individuals coming together to take collective action, as well as a legal framework that allows to hold agents responsible for their actions.

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# Study on the Soil Formation Process on the Mining Waste Dumps from Jiu Valley (Romania). A Case Study

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**Abstract.** The present paper is in fact a continuation of a research effort started approx. 16 years ago, and whose main purpose is to follow the process of transformation of rocks from coal mining waste dumps into a fertile soil. Thus, during 2022, a new sampling campaign was carried out from the Petrila waste dump, which was later subjected to laboratory tests in order to determine the main characteristics that define the soil. These new data can be seen as the result of a periodic monitoring process and they complement the systematic study carried out between 2006 and 2011 (this study also included research related to the ecological succession of the phytocoenoses present on the Petrila dump). According to these latest analyses, the soil formation process is an active one, relatively slow, being highlighted by the increase in the content of nutrients and organic substances in the composition of the dumped material compared to the previously determined concentrations, as well as by the increase in the total and physiologically useful thickness of the soil layer. The results of this study are important for the next period, when the last 4 active dumps in Jiu Valley will be put into conservation, providing relevant information regarding the pedogenesis process that takes place on these dumps, under the exclusive influence of natural factors.

**Keywords:** Disaggregation · Humus · Organic matter · Fertility · Pedogenesis

## 1 Introduction

### 1.1 Soil Formation and the Role of the Inert Waste Rocks in this Process

Soil is one of the resources that fulfill essential functions for the environment and the economy, but it is strongly affected by human activities, in particular by mining. It is considered to be a resource that is hardly renewable [1–5] or even non-renewable by some researchers [6]. The major problem is that the rate at which we lose this resource is 50–100 times greater than the rate at which it is regenerated [7]. According to the Food and Agriculture Organization of the United Nations (FAO) about 30% of the world's soils are now degraded, while a European Commission report estimates that between 60 and 70% of its soils are unhealthy [8, 9].


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The time required for soil formation depends on a series of variables (the most important of which are: parent material, climate, living organisms, topography, and time) [3–5, 10]. Thus some authors consider that it takes 100 years to form 5 mm of soil [3, 11, 12], while others consider that in a mild climate, it takes 200–400 years to form 1 cm of soil [6].

Studying the soil formation process (pedogenesis) and finding solutions to accelerate it are important steps in the reuse of by-products such as barren rocks resulting from the mining of various useful substances and generation of such a valuable and important resource for life [8].

The inert rocks from mining waste dumps can constitute an important source of basic (parent) material, which through disaggregation, a process that takes place under the action of several factors such as water, wind, temperature and pressure variations, chemical processes and through decomposition of plants and animals, over time, can form the basis of a fertile soil [11–16]. Less demanding plants also thrive on poorer soils, and as they act with other organisms (microorganisms, insects and animals) to transform or break down organic debris (dead vegetation, leaves, animal remains), a layer of thicker and more improved soil forms. All these interactions produce a variety of soil types [3, 4].

The functions of a fertile soil consist of providing essential nutrients for plant growth, providing food and medicine, filtering and purifying water, sheltering biodiversity, reducing the risk of flooding, regulating the atmosphere through its role in the carbon and nitrogen cycles. Therefore, soil has an important role in supporting life on Earth [8, 9].

Knowing that soils have become more vulnerable and that they deteriorate at an increasingly alarming rate, it is important to understand the way, importance and possibilities of its restoration.

### 1.2 Study Area

The Jiu Valley region (Petrosani intramontane depression) is inextricably linked to the exploitation of the hard coal deposit contained in the Neozoic sedimentary formations and its capitalization, primarily for energy purposes.

The systematic exploitation (on an industrial scale) of hard coal in Jiu Valley started around 1840 and as a result of this activity, impressive volumes of sterile material resulted, which were stored in external dumps, near the mining premises [17]. The sterile rocks brought to the surface determined the appearance of positive relief forms, similar to hills, but with a strongly anthropized geometry different from the natural relief forms present in the area. Today, in the active mining perimeters, the stability of waste dumps and the quality of the environmental components are periodically monitored, while in the closed mining perimeters, reclamation works have already been carried out or will be soon carried out.

After 150 years of coal mining, Jiu Valley must respond to new challenges related to the closure of mines and finding new directions for economic development. Tourism represents a field with growth potential, but the areas occupied by the mining perimeters, especially the waste dumps, are distinguished from the natural landscape primarily by the lack of vegetation and regular shapes that do not correspond to natural relief forms. Thus, the potential of the natural environment is diminished, and several solutions have been found to improve it, such as modeling, vegetation and naturalization of dumps and other lands degraded by mining [18].

As a rule, in order to accelerate the vegetation process of the waste dumps and return them to the natural circuit (vegetation and reintegration into the landscape), it is necessary to apply a layer of topsoil to support the vegetation. However, researchers have noticed over time that on some waste dumps, vegetation has installed itself spontaneously [13, 19–21, 22–25], due to the pedogenesis process in its early phase, generally speaking of less demanding plant species such as: *Tussilago farfara, Rosa canina, Betula pendula, Crataegus oxyacantha*, etc.

Starting from this observations, a study was carried out regarding the soil formation process of the material from the waste dumps in Jiu Valley, taking into account the results of the pedological analyses carried out at the present time (2022) and from a systematic study, carried out between 2006 and 2011 [13].

The previous research carried out by the authors [13] on the Petrila dump (located in the eastern part of the Jiu Valley mining basin) was supplemented by those carried out by other authors on the waste dumps from Lupeni and Vulcan (located in the western part of the Jiu Valley mining basin) [26, 27] and with the new data obtained in 2022.

It is important to state that at the present time, of the 49 waste dumps charted in 2000 (which stored more then 37 million $m^3$ of tailings and occupied an area of over 250 ha) [17], only 4 are still active (Figs. 1 and 2 and Table 1).


**Fig. 1** Location of Jiu Valley mining region [28]

The main objective of the present study was to make a comparison between the current state and the one more than 10 years ago of the specific pedological characteristics for the Petrila dump and to establish to what extent the pedogenesis process is an active one, in continuous evolution, or, on the contrary, it is at a standstill and human intervention

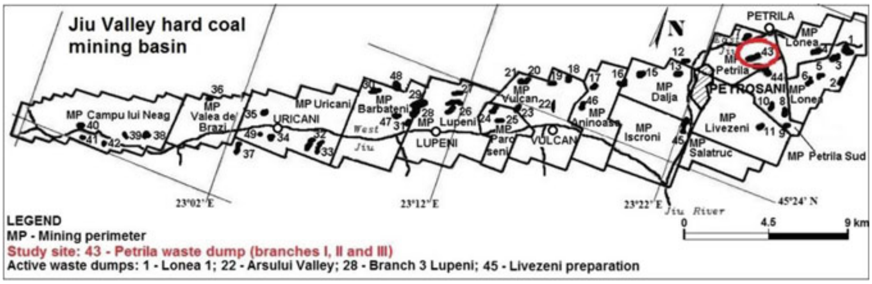


**Fig. 2** Location of waste dumps in Jiu Valley (as charted in 2000) [17]

**Table 1** Active waste dumps in Jiu Valley

| No. | Waste dump name | Mining exploitation | Occupied surface ($m^2$) | Designed capacity ($m^3$) | Used capacity (% of the designed one) | In function since |
|---|---|---|---|---|---|---|
| 1 | Lonea1 | M.E. Lonea | > 25,000 | 4,000,000 | > 12 | 1949 |
| 2 | Livezeni Preparation | M.E. Livezeni | > 38,000 | 1,144,000 | > 50 | 1970 |
| 3 | Arsului Valley | M.E. Vulcan | > 18,500 | 1,200,000 | > 33 | 1993 |
| 4 | Lupeni Branch 3 | M.E. Lupeni | > 64,000 | 2,387,800 | > 55 | 1961 |

is necessary (through specific works to stimulate and accelerate this process: application of natural or artificial fertilizers, fermented sludge from domestic wastewater treatment plants, etc.).

## 2 Methods

### 2.1 Soil Sampling

The sampling process (soil sample referred to as P6) from the Petrila waste dump between the RII and RIII dump branches (Fig. 3) was carried out at a depth of 30 cm. The sample collected from the soil profile (2 kg of material from the sampling site) was taken as a mixed sample (mixed—the sample being disturbed), and from this sample 1 kg of material with a grain size smaller than 20 mm was extracted by sieving.

### 2.2 Observations on Spontaneously Installed Vegetation

Because, as stated, an important role in the pedogenesis process is played by the vegetation spontaneously installed on the Petrila waste dump, during the 2022 field visit some

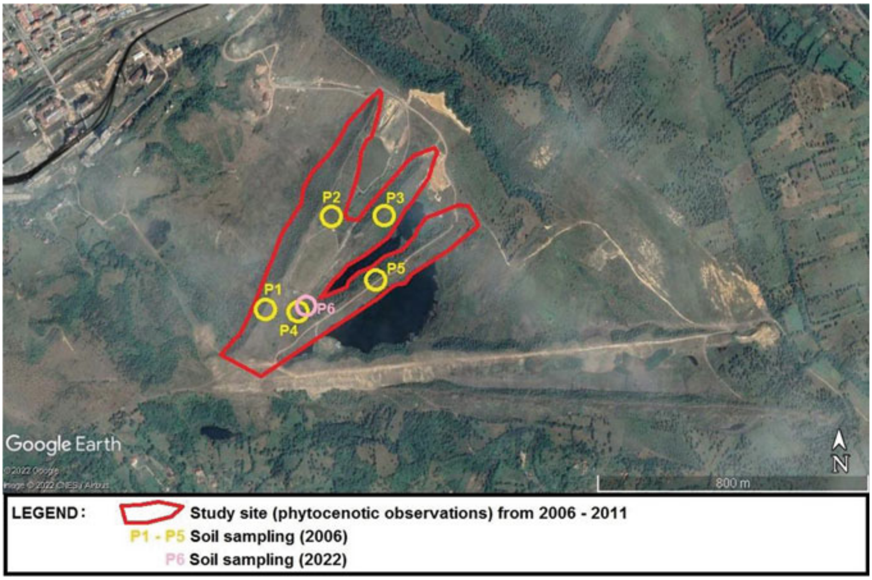


**Fig. 3** Location of the studied objective and the sampling point

observations were made to complement the systematic study carried out between 2006 and 2011 [13]. Table 2 shows the results of this study regarding the phytocenoses present on the Petrila dump (based on the phytocenologic principles of Braun-Blanquet).

An important observation is related to the disappearance of *T. farfara* at the end of 2008 (in fact, there is a gradual elimination of this species—it is still present in the area but not as a dominant one). This evolution can be directly linked with the increase of the diversity in species and to the interspecies competition on Petrila waste dump (as *T. farfara* competes with *B. pendula*, a species with similar ecological requirements but more genetically stable).

The observations made in 2022 show that there are no significant changes in this aspect, although it is worth mentioning that several young pine specimens were observed on the dump, right in the testing area (Fig. 4). As can be seen, the young pines appeared among the *B. pendula* trees, most likely spontaneously.

As for the herbaceous species, they are mainly represented by: *Poa pratensis*, *Lamium purpureum*, *Stipa lessingiana*, *Festuca velesiaca*, etc. Among the less abundant but relatively common species we notice *Mentha longifolia*, *Plantago sp.*, *Fragaria vesca*, etc.

### 2.3 Physical–Chemical Analyses of Soil Samples

In order to highlight the varied soil cover, it was decided to use the soil-terrain formula (pedotope) which includes the main features of the soil and the terrain.

The soils in the territory were classified according to the principles and criteria contained in the Romanian Soil Classification System [29] and were then correlated with the international reference documents in the field [30]. The information from the

**Table 2** Phytocenoses identified on Petrila waste dump (branches I, II and III) [13]

| Year | Scientific name | A/a | Abundance | Dominance (%) |
|---|---|---|---|---|
| 2005 | *Betula pendula* | A | 3 | 40 |
| | *Rosa canina* | a | 2 ÷ 3 | 30 |
| | *Tussilago farfara* | | 2 ÷ 3 | 30 |
| 2006 | *Betula pendula* | A | 3 | 45 |
| | *Rosa canina* | a | 2 ÷ 3 | 35 |
| | *Crataegus oxyacantha* | a | 2 ÷ 3 | 25 |
| | *Tussilago farfara* | | +÷ 1 | 5 |
| 2007 | *Betula pendula* | A | 3 | 50 |
| | *Rosa canina* | a | 2 ÷ 3 | 40 |
| | *Crataegus oxyacantha* | a | +÷ 1 | 8 |
| | *Tussilago farfara* | | + | 2 |
| 2008 | *Betula pendula* | A | 3 ÷ 4 | 50 |
| | *Rosa canina* | a | 2 ÷ 3 | 40 |
| | *Crataegus oxyacantha* | a | +÷ 1 | 8 |
| | *Tussilago farfara* | | + | 2 |
| 2009 | *Betula pendula* | A | 4 ÷ 5 | 60 |
| | *Rosa canina* | a | 2 ÷ 3 | 30 |
| | *Crataegus oxyacantha* | a | +÷ 1 | 10 |
| 2010 | *Betula pendula* | A | 4 ÷ 5 | 60 |
| | *Rosa canina* | a | 2 ÷ 3 | 30 |
| | *Crataegus oxyacantha* | a | +÷ 1 | 10 |
| 2011 | *Betula pendula* | A | 4 ÷ 5 | 60 |
| | *Rosa canina* | a | 2 ÷ 3 | 30 |
| | *Crataegus oxyacantha* | a | +÷ 1 | 10 |

A—tree species; a—shrub species

field and the analytical laboratory data were interpreted and ranked according to the norms of the “Methodology for elaboration of pedological studies” [31].

In the laboratory, on the P6 sample, a series of physical, chemical and macroscopic analyses were performed. The physical analyses concerned 4 indicators (moisture, physiological thickness, total thickness of the soil profile and clay content), while the chemical analyses included 9 indicators ($pH_{H2O}$, $CaCO_3$, content of organic matter (humus), nature of humus, soil reaction, salts content, total nitrogen, content in mobile forms of phosphorus and potassium). The nitrogen supply level was established using the nitrogen index values.

**Fig. 4** Young pine specimens in the sampling area

All physical and chemical analyses were performed by standardized methods and are shown in Table 3.

### 2.4 Macroscopic Analyses of Soil Samples

The macroscopic analyses consisted of 6 quantitative determinations to observe the physical–chemical desegregations processes of the sterile material with the formation of organic matter in the A0 horizon of the P6 soil profile (Fig. 5).

## 3 Results and Discussions

In the waste dumps from Jiu Valley (and implicitly in the Petrila dump) the deposited material is, in general, a heterogeneous mixture of hard rocks embedded in a mass of soft rocks. The rocks deposited within the waste dumps under conservation are very heterogeneous in age, grain size composition and structure.

Their petrographic nature highlights the presence of clay rocks, marls, clayey sandstones, mudstones, coal shale's and coal fragments.

From a mineralogical point of view, the dumped material is predominantly composed of quartz, potassium feldspar, biotite and calcite particles [26, 27].

The elemental composition of the material is predominantly silica, aluminum, iron, calcium, potassium and magnesium, and as for trace metals (Pb, Cu, Zn, Ni, etc.) the content is low, and does not exert negative effects on plants [27, 32].

**Table 3** Physical–chemical analyses

| No | Indicator | | MU | Determined values | | 2022 P6 |
|---|---|---|---|---|---|---|
| | | | | 2006–2011 variation interval [13] | 2006–2011 P4 [13] | |
| *Physical indicators* | | | | | | |
| 1 | Moisture | | % | 11.5–18.3 | 13.5 | 23.74 |
| 2 | Physiological thickness | | cm | – | 4 | 15 |
| 3 | Total thickness | | cm | – | 10 | 25 |
| 4 | Clay content | | % | – | 38 | 45.1 |
| *Chemical indicators* | | | | | | |
| 1 | $pH_{H2O}$ (instrumental) | | pH unit | 6.9–7.2 | 7.2 | 6.8 |
| 2 | Soil reaction | | Precipitate color | – | 6.8 | 6.5 |
| 3 | $CaCO_3$ | | % | – | < 1 | 2, weak effervescence that does not last (no foam formation) |
| 4 | Humus | | % | 0.9–3.0%, weak–medium content | 1.0%, weak content | 4.0%, medium content |
| 5 | Humus nature | | Precipitate color | Light yellowish, weak acidic, poor in humic acids | Light yellowish, weak acidic, poor in humic acids | Yellowish, weak acidic, poor in humic acids |
| 6 | Salts content | Chlorides | Precipitate color | – | Slight white cloudiness, traces | White precipitate, moderate amounts of chlorides |
| | | Sulfates | Precipitate color | – | Slight white cloudiness, traces | White precipitate, moderate amounts of sulfates |
| | | Sodium carbonate | Precipitate color | – | Faint pink color, traces | Colorless, absence |
| 7 | Assimilable N | | % | 0.10–0.18 | 0.18 | 0.57 |
| 8 | Assimilable P | | % | 0.9–2.8 | 1.8 | 5.2 |
| 9 | Assimilable K | | % | 1.5–3.1 | 2.1 | 8.6 |

## 3.1 Pedological Characterization of the Soil Cover

As a result of the environmental conditions (relief, surface lithology, hydrography, hydrogeology, climate, vegetation, etc.), a varied soil cover was formed in the area. Its diversity appears more prominently at the subtype level, but especially at the lower level, given by the association of soil and terrain characteristics in the respective are- as, conditioning the laws of their spread.

A first aspect observed is the increase in the total thickness of the soil layer from 10 to 25 cm as well as the physiologically useful one from 4 to 15 cm.

**Soil types and subtypes**. Following the pedological mapping of Petrila waste dump and using the mentioned criteria, the type of soil belonging to the class of undeveloped, truncated or sloppy soils was identified.

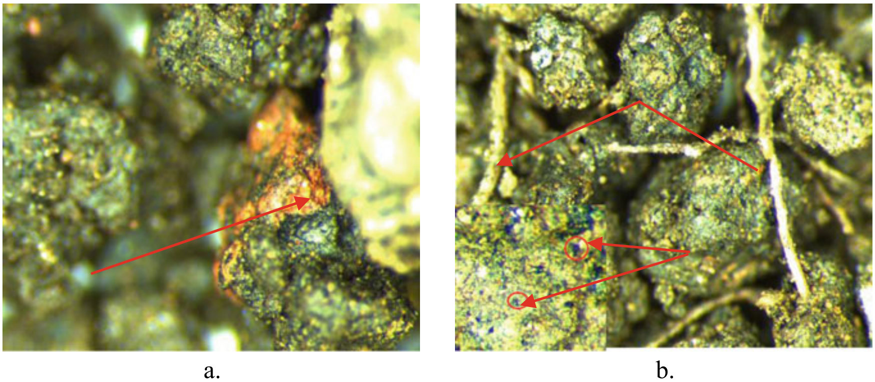

**Fig. 5** Macroscopic observations: **a** formation of iron hydroxides (1); **b** fragments of decomposing organic matter (2) and coal (3)

The class of undeveloped, truncated or sloppy soils identified, at sampling point P6, indicates the typical lithosoil subtype (LSti). In association with the base land, typical lithosoils appear (class of undeveloped soils), due to the characteristics of the parent materials (mine waste) and the land (slope).

**Typical lithosoil—LSti—(Eutri-lithic-Leptosoils)**. These soils are formed on various deposits: clays, marly clays, marls, clayey marls, sedimentary sandstones, marl limestone, compact limestone, shale and tailings, with different textural, physical and chemical properties.

In the area, they meet on narrow ridges, short or long uneven slopes, moderately–strongly inclined, on strongly inclined slopes within narrow valleys. They are present in small, discontinuous areas, appearing in association with other soils.

Their profile is $A_0$-R (hard rock), with the lithic contact occurring in the first 25 cm, which limits the thickness of the $A_0$ horizon to 5–25 cm.

### 3.2 Physical Properties

The texture of the $A_0$ horizon is loam-clay (approx. 39.1% clay $< 0.002$ mm $+$ 11.3% dust) mixed with organic material in various stages of decomposition (approx. 4%). The permeability is average and depends on the porosity of the deposited materials and the compaction degree.

### 3.3 Chemical Properties

Evolving under the vegetation spontaneously installed on the dump, lithosoils have a medium content (2.1–4.0%) of organic matter (humus), in the first 15 cm (the $A_0$ horizon) and low (0.6–1.0%) below this depth.

The reaction of the soil solution is one of the most important properties of the soil, as a plant growth medium, because different organic, organic-mineral and mineral compounds with an important role in plant nutrition are found dissolved or colloidally dispersed here.

The pH index determined in the laboratory is of interest for the general characterization of soils and for agricultural practice, because plants and microorganisms in the soil live and develop within certain pH limits, and the mobility of the nutrients interested in plant nutrition is strongly influenced by the soil reaction. From the laboratory analysis, it was determined that the soil reaction is weakly acidic $\left(pH_{H_2O} = 6.5\right)$, and the evolving lithosoils are on sedimentary rocks.

The total nitrogen content is medium to high (from 0.18% in 2006 to 0.57% in 2022), the supply of mobile P is extremely low-very low (from 1.8% in 2006 to 5.2% in 2022) and the supply of mobile K is small-medium (from 2.1% in 2006 to 8.6% in 2022).

### 3.4 Macroscopic Characterization of the Soil Cover

In the soil profile where the sample was collected, the tendency of iron hydroxides and coal particles to appear on the surface was observed. An intensification of the physical–chemical processes is observed due to the high content of clay, which also indicates a moderate fertility of the soil formed on Petrila waste dump.

There is a continuous accumulation of carbon and nitrogen in the organic matter, which has a direct and an indirect effect on the soil structure. As a result, the thickness of the humus horizon, the $A_0$ horizon, increases over time. The C/N ratio is initially very high, a category of organic matter that decomposes slowly, but as the vegetation develops, the ratio drops rapidly towards values found in higher quality soils where there is a good nitrogen cycle.

Considering the unitary character of the Jiu Valley mining basin (from a geological point of view and implicitly of the types of rocks that are stored in the waste dumps), the similar bioclimatic characteristics and the aspects related to the way the dumps were/are formed, the grain size composition of the dumped material, etc., the authors appreciate that the results of this study (the evolution of the pedogenesis process) can also be extrapolated for the 4 still active waste dumps and can be seen as a useful database for decision-makers who will have to determine the final destination of these dumps and reclamation mode.

## 4 Conclusions

The research conducted between 2006 and 2011 showed that the evolutionary stage of the ecosystem from Petrila waste dump is in its secondary succession, consisting in species characteristic for the area, and we appreciate that the situation in 2022 is similar. Ecological successions, over time, will lead to the consolidation of an autonomous ecosystem.

The main source of nitrogen supply to plants is the humus (organic matter) in the soil, which stores over 90% of the total nitrogen reserve. Under the action of microorganisms in the soil, the organic matter (humus) is mineralized, having the effect of releasing nitrogen and other nutrients and transforming them into forms accessible to plants.

It must be stated that apparently the content of organic matter is high. Actually, the organic carbon content of the soil is high (analytically determined), which comes both from the actual humus and from the organic remains (especially roots), in different stages of decomposition. It is also possible that coal fragments existing in the waste dump to have an influence on the determined humus content (total humus).

A pronounced physical–chemical desegregation of the marls and sandstones from the dump is observed, due to the large amount of clay present in the sample, which is characterized by a greater capacity to retain nutrients. The humus that forms in the A0 horizon will contribute to the increase of this nutrient retention capacity.

Compared to the previous study, a positive evolution of the physiological thickness and the total thickness of the soil is observed. These are conditions close to normal for plant development, and through the role they play (plants) in the evolutionary process of the soil, we appreciate that it will continue to be an active one and possibly unfold at a more alert pace.

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# Can the Fate of the Non-avian Dinosaurs Help us to Predict the Consequences of the Ongoing Biodiversity Crisis?

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**Abstract.** The ongoing biodiversity crisis has urged the scientific community to concentrate more research efforts on the mechanisms underlying the mass extinctions that have repeatedly affected our planet in deep time. This work implements a novel combination of palaeoecological and statistical routines to assess disruptions in the trophic architecture of non-avian dinosaur communities across the latest Cretaceous (83.6–66.0 Mya) of North America. Using these extinct beasts as model organisms, this work aims at increasing our ability to predict the susceptibility of ecological communities to extinction events under different levels of environmental disturbance. There was a trophic shift in the large, bulk-feeding herbivorous ornithischians and theropod carnivores during the Campanian–Maastrichtian transition that led to a simplification of North American terrestrial food webs several million years before the asteroid impact. Their disappearance during the Maastrichtian (72.0–66.0 Mya) made terrestrial communities more prone to extinction in the aftermath of the Chicxulub impact, which suggests that conservation schemes should pay special attention to keystone species in present-day food webs. In conclusion, palaeoecological transitions in the fossil record provide a valuable source of information for predicting the potential consequences of large-scale disturbances on contemporary biodiversity.

**Keywords:** Disturbance · Late cretaceous · Mass extinction

## 1 Introduction

The current biodiversity crisis (sensu [1]) has urged the scientific community to investigate the drivers of the mass extinctions that have affected our planet millions of years ago. The growing awareness of species conservation and the maintenance of the functioning of ecological systems leads us to address three fundamental questions: (i) how and (ii) why extinctions occur and (iii) what role do ecological dynamics (e.g., the trophic architecture) play in the survival and disappearance of species in the face of disturbing events.


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Since the beginning of this century, numerous studies have been executed to characterize the ecological role of some contemporary threatened species, such as large mammals (e.g., [2, 3]). The study of their food webs has shown that large predators play a key role in controlling top-down processes in present-day ecosystems [4], as well as that large herbivores contribute to the redistribution of nutrients in the ecosystem [3]. However, these analyses lack a reference scenario to compare their results with phenomena that occurred in the Earth's past. This aspect limits our view on the potential responses of ecosystems to disturbances that act as a factor of selection and extinction of species at large spatial and temporal scales, especially when it comes to the implications of the trophic architecture on the evolution of these events.

Paleontologists have strong background in studying and characterizing the causes of mass extinctions, their degree of impact and the resilience of different ecosystems, including the mechanisms underlying the survival or extinction of specific biotic groups following these geological events (e.g., [5–13]). However, bridging paleontological and modern ecological evidence could provide a new approach to study mass extinctions [14] and recent research seems to support the conceptual unification of these two disciplines [15–18]. Indeed, paleoecological dynamics associated with food webs of extinct biota can help us understand their resilience and recovery capacity in the face of large-scale disturbances across different spatiotemporal and paleobiogeographical contexts [19]. These conclusions might contribute to nuanced models on the potential responses of current ecosystems to human-induced impacts, thereby helping to prioritize key taxa that need special conservation status.

The last of the big five mass extinctions occurred 66 million years ago [20], marking the end of the age of the dinosaurs [9] and motivating the subsequent rise of the mammals during the Cenozoic [21–23]. Therefore, this event has been an important turning point for the ecological patterns and processes of our present-day world and the evolutionary legacies of the flora and fauna that we share the planet with today [24].

Various theories have been proposed to explain the causes underlying the disappearance of the non-avian dinosaurs, although there is a consensus in the paleontological community that suggests that it was the impact of an extraterrestrial bolide (over 10 km in diameter) that caused their dramatic extinction [5, 16, 25]. There is, however, empirical evidence that seems to suggest that the Chicxulub impact was not the only destabilizing factor during the transition between the Cretaceous and the Paleogene (K/Pg) [26, 27]. For instance, the Late Cretaceous experienced environmental changes resulting from intense volcanic activity on the Deccan Plateau [23], global temperature oscillations [28] and sea level fluctuations [29]. Some studies [30–32] also suggest that several groups and families of ornithischian dinosaurs were already in ecological decline before the impact of the extraterrestrial bolide. Nevertheless, modern re-evaluations of these hypotheses using novel statistical models seem to contradict these previous findings [15, 18].

The main aim of this work is to assess spatiotemporal disruptions in the trophic architecture of Late Cretaceous non-avian dinosaur communities. More precisely, by using a detailed database of the fossil record for the stratigraphic formations of Laramidia and applying state-of-the-art ecological models [33–35], this work hopes to contribute to the theoretical and empirical unification of the ecological science and paleontology.

More specifically, we aim to (i) evaluate the ecogeographical mechanisms underlying the distributional patterns of non-avian dinosaurs and the changes experienced in the relative importance of these factors between the Campanian (83.6–72.0 Mya) and the Maastrichtian (72.0–66.0 Mya), and (ii) identify the central nodes in the trophic interaction networks. Overall, using dinosaurs as model organisms and the changes that these animals experienced before their dramatic disappearance, this work hopes to contribute to assess the susceptibility of modern ecological communities to disturbances in the current context of biodiversity loss.

## 2 Materials and Methods

### 2.1 Fossil Database

Fossil occurrences and the geologic and paleogeographic context for the latest Cretaceous were downloaded for a total of 25 North American formations using the Paleobiology Database (https://paleobiodb.org/). Curation and data harmonization are explained in detailed in [36]. Overall, the final database included all fossil material available for the Late Cretaceous of North America, totaling 107 genera from 13 different families of ornithischian and theropod dinosaurs.

### 2.2 General Circulation Models (GCMs), Land Surfaces and Digital Elevation Models (Paleo-DEMs)

Paleoclimatic models and land surfaces used in this study are from the AOGCM HadCM3L ver. 4.5 of the BRIDGE Group (http://www.bridge.bris.ac.uk/resources/simulations). The variables included in this study (2.75° × 3.25° spatial resolution) were: near-surface (1.5 m) mean annual temperature (°C), near surface (1.5 m) annual temperature standard deviation (°C), annual average precipitation (mm), annual precipitation standard deviation (mm), net primary productivity (NPP, g C $m^{-2}$ $yr^{-1}$), and plant functional types (i.e., from broadleaf and needleleaf trees to C3-type and C4-type groundcover). The simulations and settings of the terminal Cretaceous models used here are described in full by [37–39], and their applicability in paleobiogeographic studies has been discussed previously in [15–17, 40–42].

The paleogeographies used for this study are those of [43], originally created as a paleo-digital elevation model (DEM) on a 1° × 1° grid, and upscaled to the HadCM3L Earth System model resolution (2.75° × 3.25°). This means that topographic and bathymetric information was broadly conserved as it was resolved at a lower spatial resolution [16–18]. The 117 maps created by [43] have provided a global atlas for paleogeographic interpretations at different spatial scales over the last 540 million years of Earth history, including the changing distribution of the world's oceans and continents.

Sediment flux (cm $kyr^{-1}$) is a parameter that influences the quality of the fossil record, controlling the preservation of skeletons, and is dependent on geography, geomorphology, tectonics and climate. Here, the sedimentary flow values are those from [15], who applied the predictive model BQART98 [44] in Campanian and Maastrichtian paleofluvial landscapes.

### 2.3 Statistical Analysis

Distributional patterns of non-avian dinosaurs were analyzed for each time interval (Campanian versus Maastrichtian) using a special type of joint species distribution models, hierarchical modelling of species communities (HMSC hereafter, [33]). In brief, by simultaneously analysing information from multiple taxa, the HMSC routine incorporates aspects of traditional species distribution models to quantify patterns of cooccurrence among taxa and, at the same time, accounts for variation attributed to environmental filtering (here, paleogeographies, paleoclimatic and land surfaces) and random effects (here, the number of collections and sediment flux). For this work, distribution patterns of non-avian dinosaurs were modelled using the *probit* option for presence-absence data with the R *Hmsc* package [45].

All explanatory variables were logarithmically transformed before running the models. Following the criteria established by [35], all models were fitted with 10,000 Markov chain Monte Carlo (MCMC). The first 2000 steps were discarded as *burn in* and the remaining samples were reduced by a factor of 10. The predictive performance of the models was based on Tjur $R^2$ coefficients [46].

Finally, potential species associations (sensu [33]) were examined by calculating the residual correlations in the HMSC models (see [33] for a similar approach). Note, however, that these potential associations should not be interpreted as proven biotic interactions [47]; rather, residual correlations indicate that biotic interactions might be the primary cause underlying these empirical associations [48].

All analyses were performed in R (R Development Core Team, 2018) for CentOS Linux 7.7 (The CentOS Project, https://www.centos.org/) using supercomputing resources managed by SCAYLE (Supercomputing Centre of Castilla y León, https://www.scayle.es/).

## 3 Results

### 3.1 Performance of HMSC Models

The HMSC models applied in our study showed a moderate predictive performance (Fig. 1). More specifically, the average values of Tjur $R^2$ coefficients for Campanian and Maastrichtian dinosaurs ranged between 0.29 and 0.39, which is consistent with modern assessments of present-day ecological communities (e.g., [49, 50]).

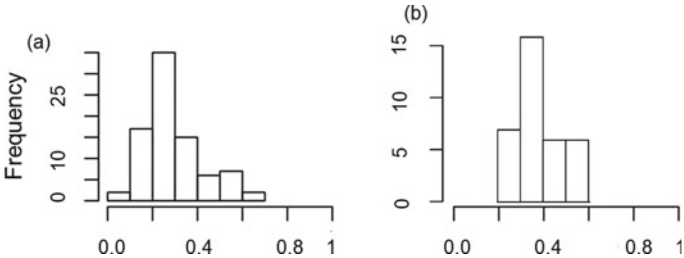
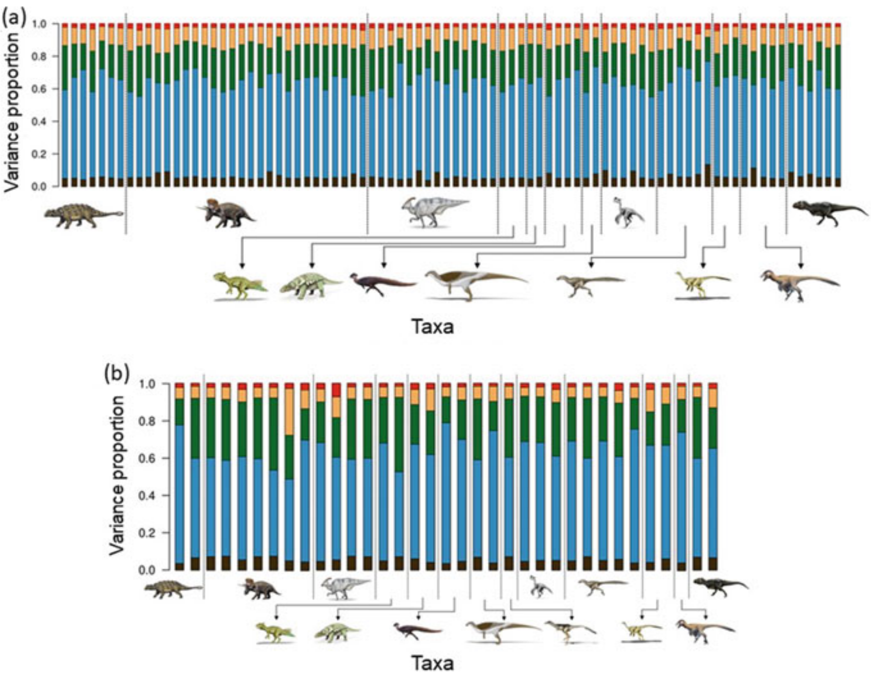



**Fig. 1** Values of Tjur's $R^2$ coefficients for **a** Campanian and **b** Maastrichtian non-avian dinosaur communities

## 3.2 Variation Partitioning

Paleoclimatic correlates (i.e., mean annual surface temperature, standard deviation of annual surface temperature, mean annual precipitation and standard deviation of annual precipitation) were the most important explanatory variables underlying non-avian dinosaur distributions in the latest Cretaceous of North America (Fig. 2). The structuring role of climatic mechanisms was consistent across taxa for both Campanian and Maastrichtian time intervals, suggesting that paleoclimates were the main ecological gradient for these tetrapods, regardless of their ecologies, such as body size or diet.



◀**Fig. 2** Results of variance partitioning from our HMSC models explaining the distributional patterns of non-avian dinosaurs during the **a** Campanian and **b** Maastrichtian of North America. Colors represent different groups of explanatory variables. Altitude: dark brown; palaeoclimatic conditions: blue; land surfaces: green; number of palaeontological collections: orange; and sediment flux: red. Taxa are ordered (from left to right) using the following criteria: [**Campanian**; *Akainacephalus, Dyoplosaurus, Euoplocephalus, Oohkotokia, Platypelta, Scolosaurus, Zuul* (Ankylosauridae), *Achelousaurus, Agujaceratops, Albertaceratops, Anchiceratops, Arrhinoceratops, Avaceratops, Centrosaurus, Chasmosaurus, Coronosaurus, Diabloceratops Einiosaurus, Machairoceratops, Medusaceratops, Mercuriceratops, Nasutoceratops, Pachyrhinosaurus, Pentaceratops, Rubeosaurus, Spiclypeus, Spinops, Styracosaurus, Utahceratops, Vagaceratops, Wendiceratops, Xenoceratops, Yehuecauhceratops* (Ceratopsidae), *Acristavus, Adelolophus, Angulomastacator, Brachylophosaurus, Corythosaurus, Edmontosaurus, Gryposaurus, Hypacrosaurus, Kritosaurus, Lambeosaurus, Maiasaura, Parasaurolophus, Probrachylophosaurus, Prosaurolophus* (Hadrosauridae), *Cerasinops, Prenoceratops, Unescoceratops* (Leptoceratopsidae), *Edmontonia, Panoplosaurus* (Nodosauridae), *Colepiocephale, Gravitholus, Sphaerotholus, Stegoceras* (Pachycephalosauridae), *Orodromeus, Thescelosaurus* (Thescelosauridae), *Apatoraptor, Caenagnathus, Chirostenotes, Epichirostenotes, Hagryphus, Leptorhynchos* (Caenagnathidae), *Bambiraptor, Boreonykus, Dromaeosaurus, Hesperonychus, Saurornitholestes, Richardoestesia* (Dromaeosauridae), *Ornithomimus, Rativates, Struthiomimus* (Ornithomimidae), *Latenivenatrix, Paronychodon, Stenonychosaurus, Talos, Troodon* (Troodontidae), *Albertosaurus, Bistahieversor, Daspletosaurus, Gorgosaurus, Lythronax and Teratophoneus* (Tyrannosauridae). **Maastrichtian**; *Ankylosaurus, Anodontosauru* (Ankylosauridae), *Anchiceratops, Eotriceratops, Ojoceratops, Pachyrhinosaurus, Regaliceratops, Torosaurus, Triceratops* (Ceratopsidae), *Edmontosaurus, Gryposaurus, Hypacrosaurus, Saurolophus* (Hadroauridae), *Leptoceratops, Montanoceratops* (Leptoceratopsidae), *Denversaurus, Edmontonia* (Nodosauridae), *Pachycephalosaurus, Sphaerotholus* (Pachycephalosauridae), *Parksosaurus, Thescelosaurus* (Thescelosauridae), *Albertonykus* (Alvarezsauridae), *Anzu, Chirostenotes, Ojoraptorsaurus* (Caenagnathidae), *Acheroraptor, Atrociraptor, Dakotaraptor, Dineobellator, Richardoestesia* (Dromaeosauridae), *Ornithomimus, Struthiomimus* (Ornithomimidae), *Pectinodon* (Troodontidae), *Albertosaurus, Bistahieversor, Daspletosaurus, Gorgosaurus, Lythronax* and *Teratophoneus* (Tyrannosauridae)]

Land surfaces were the second most important group of predictor variables for the spatial ecology of non-avian dinosaurs. However, these predictors (i.e., plant functional types and NPP) were more relevant for the megaherbivores (ankylosaurids, ceratopsids and hadrosauroids) than for the remaining species groups (Fig. 1). By contrast, the predictive role of palaeotopographic features was relatively weak (5–10%), especially compared to the importance detected for paleoclimates and land surfaces. Similarly, proxies associated with the quality and potential preservation of the fossil record played a minor role ($\leq$ 15%) in our HMSC models, supporting the reliability of our modelling exercises when it comes to reconstructing the spatial distributions and ecologies of North American non-avian dinosaurs before their demise.

### 3.3 Trophic Architecture

Residual correlations from our HMSC models suggest a relatively high degree of trophic connectivity across the Campanian communities of North America (Fig. 3a). In this regard, key taxa for Campanian food webs were (i) the megaherbivores, including ankylosaurids (e.g., *Euoplocephalus* and *Oohkotokia*), ceratopsids (e.g., *Achelousaurus*) and hadrosauroids (e.g., *Acristavus*, *Coryristavus*); (ii) some small herbivores (< 100 kg), such as *Prenoceratops*; (iii) the omnivorous caenagnathids (e.g., *Leptorhynchos*); and (iv) the medium-sized (e.g., *Bambiraptor*, *Saurornitholestes*) and large-sized (e.g., *Daspletosaurus*) carnivorous theropods.

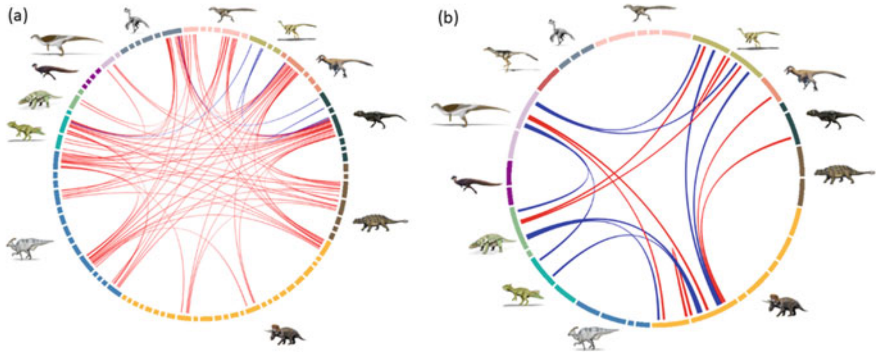



**Fig. 3** Chord diagram illustrating positive (red) and negative (blue) dinosaurian associations with at least 95% posterior probability in the **a** Campanian and **b** Maastrichtian ecosystems of North America. Dinosaurian taxa are ordered (clockwise) Fig. 2

On the other hand, we found a strong decline in trophic connectivity of dinosaurian communities during the Maastrichtian, potentially contributing to their demise. For instance, most associations for Maastrichtian food webs were constrained to those registered for few ceratopsids (e.g., *Torosaurus* and *Triceratops*), the armored nodosaurid *Edmontonia* and some ornithomimids (e.g., *Ornithomimus* and *Struthiomimus*).

## 4 Discussion

The analysis of trophic architecture has gained importance in recent decades because it plays a key role for our understanding of the complexity of ecological systems [24]. From a paleontological perspective, it is hardly difficult to delineate food webs based exclusively on empirical fossil data. This means that paleontologists and ecologists need to join forces in order to reconstruct potential species associations in ancient ecosystems. These representations of trophic structure are a reliable proxy of extent food webs (sensu [19]), not least because they overcome the limitations arising from the difficulty of collecting and interpreting all the anatomical information needed to extrapolate biotic interactions from fossil remains [24].

HMSC models have been used successfully in modern ecology and the recent implementation of joint species distribution modelling in paleontology represents an opportunity to increase our understanding of mass extinctions by overcoming the limitations associated to fossil data [51].

The relative importance of paleoenvironmental correlates for the spatial distribution of non-avian dinosaurs is consistent with recent works (e.g., [17, 18]). Paleoclimatic features have found to be one of the main mechanisms underlying non-avian dinosaur communities in North America. Interestingly, climatic control appears to be a universal mechanism for biodiversity throughout Earth's history [52], even in times when climate variability was much lower than today, as it was the case in North America during the latest Cretaceous. The destabilization of food webs and the concomitant loss of species at different spatial scales is an issue that is still under evaluation, although the fossil record in our study seems to indicate that, even in times of minor changes in climatic conditions (such as the transition from the Campanian to the Maastrichtian), environmental changes can lead to strong ecological constraints on vertebrate trophic dynamics (Fig. 3).

The second mechanism controlling the distribution of non-avian dinosaurs in North American Late Cretaceous was a combination of plant functional types and NPP. Land surfaces were particularly important for large herbivores, which depended on a stable and continuous production of plant biomass [53]. The disappearance of forests after the bolide impact by the end of the Maastrichtian significantly altered net primary production in terrestrial ecosystems on a global scale [54–56]. The few large herbivores that survived to the thermal radiation (sensu [57]) died of prolonged starvation within a few weeks [9], a signal that cascaded through the food web [51, 56, 58]. However, a long-lasting turnover in the composition of these tetrapods, associated with changes in terrestrial vegetation, was already discernible in the transition from the Campanian to the Maastrichtian [59], 6 My before the bolide impact.

While it is certainly not anticipated that an exogenous factor will interfere dramatically with modern terrestrial ecosystems, our results provide evidence of the importance of primary production and the geographical distribution plant functional types to maintain the stability of ancient food webs. Hence, we speculate that changes in the ecological characteristics of plant functional types in biomes and the spatial variation of NPP can trigger trophic disruptions at the level of entire continents that may increase the susceptibility of entire ecological communities to extinction. It is therefore essential to study species associations in ancient ecosystems in order to anticipate extinction scenarios arising under the ongoing biodiversity crisis. For instance, understanding the relationship between trophic complexity and extinction scenarios of Earth's past should be useful when it comes to predicting how trophic ecology responds to disturbances.

Our results are in line with the original findings of [30], suggesting a trophic restructuring during the Campanian–Maastrichtian transition that was characterized by strong decline in the trophic role of large herbivorous ornithischians. Relationships between food web structure and the susceptibility of Late Cretaceous ecosystems to extinction are still subject to debate (e.g., [15] versus [32]). In this context, interest in understanding how ecosystems respond to large-scale human-induced disturbances under different biogeographical settings has been growing in recent years [60]. According to [61], trophic architecture is, indeed, one of the main features underlying the functioning of present-day ecosystems, a view that supports classical assertions from [62–64]. These authors argued that structurally and functionally complex ecosystems are more stable against disturbances. Hence, the trophic architecture of dinosaurian guilds during the Campanian would have been more stable than Maastrichtian food webs, which argues in favor of previous conclusions in the original paper of [30]. For instance, as in the case of dinosaur-dominated ecosystems in North American Late Cretaceous, the loss of the megaherbivore component likely resulted in a widespread destabilization of Maastrichtian food webs, with concomitant higher secondary extinction rates across most (if not all) trophic guilds. Hence, conservation strategies should focus on *keystone species* for the development of heterogeneous habitats [65] in the context of the ongoing climate change (e.g., [66, 67]), especially when it comes to the gradual simplification of trophic structures in current ecosystems [68–70].

However, only a handful of trophic studies have been explicitly considered to design ecological management strategies (e.g., [4]), and ignoring this facet of nature (sensu [71]) could compromise the effectiveness of management schemes aimed at conserving ecosystem functionality. For instance, studying the evolution of ancient food webs and their response to disturbances in deep time offers a novel perspective to guide predictions on the long-term effects of human-induced impacts on present-day biotas. Researchers now have the opportunity to make reliable predictions and test hypotheses under different working scenarios by using intensely sampled and stratigraphically constrained fossil databases. Their findings, including those available in this chapter, have the potential to support modern decision making and conservation strategies aimed at bending the curve of biodiversity loss [72, 73].

## 5 Conclusions

- Improving our understanding on the background of mass extinctions may help us to predict how present-day ecosystems may respond to human-induced disturbances at large spatial extents (e.g., an entire continent).
- Paleoclimatic conditions and spatial variation in NPP and plant functional types were the main mechanisms explaining the distributional patterns of non-avian dinosaurs in the latest Cretaceous of North America. It is therefore expected that changes in climatic conditions and land-use at the level of biomes will lead to trophic disruptions that may increase the susceptibility of entire ecological communities to extinction. Thus far, the dinosaurian fossil record suggests that the Campanian–Maastrichtian transition was characterized by a strong decline in the trophic role of large herbivorous ornithischians that made Late Cretaceous dinosaur communities more susceptible to extinction, at least in North America.
- Our results encourage the protection of key species of large herbivores and carnivores in their natural ranges, not least because many of them may act as central nodes of present-day food webs at different spatial levels of interest. The disappearance of these large faunas from ancient food webs made Maastrichtian ecosystems more prone to extinction following the bolide impact.
- Overall, this study emphasizes how palaeoecological disruptions in the fossil record provide a valuable source of information for predicting the effects of large-scale anthropogenic impacts on biodiversity.

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# Reducing Food Waste in Supermarkets with Machine Learning

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**Abstract.** Around one-third of produced food is wasted, which is almost 1.3 billion tons of food per year, affecting the world economically, environmentally, and socially. Over the years, different solutions for food waste have been developed; however, machine learning within this area has not been sufficiently explored. The food rescue process is very time sensitive since the food can be close to turning rancid, so forecasting the supply of food to be donated could significantly increase the amount of food being rescued. Our objective is to optimise the use of food and reduce food waste in supermarkets. We propose a framework to predict the amount of expiring products donated with machine learning models. In the paper, a first test of the framework, using simulated data, is presented, showing that the Support Vector Regression would be the most appropriate machine learning model for the framework, giving a score of 0.732 While the paper shows that the framework can generate valuable results, the difficulties with applying it to the real world lie in the data acquisition phase. Supermarkets are private companies that might not be willing to share their business data, which is a problem for future research.

**Keywords:** Smart city · Food waste · Machine learning · Sustainable consumption

## 1 Introduction

Around one-third of produced food is wasted, which is almost 1.3 billion tons of food per year [5]. Food waste affects the world economically, environmentally, and socially. In the economic aspect, food waste costs $940 billion each year globally. To produce food, we need water, land, and energy, which impacts the environment seriously. Even though enough food is produced, nearly 800 million


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people still suffer from hunger and malnutrition. Food waste is an important issue we need to solve according to the previously presented problems. Using new technologies, including mobile phones, is an excellent strategy to be aware of personal needs. There are different solutions to using mobile applications to fight the problem of food waste. The mobile applications that are implied in reducing waste food can be divided into different types depending on the relation between consumer and business: C2B, C2C, B2C, and B2B.

- C2B (Consumer to Business): Applications for consumers to record the information of the food needs (bought date, expiration date, amount etc.).
- C2C (Consumer to Consumer): Consumers can share their food with the applications.
- B2C (Business to Consumer): Business can sell their products that are about to expire to the consumer.
- B2B (Business to Business): Business can provide their products that are about to expire to the organisation in need.

However, these solutions all have limitations and can be improved [1]. This study will focus on the fourth category, Business to Business. This type of food saving is usually based on volunteering and unpredictable activity. This study aims to facilitate this activity to motivate and engage more people to take part in it. We will use the selling data and product expiration date to predict the products that are available for donation. With the information on the availability of the donating product, volunteers can know in advance and facilitate the willingness to deliver the donating product.

Studies have been done on using intelligent systems to facilitate food rescue. Some previous literature focuses on the routes for picking up the food at the providers and delivering it to the people in need to find suitable matches [6] and optimised matching [8]. Work has also been done around making good distribution of the rescued food to the food banks [2]. Other literature has approached the problem more from the volunteer side, for example, by developing push notification systems for volunteers who are most likely to be able to rescue the food [10]. One of these studies proposes a machine learning model, a recommended system to improve the notifications process and reduce the number of unnecessary notifications that would discourage people from using the application [7]. The system managed to improve the applications hit ratio from 44% to 73%.

Since the food rescue process is very time sensitive since the food can be close to turning bad, being about to forecast the supply of food to be donated could highly increase the amount of food being able to be rescued. Together with previously mentioned solutions, this could also increase the engagement of volunteers as it would facilitate the process since it could be better planned.

Forecasting techniques to estimate the future based on historical data are used extensively in several different areas, such as the economic sector, transportation, and weather. However, in other areas similar to food rescuing that are very time sensitive such as organ and blood donations, there is surprisingly very little work done is used in forecasting [4] and prediction [9].

The rest of the paper is organised as follows: In Sect. 2 a framework is presented, and we use a machine learning model as the method to predict the amount of food that supermarkets will donate; in Sect. 3 the method is tested using a simulated data set and the conclusion and future work of the paper is provided in Sect. 4.

## 2 Framework and Method

To make predictions about the amount of food that will be available for donation, the data needs to be collected, stored and processed, and an application has to be developed to connect the volunteers and the food providers (supermarkets). In this section, a framework for these processes is proposed. The system consists of three layers; the edge layer, the cloud layer, and the fog layer (see Fig. 1), all of which will be described in further detail.

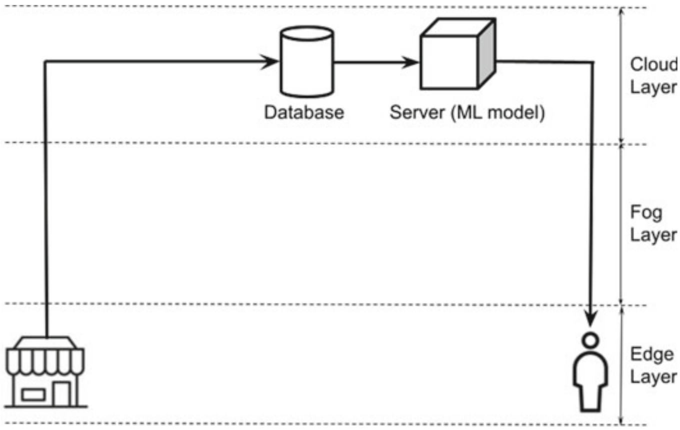


**Fig. 1.** The framework of reducing food waste in supermarkets with machine learning. In the edge layer, we use sensors to get the data from the supermarket. Data from supermarkets are sent to the cloud layer to be stored in the database and later used as the input of the machine learning model

### 2.1 Edge Layer

At the edge layer, sensors will be used to get the data from the supermarket. The data we get include (1) Product information: category, expiring date, in-stock date, selling date(if any), (2) Stock information: amount being sold, amount being in-stocked, amount being donated, (3) Supermarket information: size, population around the area, and (4) Donation history. The information about the supermarket is only sent once. The stock data is accumulated each day and then sent to the cloud at the end of the day. The product information is sent to the cloud every time there is a new delivery of products to the supermarket. The selling date of a product is reported when the product is sold. We assume that all products that are not sold, i.e. do not have an expiration date, are donated, which is how we get the donation history. We use the smartphone application as an actuator to send information about the food to be picked up, i.e. location, time, and amount.

At this stage, we need to filter the data from the stock information of the supermarket so that we only get the data related to products that have an expiring date. Besides food, most supermarkets also sell things that might not have an expiry date, e.g. toothbrushes and bin bags, so the stock of these articles will not be part of the data used in the model.

### 2.2 Cloud Layer

The data from the supermarket edge is sent to the cloud to be stored in a database, further processed and entered into the machine learning model, to then be able to be sent to the volunteers on the other edge of the system. From the data gathered from the edge layer, a few new variables are generated. For each food category, the days before a product is sold, days between in-stocks, and donation rate per in-stock is calculated. These variables are then added to the database to get the average and standard deviation. The average and standard deviation are also calculated for quantity sold per day, quantity in-stocked per day and amount donated per day (Table 1).

**Table 1.** Variables involved in food use optimisation calculations and formulas used to obtain them

| Variable | Formula |
|---|---|
| Days_before_being_sold | sold_date - in_stock_date |
| Days_between_in_stock | recent_in_stock_date - previous_in_stock_date |
| Donation_rate_per_in_stocked | quantity_donated / quantity_in_stocked |

These variables are then used for machine learning. The goal of the machine learning is to be able to determine the amount of products of a certain type of food that is going to be donated in the next couple of days (see Fig. 2). Since the process of delivering the food from the supermarket to the food banks is very time sensitive, being able to know in advance when there will be a donation and in what amount is essential to be able to get as much use of the expired products as possible before they turn bad. To do this estimation machine learning models (e.g. Linear Regression, Decision Tree Regression, Support Vector Regression) will be used to predict a donation amount for each product type, for each day, at each supermarket. The model will be trained with historical data about the supermarkets' donations. This will make it possible for the provider to in advance get the prediction of the type and amount of products that are going to be up for donation. The volunteer gets a notification about this so they can plan in advance and the provider later on has to confirm what products they are actually going to donate.

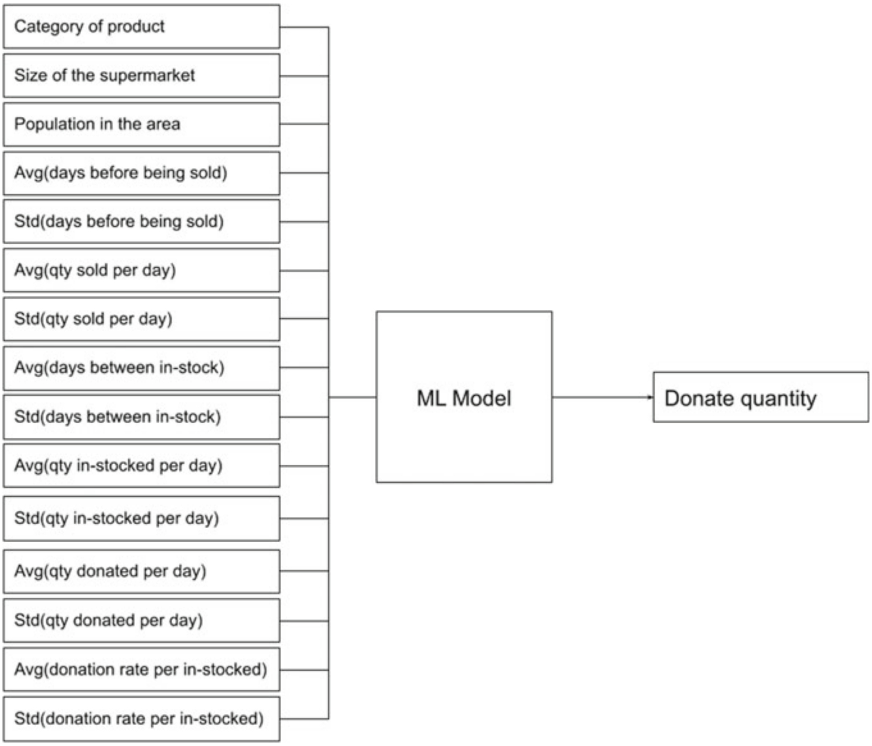


**Fig. 2.** Variables from the selling history, in-stock history and the information of the product and supermarket are then used to train the machine learning model to predict the donation quantity

## 2.3 Fog Layer

As mentioned before, the process of food donation is very time sensitive and it is therefore necessary that the volunteer is located within a reasonable distance from the supermarket in order to be able to pick up the food in time. This is kept track off by the fog layer that connects the volunteers primarily to the supermarket in their location. The supermarkets located in long-distance, or other cities, are not relevant to the volunteer, only the ones at a reasonable distance. A minimum distance between donors and recipients must be considered to avoid compromising situations. Likewise, there is a maximum distance between donors and recipients to optimise delivery. Consequently, distances will be one of the aspects of planning that are taken into account and can be improved in future extensions. It is also the fog layer that provides the volunteer with information about the exact location of the supermarket and the times that the supermarket has entered that they are available for donations pick-ups.

## 3 Experiment and Results

In this study, the proposed framework will be tested on a basic level through a simulated scenario. In the following subsections, the experiments will be described together with a presentation of the results.

### 3.1 Data Acquisition

Our objective is to optimise the use of food and reduce food waste in supermarkets. We propose to predict the number of products of a specific category that is expiring in two days that will be donated. Knowing if there will be food for donation in advance, the volunteers can prepare to get and deliver the food to the food bank before expiring.

The supermarkets are private companies, so getting any data from them can be difficult, and there are no open data sources available that contain the information we need to train and test the model. Therefore simulated data will be generated to work as the data source instead. The data will be created in a spreadsheet using Python to be able to generate data randomly and quickly. Even though a randomly created data set is not representative of a real-world scenario, it is still sufficient for a first test of the model.

The data for the simulation consisted of five randomly generated supermarkets that each have data tracked for 5000 randomly generated products. The product could either be of the category "Fruit", "Meat", "Bread", or "Dairy" and have an in-stock date between 2022-03-15 and 2022-04-15. The date when the product gets sold was randomised to be 0–20 days after getting in stock, and the variable is_sold (either 0 or 1) determined whether the sold date is used or not (if 0, the product is considered donated, and the sold date is not used). The product is also randomly assigned an expiring date ranging from 2 to 20 days from the in-stock date (Fig. 3).

### 3.2 System Simulation

A program was built using Python to simulate the cloud layer to first process the data and then test the machine learning and prediction. After calculating the averages and standard deviations the data set looked as Fig. 4. 10% of the initial randomly generated data has been used for training, with the remainder used for validation. As this study is in the model validation phase, cross-validation has not been carried out, which is one of the aspects to be addressed in future experiments.

Four methods were tested for the machine learning [11]: Support Vector Regression, Linear Regression, Gradient Boosting Regressor and Random Forest Regressor. Each of these was trained and tested on their ability to predict the number of products donated daily. The models were created using the Scikit-learn Python module.

| | supermarket_size | population | id | qty | category | instock_date | is_sold | sold_date |
|---|---|---|---|---|---|---|---|---|
| **0** | Small | 189 | 0 | 1 | Dairy | 2022-03-30 | 0 | 2022-04-17 |
| **1** | Small | 189 | 1 | 1 | Bread | 2022-03-18 | 0 | 2022-03-28 |
| **2** | Small | 189 | 2 | 1 | Fruit | 2022-04-10 | 1 | 2022-04-25 |
| **3** | Small | 189 | 3 | 1 | Fruit | 2022-03-27 | 0 | 2022-04-12 |
| **4** | Small | 189 | 4 | 1 | Fruit | 2022-03-26 | 0 | 2022-04-11 |
| **...** | ... | ... | ... | ... | ... | ... | ... | ... |
| **24995** | Medium | 345 | 24995 | 1 | Fruit | 2022-03-16 | 0 | 2022-03-31 |
| **24996** | Medium | 345 | 24996 | 1 | Bread | 2022-03-19 | 1 | 2022-03-23 |
| **24997** | Medium | 345 | 24997 | 1 | Bread | 2022-04-03 | 1 | 2022-04-16 |
| **24998** | Medium | 345 | 24998 | 1 | Meat | 2022-03-24 | 1 | 2022-04-02 |
| **24999** | Medium | 345 | 24999 | 1 | Fruit | 2022-03-24 | 0 | 2022-04-06 |

**Fig. 3.** Example of the result after simulate the information of the supermarket and product, selling history and in-stock history to get the data set

| size | population | date | sold_qty | donated_qty | avg_days_before_sold | std_days_before_sold | avg_qty_sold | std_qty_sold | avg_qty_instock | std_qty_instock | avg_qty_ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 189 | 2022-05-03 | 3 | 1 | 10.640602 | 5.025703 | 15.113636 | 7.662096 | 40.419355 | 5.445329 | 12 |
| 1 | 189 | 2022-05-02 | 0 | 2 | 10.640602 | 5.025703 | 15.113636 | 7.662096 | 40.354839 | 5.565060 | 12 |
| 1 | 189 | 2022-05-01 | 1 | 2 | 10.628012 | 5.018986 | 15.441860 | 7.433202 | 40.258065 | 5.603378 | 12 |
| 1 | 189 | 2022-04-30 | 4 | 7 | 10.586364 | 5.004714 | 15.714286 | 7.302808 | 39.903226 | 6.018609 | 13 |
| 1 | 189 | 2022-04-29 | 10 | 4 | 10.484615 | 4.972086 | 15.853659 | 7.336760 | 39.451613 | 6.179745 | 13 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| 2 | 345 | 2022-03-24 | 11 | 4 | 4.133333 | 1.795268 | 5.000000 | 3.741657 | 9.000000 | 4.654747 | 5 |
| 2 | 345 | 2022-03-23 | 9 | 6 | 3.761905 | 1.261141 | 4.200000 | 3.563706 | 8.000000 | 4.000000 | 5 |
| 2 | 345 | 2022-03-22 | 5 | 10 | 3.437500 | 0.963933 | 4.000000 | 4.082483 | 6.600000 | 2.190890 | 4 |
| 2 | 345 | 2022-03-21 | 10 | 8 | 4.166667 | 0.752773 | 2.000000 | 1.000000 | 3.750000 | 3.095696 | 3 |
| 2 | 345 | 2022-03-20 | 3 | 4 | 3.666667 | 0.577350 | 1.500000 | 0.707107 | 4.000000 | 1.414214 | 2 |

**Fig. 4.** Example of the result after calculate the data from the simulated data set to get the variables for the machine learning model

### 3.3 Results

We use the Coefficient of Determination (R-squared) as the score of our prediction result [3]. R-squared is calculated by the sum of the squared prediction error divided by the total sum of the square, which replaces the calculated prediction with the mean. The R-squared value is between 0 and 1, and a more significant value indicates a better fit between prediction and actual value. As shown in Table 2, four regression models have the R-squared score of around 70%. However, Support Vector Regression gets the best result with 73.2% in R-squared.

**Table 2.** Results

| Model | Score |
|---|---|
| Support vector regression | 0.732 |
| Linear regression | 0.725 |
| Gradient boosting regressor | 0.719 |
| Random forest regressor | 0.708 |

In Fig. 5, the scatter point is the actual donation amount, and the linear line is the predicted donation amount. As we can see from the figure, the prediction result is quite close to the actual result. This means that with the machine learning model, we can get quite precisely predicted amounts that can be donated to the food bank. With the predicted donation amount, the volunteer can plan to deliver the food so that we can reduce the food waste problem from the supermarkets.

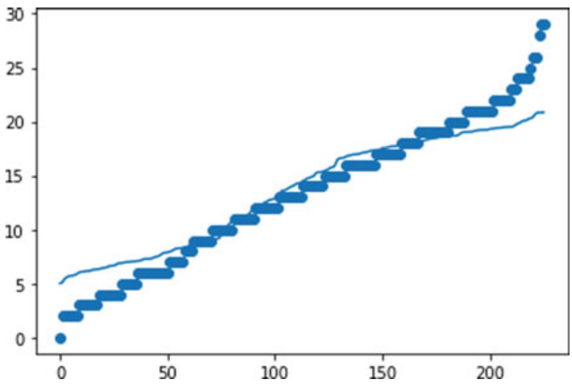


**Fig. 5.** The actual donation amount and the predicted donation amount are pretty close, which means the machine learning model can be an excellent method to predict the donation amount of the supermarket

## 4 Conclusion and Future Work

This paper proposes a framework that would facilitate the vital work of the people volunteering to deliver expired food from supermarkets to food banks to reduce food waste. The process is very time sensitive since the food has to be delivered to the food bank before it goes wrong, so by predicting how much food will be donated and where the volunteers will be able to plan the process better. With the experiment using simulated data, the paper shows that a system like this is possible to build and would generate valuable results, especially using the support vector regression, giving a score of 0.732. However, the problems of implementing a system like this lie in data acquisition, which this paper has not covered. Getting data from private companies can be difficult, but as the cities are becoming more innovative and intelligent, this probably won't be a problem shortly. This paper has focused mainly on the cloud layer of the system, but future research should look deeper into the edges both on the supermarket's and volunteer's side.

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# Validation of Double Wall Reactor for Direct Biogas Upgrading via Catalytic Methanation

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**Abstract.** Actively cooled fixed bed reactors for catalytic methanation provide the opportunity for stable operation as temperature hotspots and thermal runaways occur in existing multi-stage fixed bed set-ups in commercial scale. This short paper reports on the experimental investigation of three cooled double wall reactors for direct biogas upgrading via catalytic methanation. The inner diameter (14, 18 and 27.3 mm) of the reactors has been significantly reduced to evaluate the improvement of the thermal management. The reactors have been tested in an existing pilot plant under varying operation parameters such as pressure and gas hourly space velocities (GHSV). As validation parameters, the $CO_2$ conversion rate and the measured temperature profile in the catalyst bed are considered. The thinnest reactor with an inner diameter of 14 mm performs best regarding the $CO_2$ conversion rate at all operating points, and the $CO_2$ conversion ranges between 99.7 and 97.6% at GHSV of 4,000 and 20,000 $h^{-1}$, respectively. Also, the maximum catalyst temperature of 510 °C is not exceeded at high catalyst loads (15,000 and 20,000 $h^{-1}$) to ensure long stability and activity of the catalyst. In comparison, in a reactor with an inner diameter of 27.3 mm far lower conversion rates (98.5% and 88.5% at 4,000 and 20,000 $h^{-1}$, respectively) can be achieved in one reactor stage while the maximum measured temperature in the catalyst bed lies around 600 °C. The most favorable reactor design for biogas upgrading at high catalyst loads corresponds to the reactor with the thinnest inner diameter. Beside well performing, a thin cooled reactor is characterized with a reduced system complexity and low investment costs. Furthermore, an easy scale up is possible while ensuring simplified operation.

**Keywords:** CCU · Heat management · Power-to-Methane

## 1 Introduction

Power to gas (PtG) processes enable the transformation of electrical into storable chemical energy. A water electrolysis and a subsequent catalytic methanation of carbon rich gases (e.g. biogas or industrial off-gases) fed with renewable energy produce green synthetic natural gas (SNG) [1, 2]. For catalytic methanation different reactor set-ups are available which need to ensure stable operating performance. PtG plant layouts with multi staged fixed bed reactors are an established concept that is already realized in


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demonstration and commercial scale (e.g. Lurgi [3], TREMP [4]). Also dynamic operation of adiabatic fixed bed reactors with intermediate cooling and gas recirculation has been evaluated in commercial plants by Rönsch [5] whereas heat management remains challenging due to thermal runaways. Even cooled reactor systems for enhanced methanation performance are designed by e.g. Linde but have never been brought to commercial scale [6]. Only scarce and little information about the thermal management of methanation reactors is available. Lefebvre et al. models the performance of a cooled tube bundle reactor at steady state operation as this set up facilitates higher catalyst loads as e.g. slurry bubble column reactors [7]. The challenge of operating fixed bed reactors for methanation consists in heat management as temperature hot spots and high gas output temperatures thermodynamically limit full conversion of $CO_2$ from the feed gas and load flexibility is little or not given [8].

## 2 Objectives

The central purpose of this work is an experimental performance validation of double wall reactors for direct biogas upgrading via catalytic methanation. Three different reactors are featured with a reduced inner diameter (14, 18 and 27.3 mm) and are equipped with an active cooling in the outer tube. Experimental test runs are conducted with commercial bulk catalyst, varying inlet gas flow rates and at different pressure levels. Higher turbulences are expected with higher gas flows resulting in enhanced heat and mass transfer for better thermal management of the exothermic reaction. Evaluation criteria comprise the achieved $CO_2$ conversion rate after one reactor stage and the measured temperature profile in the reactor. The results of the experimental test runs serve as a basis for further up-scale to an industrial tube-bundle methanation reactor.

## 3 Methods

In Fig. 1 a schematic design of the reactor is shown. In Table 1 the different dimensions of each reactor (inner and outer pipe dimensions and the resulting annular gap) are depicted.

For all three reactors, the reactor total length is 980 mm whereas the tempered zone for cooling measures 700 mm. The thermal fluid in- and outlet are positioned at the start and end of the attached welded outer pipe. In each reactor set-up, a gas pre-heating zone of around 100 mm has been realized before the catalyst zone in every reactor set-up.

The cooled reactors have been implemented in the existing pilot plant for catalytic methanation at the Chair of Process Technology and Environmental Protection at Montanuniversität Leoben. The peripheral plant components as the gas dosing station, product gas conditioning and safety equipment (gas detectors and torch) are available from further plant set-ups. More details of the experimental set-up can be found in the publication of Krammer et al. [9].

Each cooled reactor is equipped with eight thermocouples to display the axial temperature profile inside the catalyst bed. As an example, the set-up of the reactor Nr. 1 is shown in Fig. 2 with a height von 600 mm of catalyst. As the gas enters the reactor from the bottom, two thermocouples indicate the temperature in the gas pre-heating zone

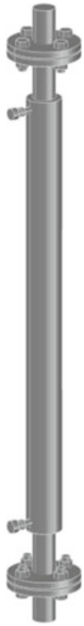

**Fig. 1** Schematic illustration of the double tube reactor with the in- and outlet fittings for the thermal fluid

**Table 1** Dimensions of active cooled reactors in mm

| All in mm | Nr. 1 | Nr. 2 | Nr. 3 |
|---|---|---|---|
| Dimensions outer pipe | 25 × 1 | 32 × 2 | 48.3 × 3.2 |
| Dimensions inner pipe | 18 × 2 | 22 × 2 | 33.7 × 3.2 |
| Inner diameter $d_i$ | 14 | 18 | 27.3 |
| Annular gap a | 2.5 | 3 | 4.1 |

which is filled with inert stoneware balls (1/8″). Also, one thermocouple measures the gas output temperature after the catalyst bed. The catalyst volume is increased stepwise from reactor Nr. 1 to Nr. 3 in each case by roughly 37%. The gas hourly space velocity (GHSV in $h^{-1}$) represents the catalyst load and is calculated by the standard input volume flow divided by the catalyst volume. It is also known as the reciprocal value of the residence time which has a strong impact on reaction kinetics and achieved conversion rates. For all three reactors the same range of GHSV has been tested and in every set-up commercial bulk catalyst with an average particle size of 3.5 mm and nickel as the catalytically active material. The catalyst volume for each reactor is as follows: 0.09236 L (Nr. 1), 0.12723 L (Nr. 2) and 0.1756 L (Nr. 3) that corresponds to a height of 600 mm, 500 mm and 300 mm of catalyst, respectively to the reactor types.

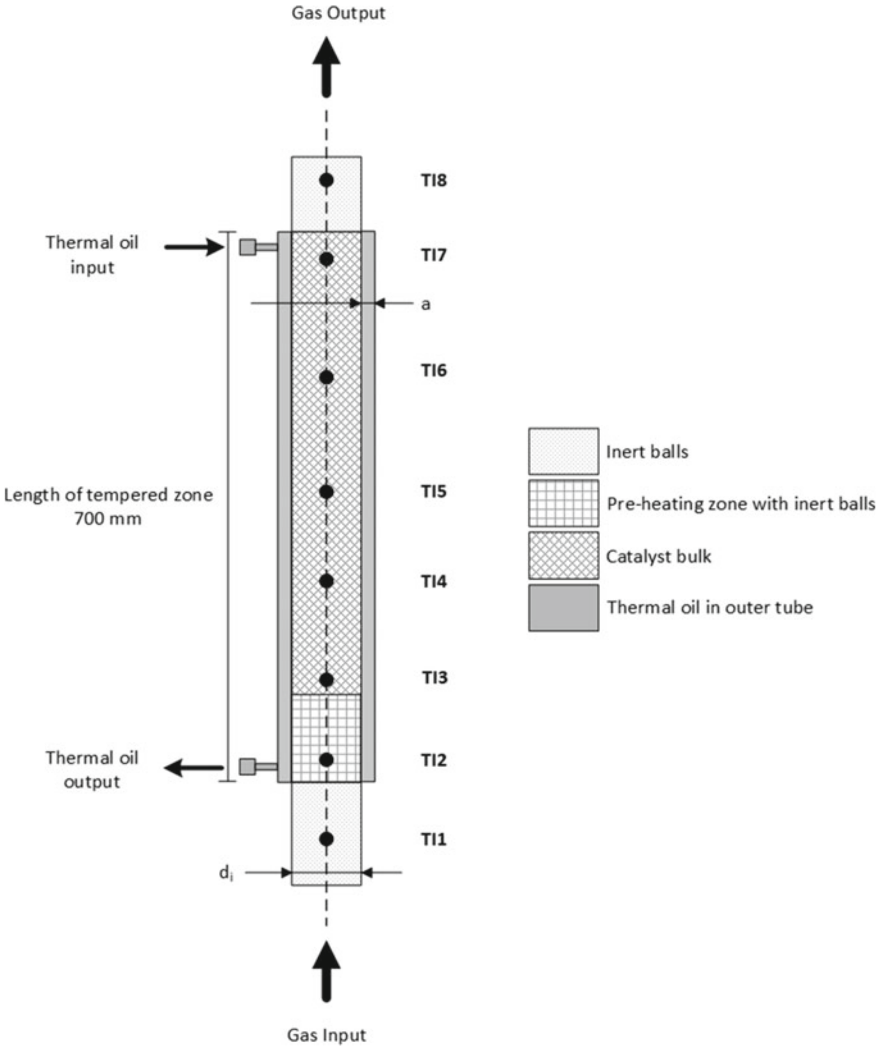


**Fig. 2** Schematic drawing of reactor Nr. 1 with di = 14 mm and 600 mm of catalyst height including a multi thermocouple inside the reactor ($d_i$, a and height of catalyst are varying for each reactor type)

Due to the strongly exothermic character of the methanation reaction (1), the reactor is cooled in the outer tube by a thermal oil and its cooling temperature is set to 320 °C.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad \left(\Delta H_R = -176.4\ \text{kJ mol}^{-1}\right)$$

As an input, a typical biogas mixture with a composition of 52 vol.% $CH_4$ and 48 vol.% $CO_2$ is fed with an over-stochiometric hydrogen feed (4% above methanation stoichiometry). The methanation performance has been validated in each reactor with the same feed gas mixture at different pressure levels (4, 6, 8 and 10 bar) and gas hourly space velocities (4,000, 6,000, 8,000, 10,000, 12,000, 15,000 and 20,000 $h^{-1}$).

## 4 Results

The following beam diagram clustered by gas hourly space velocity and different reactor dimensions shows $CO_2$ conversion rates exemplary at 8 bar operating pressure (see Fig. 3).

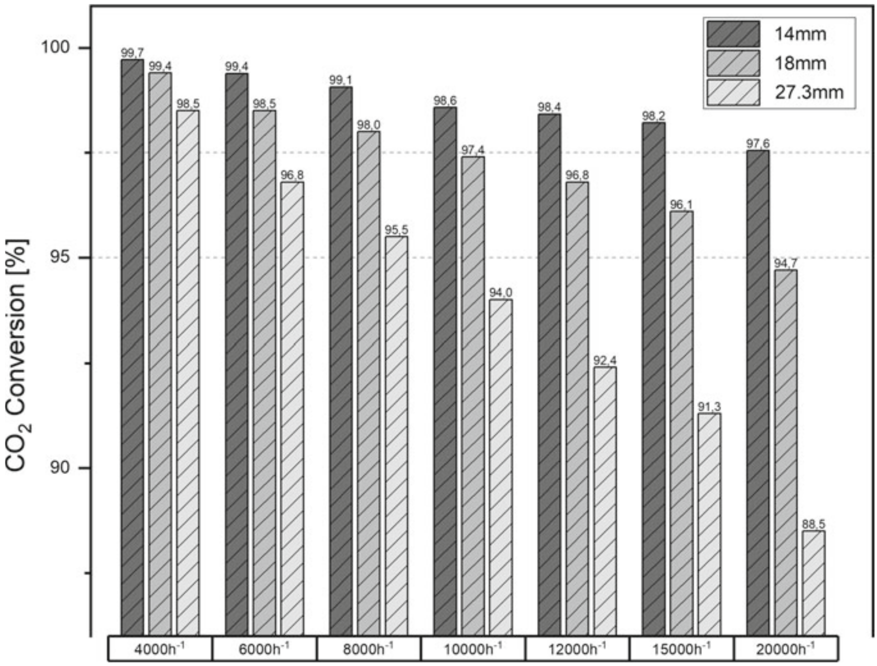


**Fig. 3** $CO_2$ conversion rates of biogas methanation with 4% hydrogen surplus at 8 bar for all three cooled reactor set-ups at different catalyst loads

In general, the trend shows the higher the catalyst load the lower the $CO_2$ conversion rate though it satisfyingly never falls below 88%. There is a significant difference in conversion rate between the three different reactor layouts. The highest $CO_2$ conversion rates are reached in reactor Nr. 1 with 14 mm inner diameter between 97.6 and 99.7%. Reactor Nr. 2 achieves slightly lower conversion rates at each operating point which lie between 94.7 and 98.5%. Reactor Nr. 3 with the widest inner diameter of 27.3 mm can only keep up with the thinner reactors at a very low catalyst load (4,000 $h^{-1}$) while achieving a conversion rate above 98%. At all other operating points, the gap between the conversion rates of the thinner reactors and reactor Nr. 3 lies between roughly 4 (at 10,000 $h^{-1}$) or even 10% (at 20,000 $h^{-1}$). The lowest conversion rate with 88.5% is reached in reactor Nr. 3 at 20,000 $h^{-1}$.

In Fig. 4, the highest measured temperature peaks at all operating points (4,000 to 20,000 $h^{-1}$) are marked for reactor Nr. 1 (as circles), Nr. 2 (as triangles) and Nr. 3 (as squares). The grey shaded area in the background of the graph indicates the maximum tolerable catalyst temperature (510 °C) to ensure stability and long activity.

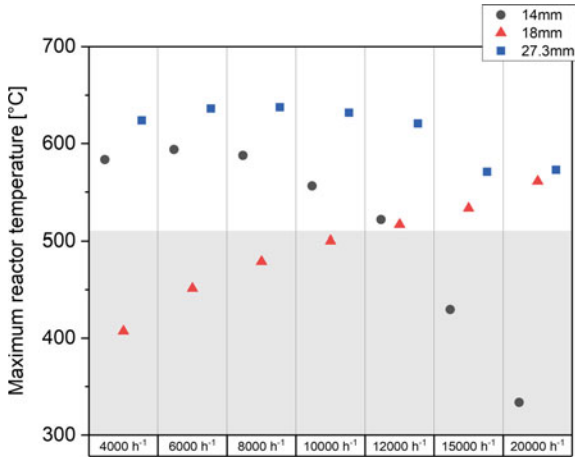


**Fig. 4** Highest measured temperature peaks at biogas methanation at 8 bar in all three cooled reactor layouts

In reactor Nr. 3 with 27.3 mm inner diameter (squared markers) heat accumulates in the catalyst bulk and leads to high temperatures between 580 and 630 °C at all operating points. The intra bed heat transfer is limited even tough high turbulences are present for intended heat removal from the bulk. In reactor Nr. 2 (triangled markers) with 18 mm inner diameter, high temperatures above 510 °C can be avoided at catalyst loads below 10,000 $h^{-1}$. At higher catalyst loads, the maximum reactor temperature rises to around 580 °C. Reactor Nr. 1 shows high temperatures (above 510 °C) at low catalyst loads but at 15,000 $h^{-1}$ and 20,000 $h^{-1}$ the maximum temperature is measured at 420 and 388 °C, respectively.

## 5 Discussion

Although the reactor inner diameter has been significantly reduced in comparison to former set-ups (inner diameter of 80 mm [9]) in the pilot plant for catalytic methanation at the Chair of Process Technology the inlet gas flow rate and GHSV can be increased to a fivefold (from 4000 to 20,000 $h^{-1}$) while $CO_2$ conversion rates can be kept above 90% for reactor Nr. 1 and Nr. 2 in a single reactor stage.

For industrial scale $CO_2$ upgrading plants that enable decarbonization of industry in the future, high amounts of gas (especially $CO_2$) need to be captured and converted to green fuels as synthetic natural gas. In adiabatic fixed bed reactors GHSV values from 2,000 to 5,000 $h^{-1}$ have been tested in technical plants until now [10]. Hence high catalyst loads have been successfully tested in different reactor layouts although the residence time has been strongly reduced. The set ups Nr. 1 and Nr. 2 are not kinetically limited as especially high conversion rates can be achieved at high gas loads. The maximum acceptable catalyst temperature has been far exceeded at some operating points (especially at low catalyst loads). The most favorable reactor design for biogas upgrading at high catalyst loads corresponds to reactor Nr. 1 with 14 mm inner diameter with maximum measured reactor temperatures below 400 °C. The reduced diameter to 14 mm enhances heat transfer from the thermal fluid to the catalyst bed and turbulences from very high inlet gas flows contribute to the cooling effect. Beside well performing, a thin cooled reactor is characterized with a reduced system complexity and low investment costs. Furthermore, an easy scale up is possible while ensuring simplified operation. As a future step, the optimal cooling temperature will be investigated for each reactor layout. The aim of this effort is to meet the quality requirements for injection into the Austrian natural gas grid [11] with a methane share of higher 90 mol.% at best with one single reactor stage. The experimental results will be compared to modeled results from Matlab and CFD simulations.

## 6 Conclusion

Fixed bed reactors for catalytic methanation are characterized by challenging heat management. Especially in industrial scale applications stable operation without thermal runaway needs to be ensured. Three different cooled double wall reactor set-ups with an inner diameter of 14, 18 and 27.3 mm have been tested in a methanation pilot plant at Montanuniversität Leoben under varying operation parameters such as pressure level and catalyst load. As feed, a typical biogas mixture with a hydrogen surplus of 4% to stoichiometry has been used. The $CO_2$ conversion rate and the measured temperature profile in the catalyst bed describe the evaluation parameters. The highest $CO_2$ conversion rates can be achieved in the thinnest reactor with an inner diameter of 14 mm. At all catalyst loads, from 4,000 to 20,000 $h^{-1}$, the conversion rate is between 99.7 and 97.6%. Moreover, at high gas hourly space velocities, such as 15,000 and 20,000 $h^{-1}$, the maximum measured temperature in the reactor is below 510 °C which is specified as the maximum acceptable catalyst temperature during operation. The reactor set-up with an inner diameter of 18 mm achieves slightly lower conversion rates between 99.4 and 94.7% from 4,000 to 20,000 $h^{-1}$. As the low conversion rate of 94.7% indicates, high gas temperatures are measured with a maximum of nearly 550 °C at 20,000 $h^{-1}$ that thermodynamically limit the conversion rate due to high gas outlet temperatures. The reactor with 27.3 mm of inner diameter performs the poorest and shows far lower conversion rates with 98.5 and 88.5% at 4,000 and 20,000 $h^{-1}$, respectively. The maximum measured temperature in the bulk lies at all operating points and 8 bar pressure level slightly below or above 600 °C. As a result, the thinnest reactor with 14 mm describes the most suitable reactor design for direct biogas upgrading. It is also characterized by a reduced system complexity what also positively contributes for plant scale ups.

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# Circularity and Sustainability of Bio-Based Polymer/Natural Fiber Reinforced Composite

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**Abstract.** Amidst growing concerns about sustainability of composite materials, the renewed push towards adoption of bio-based polymer/natural fiber reinforced composites (Bio-composite) are gaining increasing demands for various applications which are being the environmental and eco-friendly alternative to synthetic composite materials. Hence, the bio based composite development should be integrated in the circular economy (CE) model to ensure a sustainable production that leads to the conception of closed loops in which resources are in the circulation of production and consumption. However, ironically, the environmental sustainability of composite materials itself is still a challenge, due to the difficulty of recycling and reusing its components when the products reach the end of their useful life. In this context, a holistic attainment of sustainability makes it imperative to adapt sustainable practices not only for raw materials but at every stage of the product. Hence, this work provides a detailed exploration of the appropriate processing of natural fiber reinforced bio-polymer composites and an insight on using recycled bio based composite constituents which could lead to a reduction in material waste and environmental footprints.

**Keywords:** Bio-based polymer · Circular economy · Liquid composite molding · Natural fiber reinforced composite · Sustainability

## 1 Introduction

A circular economy is an effective technology for the recycling and reuse that impact of resource consumption and waste on the environment. This led to the sustainable growth and creation of alternative closed loops in which resources are in the circulation of production and consumption. As the circular economy goes beyond the linear model based on the principle: extract-use-dispose model, to create circular systems that gain the maximum value by reducing and recirculating natural resources [1]. The circular economy advocates sustainable development, promoting the necessity to strike a balance between environmental and economic values. In this context of sustainable development, there is great potential for an increase in the demand for renewable and bio-based polymers and the focus on the use of natural fibers have offered opportunities to produce highly durable natural fibers reinforced composite into new products.


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Natural fiber reinforced composites are growing demand in the global sustainability and energy efficiency because as the result of biodegradability, excellent stiffness to weight ratio, low abrasion, low-cost composite with synthetic fibers such as glass or carbon fibers [2, 3] and environmental friendly reinforcement to produce sustainable composite for a wide range of applications of sports, automotive and building materials [4, 5]. This demand can be met by recycling of bio-based polymer and renewable resource as shown in Fig. 1 shows the recyclability for biocomposites.

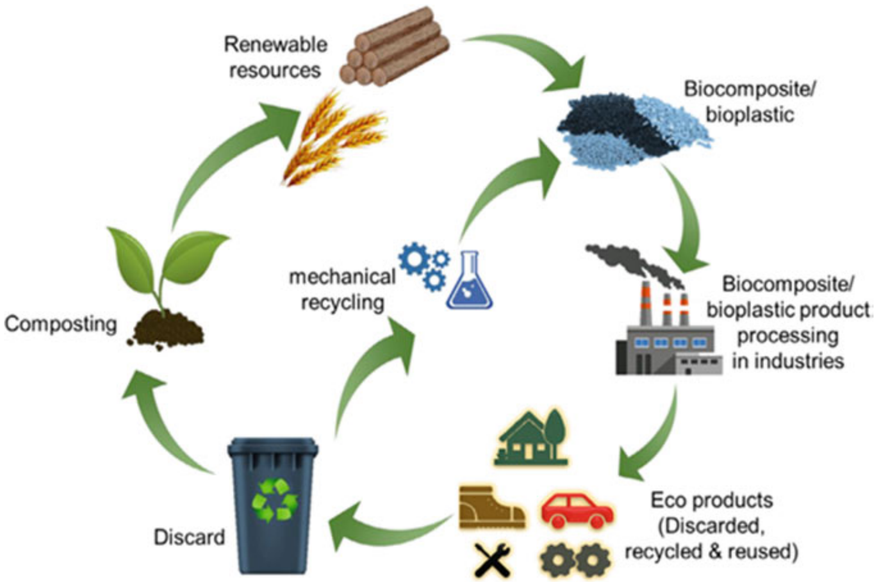



**Fig. 1** A flow diagram of recycling natural fiber composites toward a circular economy in which future manufacturing processes will be designed to minimize and remove waste from the system. Figure adapted from Ref. [6]

The increasing demand for the use of natural resources in biocomposites manufacturing exemplifies the need for a CE in biocomposites that also allows for their recycling and reuse [7]. Although the concept of CE is concerned with reducing the carbon footprint at every stage of a product's life cycle. Adaptation of the CE in biocomposites improves their recyclability, reusability and convert biocomposites waste into useful products, energy or secondary materials, which could lead to a reduction of carbon footprints and bio composites waste landfilling [8].

### 1.1 Objectives

In the transition toward circular economy practices it is important to have a complete understanding of the impact of recycling and reprocessing on material properties of Natural fiber as they are reused in subsequent product applications. Several research studies have been reported over the past decades. The aim of the present work is to elaborate on the suitable processing method for bio based natural fiber reinforced composite by Liquid composite molding (LCM) techniques and characterize the materials for determination of durability of the product. Furthermore, provided an overview on the use of recyclate constituent into sandwich composite laminate.

## 2 Materials and Methods

The material studied is based on the bio-based matrix system alternative to fossil based were supplied by bto-epoxy GmBH Amstetten, Austria. The matrix is Epinal b.poxy IR 78.31 with bio-based content of 37.58% and Epinal IH 77.11, a conventional fossil-based hardener. The reinforcement plies used for the composite laminate is a balance woven fabric made of flax fiber known as Amplitex 5042 from Bcomp Ltd, Fribourg, Switzerland. The flax fiber is a twill 4/4 weave with nominal area weight of 500 g/m$^2$ and fiber density of 1.47. The textile reinforcement was cut into 270 mm × 270 mm (length and width), the preform stack was composed of 6 layers of textile with nominal thickness of composite of 4 mm which has nearly fiber volume content of 48%. Since the natural fiber have tendency to absorb moisture, the preform are dried in the heating oven at 120 °C for 30 min. Bio based natural fiber reinforced composites were processed by vacuum assisted resin infusion (VARI) and resin transfer molding (RTM) (shown in Fig. 2a and b). Vacuum assisted resin infusion is the process in which composite is fabricated using a single sided rigid mold and vacuum bagging where vacuum pressure is applied. The schematic representation of VARI composite manufacturing is depicted in Figure 2a. Composite laminate were fabricated with nominal thickness of 4 mm using the dry virgin preforms composed of six plies were laid on the mold with distribution channel, which has been previously coated with a release agent. Release peel ply is placed over the preform, allowing easy separation from the vacuum bagging and resin distribution media is usually laid over the peel ply to enhance the speed of resin flow. Once the inlet and vent tubes are positioned, the mold is closed by the vacuum bag using the sealant tape (tacky tape). The vacuum bag provides consolidation of plies with the vacuum pressure applied to the vent where inlet is clamped. The mold tool temperature set at 60 °C and vacuum pressure of -1 bar is applied. Before infusion, the entire layup is subjected to the vacuum drop test by clamping the vent to check for leakage in the vacuum bagging. The resin hardener mixture of 100:25 (by weight) is degassed in a pressure pot under vacuum to reduce the air bubbles in the mixture. The degassed resin mixture is drawn into the perform by the differential pressure between the vent and the inlet (resin front). Once the preform is fully infused, inlet and vent are clamped, as the resin pressure gradients gradually dissipate and the pressure boundary conditions are maintained until the resin is cured for 180 mins. After the curing, the mold is cooled down to the room temperature and the composite laminate is demolded. Resin transfer molding is a closed mold process where the composite laminates are formed between rigid mold halves. The schematic representation of RTM composite manufacturing is depicted in Figure 2b. The mold carrier used for the RTM test series was a laboratory press, LZT-OK-80-SO from Langzauner (Lambrechten, Austria). Composite panel were fabricated using the dry virgin preforms composed of six plies were placed into the mold cavity. It should be noted that the thickness of the composite was defined by a mold cavity of 4mm. The mold is closed and temperature was held constant at 60 °C during the injection and curing. The resin mixture in a proportion of 100:25 (by weight) is injected at constant pressure of 6 bar and flows gradually into the mold. Once the resin was observed at outlet, the vent port was closed and cured under constant pressure condition for 180 min. After the curing, the mold tool temperature is cooled to room temperature and composite laminates is demolded. The natural fiber reinforced composite laminates were mechanically and physically characterized and evaluated for tensile properties and density measurements to emphasize on the processes for obtaining longer lasting products.

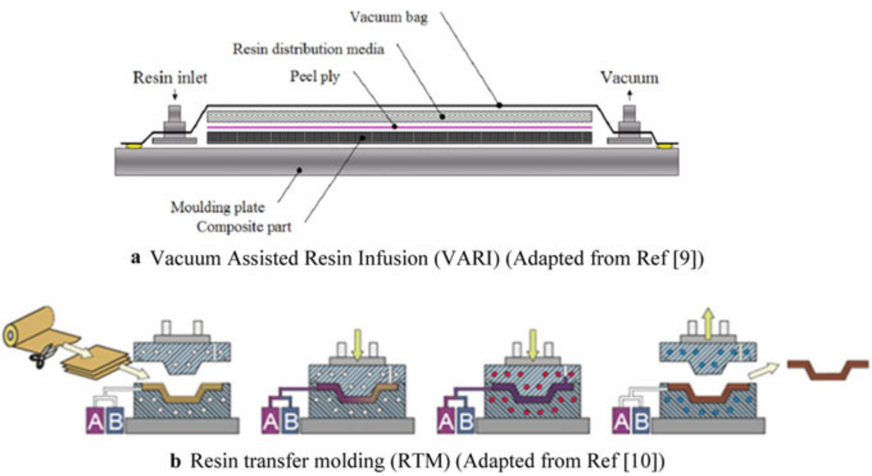



**Fig. 2** **a** Vacuum assisted resin infusion (VARI). Adapted from Ref. [9]. **b** Resin transfer molding (RTM). Adapted from Ref. [10]

The specimens for tensile test were prepared according to the standard DIN EN ISO 527–4. The samples were prepared according to specimens type 2 with dimension of 250x25x4 mm with gage length of 150 mm. Glass fibre reinforced composites were used as end tabs. The experiments were performed using Z250, Zwick Roell universal testing machine (Zwick GmbH and Co., Ulm, Germany) equipped with a load cell of 20 kN and test speed of 2 mm/min. With the guidance of an extensometer, the experimental data were collected and processed automatically using testXpert III software (Zwick GmbH and Co., Ulm, Germany). Tensile characteristic was investigated on five specimens of each configuration of composite panel. Density of composite panels were measured by using the Archimedes principle of immersion method according to the standard DIN EN ISO 1183 [11]. Distilled water is used as medium of liquid for the density calibration and the specimens are prepared according to the system specifications. The specimen dimensions are 25 x 25 mm and the samples should "preferably have a mass of at least 1 g. An analytical balance, AG204 Mettler Toledo (Columbus, Ohio, United States) is used for calibration. The densities are measured for at least five specimens per composite panels for in order to get statistically relevant results.

## 3 Results and Discussion

In this study, the tensile modulus and strength obtained for the bio-based natural fiber reinforced composite laminates are significantly higher in the RTM process than the vacuum infusion process. Figure 3a shows the graph of tensile modulus and strength of bio based natural fiber reinforced composite processed by RTM and VARI method. Result shows that due to lower compaction behavior of the preform, the fiber content in VARI method is varied than RTM method. Table 1 shows the tensile properties, where there is small drop in strength by 7.8% (from 141.84 to 131.14 MPa), modulus by 43% (from 19.53 to 12.52 GPa) between the plates processed by RTM and VARI. However, the composite processed by VARI shows increased strain by 29% than the composite processed by RTM.

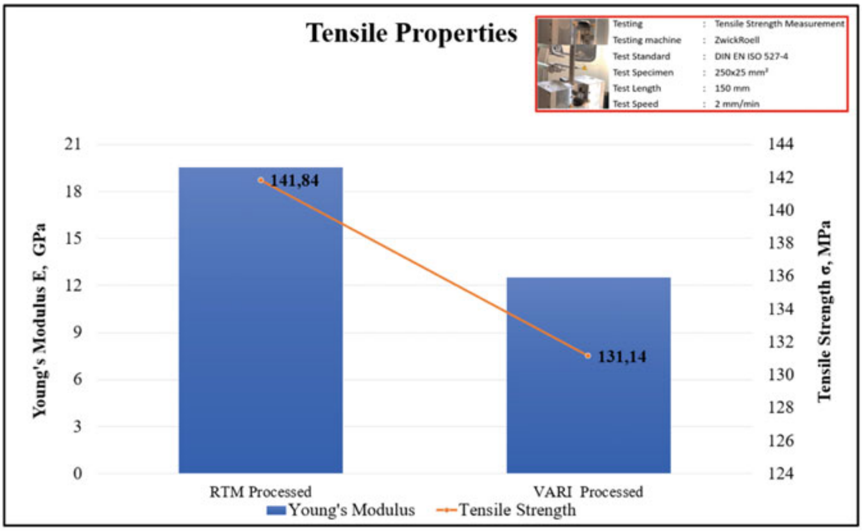
Density is also required to be known for estimating composite weight and evaluate fiber content as well as void content for property predictions. Figure 3b shows the density measurement of composite laminates processed by VARI and RTM method, as the result shows the density properties are significantly scattered over the plates manufactured. However, the average density values in RTM processed laminates have improved density value than the VARI processed, because of the better compaction and packaging of flax fiber that enhance fiber volume content in RTM method. Figure 3b shows the graph of density measurement, where there is a drop-in density measurement by 3.45% (from 1.292 to 1.251 g/cm$^3$) within processes RTM and VARI method.

The composite laminates are analyzed in terms of their physical and mechanical properties to judge their endurance, as the properties are strongly dependent on the processing route. Nevertheless, the properties of flax/bio-based polymer composite laminates have been shown to be very promising in RTM process when compared with VARI process.

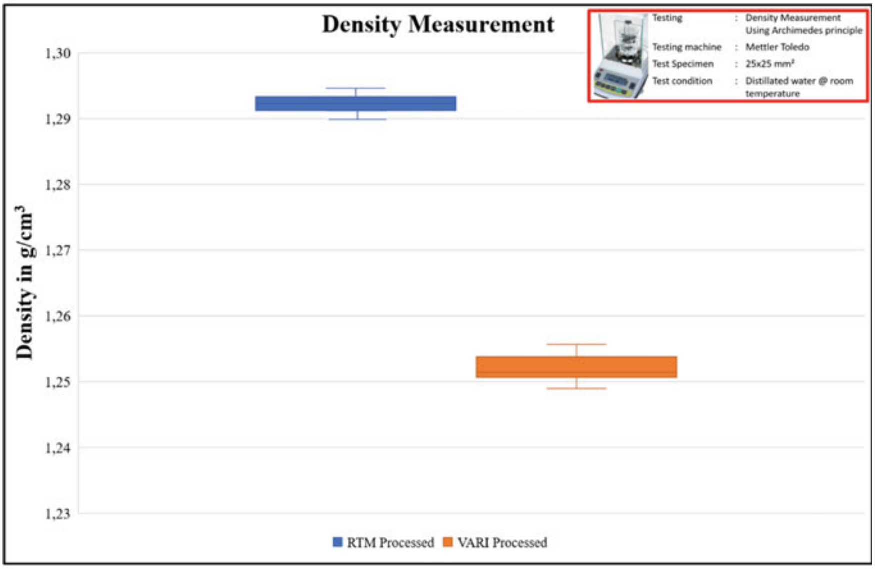
## 4 Conclusion and Future Outlook

In this paper, we have provided an overview of the most promising processing technique of bio-based polymer natural fiber reinforced composite using appropriate liquid composite molding (LCM). It was observed that the laminates have higher tensile strength/modulus and greater density measurement in RTM process than VARI process, but this difference is due to the compaction behavior of the fabric. However, we found that besides suitable processing methods, the mechanical properties and physical properties are interesting to judge the durability and longevity of products.

To ensure a sustainable production that leads to the conception of closed loops in which resources are in the circulation of production and consumption, the recycled natural fiber composites are utilized. The surplus natural fiber composite are mechanically recycled where the process is distinguished in three main steps, shredding, milling and classifying and shred composite waste into small particles (fibrous and resin rich powder), which is known as recyclates. The shredding process make the laminates into coarsely small fragment. Depending on the particle size and fiber quality, the recyclates can be used either as reinforcing materials or as matrix fillers in new product [11, 12]. The composite waste was shredded by DWZ shredder and the shredded samples are




**a**




**b**

**Fig. 3** **a** Tensile properties natural fiber reinforced composite processed by RTM and VARI. **b** Density measurement of natural fiber reinforced composite processed by RTM and VARI

immersed in liquid nitrogen to maintain a low temperature during milling in universal cutting mill pulverisette 19.

**Table 1** Tensile properties of bio-based/natural fiber composite processed RTM and VARI

| Process | Tensile strength $\sigma$ (MPa) | Young's modulus $E$ (GPa) | Ultimate strain $\varepsilon$ (%) |
|---|---|---|---|
| RTM | 141.84 | 19.53 | 0.94 |
| VARI | 131.14 | 12.52 | 1.26 |

The samples were cut in different sieve sizes of 4 mm and 10 mm (see in Fig. 4). In the context of developing the circularity concept to reduce the risk of downcycling, the mechanical recyclates can be used as a filler between the raw materials into sandwich laminate as represented in Fig. 5 which results in potential semi structural application. The sandwich natural fiber composite is processed using liquid composite molding (LCM) method for different recyclate particle size.

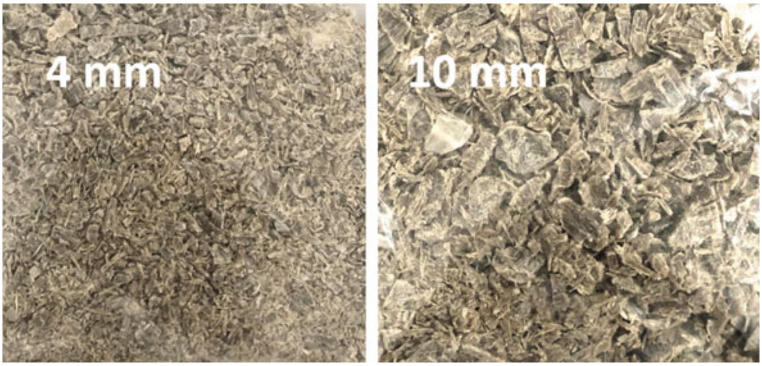



**Fig. 4** Recyclate particles (4 mm and 10 mm)

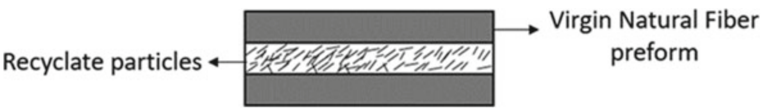



**Fig. 5** Sandwich bio-based/natural fiber composite

These studies have focused only on processing the bio-based polymer natural fiber reinforced composite using appropriate liquid composite molding (LCM) technique. In contrast to this, this study looks at the wider picture and desired to expands on the processing of recycled sandwich bio-based/natural fiber composite leads to the conception of closed loops in which resources are in the circulation. To summarize, the bio-based polymer/natural fiber composite ensures reducing the ecological footprints and maintain sustainability as well as leads in potential improvement of semi structural applications.

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# Wireless Industrial Access Control Systems for Autonomous Transportation

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**Abstract.** The digitization of industrial assets enables automation, generating added value to manufacturing processes. Digitalization is exemplified by the use of Wireless Sensor Networks (WSN) to monitor mobile robots and personnel in the industrial plant. Based on this infrastructure, the authors propose a novel access control system without the need to interact with any equipment. Hence, the implementation costs are reduced because the same Cyber-Physical Systems (CPS) technologies are reused, preventing the implementation of complementary equipment for both operators and mobile robots. In addition, the security of the wireless protocols has been analyzed by proposing a robust and scalable solution. Therefore, the accessibility to restricted areas is improved by reducing the authentication time compared to other technologies, especially for mobile robots.

**Keywords:** Autonomous mobile robots (AMR) · Bluetooth low energy (BLE) · Cyber-physical systems (CPS) · Industry 4.0 · Industrial Internet of Things (IIoT)

## 1 Introduction

The industry is immersed in a digital transformation where information and communication technologies are combined in order to generate higher added value. This new transformation, known as Industry 4.0 [1], is based on the digitization of assets in order to achieve more efficient, autonomous, and sustainable production. To achieve this, data is required, which is obtained by the CPS [2] according to the philosophy of the Industrial Internet of Things (IIoT) [3] which is critical for the connectivity of production processes.

The transport of materials and personnel in the manufacturing plant is an asset where data must be digitized as it is necessary for the optimization of the supply chain [4]. In this context of mobility, there may be restrictions on access to certain facilities due to various factors (e.g., security, regulations). For this reason, access control systems are used in industry and other sectors to manage the entry and exit of both vehicles and personnel into and out of certain areas [5].

However, industrial access control systems are based on technologies which are independent of CPS. This fact implies a greater complexity in the equipment, increasing


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its cost, as well as the implementation time. Moreover, most of the technologies used require physical interaction with the system, making it harder to integrate them into mobile robots [6]. In addition, all access control equipment requires data for decision-making either by human or expert systems.

In this context, digitalization of the process is sought through the use of CPS already existing in the industry in both humans and mobile robots in order to improve productivity. For instance, an example of digitization is wearable devices (e.g., smartwatches, augmented reality glasses, headphones) where the human is able to interact with the information in a more natural way. Autonomous mobile robots (AMR) which transport materials within the industrial plant according to the supply chain management are another application case [7].

Given this paradigm of digitization in the industrial plant, new access control systems can be developed that are compatible with the wireless technologies used in existing CPSs. In this way, no other complementary equipment will be required for the implementation of access control, thus achieving a collaborative industrial environment. Furthermore, with the implementation of this methodology, no new electronic equipment is required, thus reducing its use and its impact on the environment.

Therefore, the aim of this work is to adapt wireless CPS technologies to allow contactless access. In this way, the access accreditation time is reduced, improving the accessibility for both mobile robots and humans, which is a novelty in the scientific literature.

In addition, the use of wireless technologies allows us to know the room in which the equipment is located by creating a network of wireless sensors. In this sense, there are studies where the placement of beacons is optimized to maximize coverage [8, 9]. Therefore, this methodology also allows the monitoring of the approximate location of personnel, as well as key AMRs for organizational decision making.

The paper is organized as follows: In Sect. 2, the technologies used for access control in industries will be reviewed. Then in Sect. 3, the wireless technology used to achieve the stated objectives will be presented. Then in Sect. 4, the vulnerabilities of the technologies will be shown while in Sect. 5 proposals will be made to avoid the vulnerabilities. Section 6 shows the architecture demonstrator to reach the conclusions in Sect. 7.

## 2 State of Art

Access control in the industry applies different technologies depending on the needs of the processes or protocols. For this reason, the authors analyze in the scientific literature the different technologies used for access control in order to compare them with the proposed one [10, 11]. Table 1 below compares the technologies used to obtain data on the identification of mobile robots or people.

According to the information shown in Table 1, access control interaction is required for all technologies (i.e., swiping a card or device, looking into a camera, reading a fingerprint). Moreover, biometric systems are only supported by humans, thus requiring additional systems. In addition, RFID and Near Field Communication (NFC) contactless technology does not have sufficient range to identify mobile robots [12]. In addition, none of these technologies is usually incorporated in industrial equipment and these technologies must be implemented in a complementary way.

**Table 1** Comparison of the different methods used for access control in industrial environments

| Method | Type | Technology | Max range | Energy used | Reliability | Cost |
|---|---|---|---|---|---|---|
| Electronic card | Contactless | RFID | 5 cm (13.56 MHz) | Built-in battery | High | Low |
| Facial recognition | Biometrics | Camera/algorithms | 40 cm approx. | Power supply required | Dependence on conditions | High |
| Fingerprint recognition | Biometrics | Capacitance readers/algorithms | Contact required | Built-in battery | Dependence on conditions | Middle |
| Short-range wireless | Contactless | NFC | 20 cm | Built-in battery | High | Middle |

For this reason, an access system capable of identifying people and AMRs at a greater distance without the need to incorporate complementary systems is required. In this way, the number of devices is reduced, reducing the cost of implementation and improving accessibility. To this end, the authors propose the following technologies based on wireless communications.

## 3 BLE and Wi-Fi Technologies

Bluetooth Low Energy (BLE) and Wi-Fi technologies are widespread communication interfaces in industrial CPS and most wearables [13]. The Bluetooth standard works in the industrial, scientific, and medical (ISM) 2.4 GHz band using 40 channels of 2 MHz in order to avoid interference. On the other hand, the Wi-Fi standard, despite operating on the same frequency, has a longer range (i.e., tens of meters) due to its transmitting power, resulting in higher power consumption. In this context, BLE technology, having a shorter range than Wi-Fi (i.e., 2–3 m) as well as lower power consumption, is the most suitable for wireless access control systems.

Based on BLE standard specifications of the Generic Access Profile (GAP), devices have four roles: broadcaster, observer, central and peripheral [14]. Sender devices use the 3 advertisement channels to publish information in the broadcast format (i.e., multi-point) while observers within range are able to read it. However, this information is not encrypted so any device can listen to it making device authentication difficult. However, this methodology does not require a previous connection to be established, decreasing the response time of the system.

Another method is the establishment of a point-to-point encrypted connection to determine identity by sending a password or token. This requires a central device and a peripheral device which requires a pairing or prior connection. Once authenticated, the link is encrypted and long-term keys (LTK) are stored for a faster connection. For pairing the devices must negotiate a methodology for the generation of the temporary secret key (STK) with 3 main methods [15]:

- **Just work (JW)**: The STK is generated on both sides according to the packets exchanged. Nevertheless, this procedure is vulnerable to man-in-the-middle attack (MitM), which is a security vulnerability. However, since version 4.2 BLE has incorporated the Elliptic Curve Diffie-Hellman (ECDH) algorithm which is based on discrete logarithms [16]. As a result, it is simple for the partners to compute a symmetric password while for MiTM the computation of LTK is unfeasible computationally. LTK is stored in both in order to facilitate future connections.
- **Out Of Band (OOB)**: The devices use other protocols (e.g., Wi-Fi, NFC) in order to exchange the pairing and authentication password. Unfortunately, not all industrial devices have multiple communication interfaces.
- **Pass-keys**: One device generates a code which has to be manually entered into the other device by a user. Although this procedure is only performed on the first connection, not all industrial devices have to write and display interfaces.

Given the diversity of communication modalities, Fig. 1 shows an outline of the type of connections, as well as their vulnerabilities.

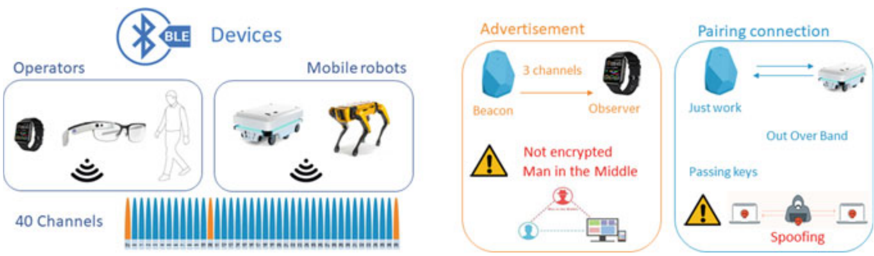


**Fig. 1** Diagram of BLE functionalities and vulnerabilities in industrial environments

## 4 Vulnerability Analysis

Based on the methodologies presented in Fig. 1, to achieve a secure communication channel without the need for the user or mobile robot interaction, the JW or OBB method is required. However, the connection does not involve user authentication but the creation of a secure channel that avoids MiTM. Moreover, the BLE stack provides the message authentication service but does not provide the device authentication service.

Furthermore, a recent study [17] alerts to security vulnerabilities in the authentication of equipment reconnection via LTK. For this purpose, the researchers developed the BLE spoofing attacks (BLESA) tool where they spoof other devices by violating the authenticity of the messages. In this context, a design vulnerability for reactive authentication and implementation issues for proactive authentication of messages were discovered. Therefore, this security gap is unacceptable in an access control system. Hence, the authors propose the following proposals.

## 5 Proposals

To solve the authentication of the devices it is necessary to create asymmetric keys (i.e., public and private) in order to certify the authentication of both devices (i.e., central and peripheral) preventing spoofing. In addition, this way, vulnerabilities to BLESA are resolved. However, this methodology needs to be developed in the application as the BLE protocol layers are not secure, which makes it difficult to integrate into CPSs.

Alternatively, every access point could incorporate a Beacon which would issue temporary codes on advertisement channels which are public and exposed to MiTM attacks. In this case, the temporary codes would be hashed based on timestamps in combination with an identifier token and a random number. Moreover, both beacons and mobile robots must have another secure communication interface (i.e., authentication, message integrity, accessibility) in order to communicate with an access manager. Thus, beacons constantly emit different hashes which are meaningless in the case of MiTM. Moreover, in case of spoofing, since there is no connection to the server and the connection is authenticated, access would be denied in case of attack. Furthermore, this ephemeral key method hinders attacks due to the temporary limitation of access without the need for pairing. Figure 2 illustrates the architecture of the access control system.

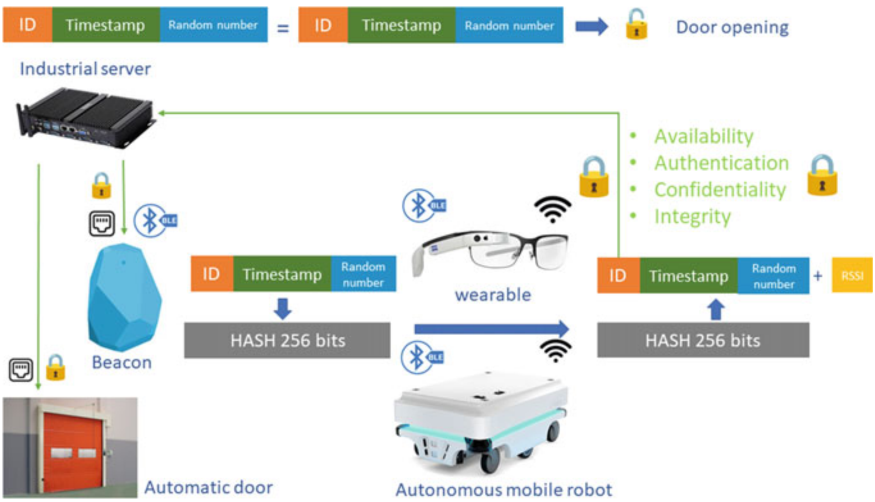


**Fig. 2** Proposed architecture for wireless access control system in industrial environment

According to Fig. 2, the system would enable access control from an external point, as well as the location of mobile robots and industrial plant personnel. Furthermore, the transmitting power can be regulated from the beacons to modify the radius of action, as well as the power consumption. In addition, the receivers can delay the strength with which they receive the signal (e.g., RSSI) as an indication of proximity to the access points. This parameter, as well as access policies, can be controlled in real-time from industrial data acquisition and control systems (SCADAs) or industrial computers.

However, this same philosophy can be used in reverse, with the beacon being the mobile agent acting as the observer beacon. The following is a detailed description of how a demonstrator of this technology has been implemented for both human and mobile robots.

## 6 Architecture Demonstrator

Considering the diversity of equipment, two generic ESP-32 development boards have been used to test this methodology, both of which have Wi-Fi and BLE communication interfaces. To this end, one board acts as a beacon while the other simulates a CPS. The CPS and the beacon send the information to the access control server using Message Queuing Telemetry Transport (MQTT) with Transport Layer Protocol (TLS).

The access control server has been programmed with the node-red tool which allows connecting hardware as well as APIs. When the message emitted by a CPS matches the one sent by a beacon, the server gives the order to open the door using the same protocol. In addition, the location of the CPS can be monitored from the access control interface. In addition, the access control policy can be defined from this interface.

Meanwhile the CPS and beacons have been programmed in C ++ using visual studio by Platformio editor. In this case the door opening control and the beacon are integrated on the same board simulating with a LED diode the opening signal. This demonstrates that the architecture is operational and functional for integration in industrial CPS. Furthermore, the demonstrator is suitable for industrial mobile equipment such as operator wearables.

## 7 Conclusions

The wireless access control systems increase the productivity and comfort of the personnel. In order to achieve this, wireless technologies compatible with the CPS have been used, which have a wider range of action, such as BLE, as opposed to the current ones. Nevertheless, the security in the authentication of the devices is a problem in the BLE protocol. However, this problem has been solved through the use of industrial ethernet platforms characteristic of Industry 4.0. In this way, it has been possible to connect a digitized ecosystem allowing greater information on the location of industrial assets. Therefore, it has been possible to automate access control to mobile robots and personnel in a secure way, which is a novelty in the scientific literature. Furthermore, this methodology can be applied to other sectors (e.g., hospitals, and hotels) where access control is a problem.

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# Unconscious and Conscious Aspects of Healthy Food Consumption: A Neuromarketing and Artificial Intelligence Approach

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**Abstract.** Consumers' unconscious perception of packaging is essential, especially regarding food products where people usually have to choose among relatively similar products. In addition, this perception can be affected by the opinions of other users published on social networks. Researchers must set new goals to better understand user behavior through the information they have at their fingertips, and which influences them. The application of neuromarketing and artificial intelligence techniques to packaging has recently gained considerable popularity both, in academia and practice. With the combination of these methodologies, this study explores how people process and communicate healthy food products, and how people's thoughts and behaviors are informative to other users when it comes to understanding their consumption patterns. Two studies have been carried out. The first one with an eye-tracking technique, in which the attention of 20 participants has been analyzed through first fixation and fixation duration metrics. The second study is based on 448 comments from users who have posted on the social network Instagram. The results obtained show, on the one hand, that healthy statements in food packaging attract unconscious attention, and on the other hand, that healthy claims on food packaging are not enough to achieve consumer satisfaction after purchasing the products. Our study is one of the first to analyze how people perceive unconsciously and consciously healthy products, and how they talk after trying them.

**Keywords:** Healthy consumption · Artificial Intelligence · Eye-tracking · Neuromarketing · Food packaging

## 1 Introduction

The importance of food packaging in marketing strategies has been extensively studied since packaging not only is the container to protect, preserve, and facilitate the handling and commercialization of products [1], but it also communicates brand identity and attracts consumers' attention [2]. Moreover, packaging is especially important in generating added value for products and influencing consumers' shopping behavior [3]. The conclusion of most studies confirmed that packaging is a critical factor in the consumer decision-making process because it can influence consumers when they are deciding


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what to purchase [4]. Given the above, consumers' perception of packaging is essential, especially regarding food products where people usually have to choose among relatively similar products [2].

Also food is a prominent topic on social media platforms [5], and recently, researchers have begun to discover how the language of food can reveal information not only about the origin of food, but also its connection to psychology in general [6]. Online communities such as social networks have provided researchers with a crucial context to study how groups talk about particular topics and their behaviors [7]. With the emergence of these types of platforms, researchers found that the words used to describe healthy or unhealthy foods were predictive of influencing people's psychological states, such as feelings attracted to food or even increasing consumption of healthier food products [8].

Given the large amount of data that we can access today on these online platforms, researchers must set new goals to better understand user behavior through the information they have at their fingertips, and which influences them. In addition, access to user reviews posted on social media allows researchers to understand shopper behavior in a broader context, for example, tweets containing references to healthy or unhealthy foods were found to be related directly with the consequences of food consumption and subsequent purchasing behavior [9]. Therefore, the fundamental role that social networks can play in identifying the relationship between eating patterns and their impact on people's health has already been demonstrated, however, although several studies examined the effects of language use on people's perceptions of food [6, 9], very few studies have explored what kind of language users use after trying a product, how they reflect their opinions and feelings about products related to healthy lifestyle.

The application of neuromarketing and artificial intelligence techniques to packaging has recently gained considerable popularity both, in academia and practice. By understanding how consumers perceive, choose, and evaluate food products, the industry will optimize its packaging design and achieve an added value that can contribute to brands' business strategies [10]. Thus, with the combination of these methodologies, this study explores how people process and communicate healthy food products, and how people's thoughts and behaviors are informative to other users when it comes to understanding their consumption patterns.

## 2 Literature Review

For food products, labels play an important role in the marketing system through their impact on communication and consumer confidence in food quality [11]. In addition, researchers have studied over the years how consumers' perceptions of the nutritional properties of products are affected by the way in which information about them is expressed [12]. It has also been investigated how consumers are interested in being directly informed of the quality of the nutrients that make up the food [13]. This occurs because food packaging is one of the sources of information available to the buyer that allows him to understand the composition of the products.

Generally, in order to inform people about the ingredients and nutrients of a product, specific labels and logos related to the characteristics of the product are displayed on the packaging [14], and for this reason labels are considered one of the most reliable sources, according to European consumers [15].

The use of social media by organizations is effective in promoting a healthy lifestyle and constitutes an innovative and promising option [16]. However, not only is the marketing effort that organizations make to transmit this type of value important, since currently the user is also the creator of content through user generated content (UGC). As much as a company tries to transmit values aligned with healthy lifestyle and sustainable habits, there is a gap between what the company wants to transmit and what actually reaches users in various unconsciously and consciously ways. For instance, users read reviews from other users' opinions about different products and services. This information can directly influence consumer behavior more than a company marketing campaign [5].

On the other hand, Signaling theory has been used to explain the sustainable and healthy behaviors of consumers. Signaling theory implies that visual signals attributes of packaging ("low in sugar", "sugar-free", "more protein" or "low carbs"), can be quality and healthy indicators for consumers, which in turn affect behavior related to healthy lifestyle, purchase intentions and willingness to pay for organic products [14].

Based on consumer perspectives and signaling theory [17, 18], this study evaluates the role of healthy food products packaging in consumer food purchasing decisions. Healthy packaging design works as a signal that unconsciously and consciously influences consumer purchases behavior and improves their healthy lifestyle.

Hence, the research questions that guide this work establish the following:

**RQ1**. Healthy statements in food packaging attract unconscious attention (first fixation and more fixations durations than other areas of interest).
**RQ2**. Healthy claims on food packaging are not enough to achieve consumer satisfaction after purchasing the products.

## 3 Materials and Method

The research objective was addressed through two separate studies. Study 1 was used to analyze unconscious reactions of consumers to two different food packaging (milkshakes and cereals) by using an eye-tracking (ET) technology. ET was used to measure participants' visual attention towards healthy food packaging. This technique is increasingly being applied in the fields of consumer research and marketing as a means of exploring how consumers process visual information [19], and it has been used in the field of packaging design evaluation for many years, essentially to establish how people explore packaging and also to identify which packaging elements are able to catch the consumers' attention [20–23]. In this study, the subjects' eye movements (first fixations and fixations duration) were recorded with Gaze Recorder software (sampling frequency: 30 Hz, accuracy: 1.05°, and precision: 0.129°).

Study 2 was designed to examine the conscious and declarative comments of these products in the social network Instagram. To study the post-purchase opinion of users, this study applied the MeaningCloud text analysis tool. Sentiment Analysis is MeaningCloud's solution for performing a detailed multilingual sentiment analysis of texts from different sources. This software identifies the positive, negative and neutral polarity in any text, including comments in surveys and social networks. It also extracts opinions at the document level or based on aspects. To do this, the local polarity of the different sentences of the text is identified and the relationship between them is evaluated, resulting in a global polarity value for the entire text.

### 3.1 Study 1 Procedure

The eye-tracking experiment was developed at the NeuroLab (Faculty of Economics and Business Sciences) at the Universidad de León. Participants included 20 healthy right-handed adults (12 women–8 men) aged between 20 and 25 years (M/SD = 23.3/2.61) who were recruited to participate in the study by using convenience sampling. None of them informed us of any history of neurological or psychiatric illness, nor visual problems. The research was conducted in compliance with the guidance of the Helsinki Declaration.

A within-subject experimental design was used. Thus, in the present study, every participant has seen two different packaging for milkshakes (strawberry and banana) (Fig. 1), and three different packaging for cereals (cereal mix, oatmeal, and spelt) (Fig. 2). Product categories were selected among packages of everyday commodities and based on the following: (1) the analysis of products most often tested on previous studies [2], (2) marketing stimuli used by real Spanish supermarkets when promoting their products, and (3) food products with some healthy statements in their packaging. All stimuli were presented in full-color and had the same size and format.


**Fig. 1** Two different milkshakes packaging used for the eye-tracking experiment and their AOI (areas of interest)

One advantage of within-subjects is that the difference between the outcomes across conditions can not be due to age, personality, or any other individual difference. However, one disadvantage is that by exposing each participant to all interventions, there is a risk of learning effects [24]. In order to avoid this effect, the stimuli were presented individually and randomly, and the exposure time was uniform for all participants (10 s) [19]. The


**Fig. 2** Three different cereals packaging used for the eye-tracking experiment and their AOI (areas of interest)

average duration for each participant was 10 min, including briefing participants about the protocol and physiological recording.

The ET used was fixed on the computer screen in front of participants, and to calibrate it, subjects had to follow the points on the screen with their eyes. When the ET was calibrated, the experiment began.

### 3.2 Study 2 Procedure

In order to conduct the sentiment analysis through MeaningCloud text analysis tool, 5 posts related to milkshake products (Fig. 3) and 8 posts related to cereal products (Fig. 4) have been selected. In addition, a total of 1054 comments were collected.

## 4 Results

### 4.1 Study 1

Related to milkshake packaging (see Fig. 5), the results show that protein statements included in healthy food packaging draw more attention than private labels or fruit images. The first fixations of milkshakes packaging are located in these healthy claims, as well as the fixation durations, which are higher in the protein statements than in the other areas of interest.

Talking about the cereal packaging analyses (Fig. 6), results show that all the healthy statements (0% added sugar and 85% of oatmeal) received first fixations and higher fixation durations than the cereal images or the private label.

These results together show an interest in healthy related issues when it comes to food packaging. Indeed, the 90% of sample size have seen the healthy visual signals attributes of packaging, in comparison with the 40% of sample size that have visualized the private label or the fruits/cereals images. Thus, demonstrating an unconscious interest in this type of information.

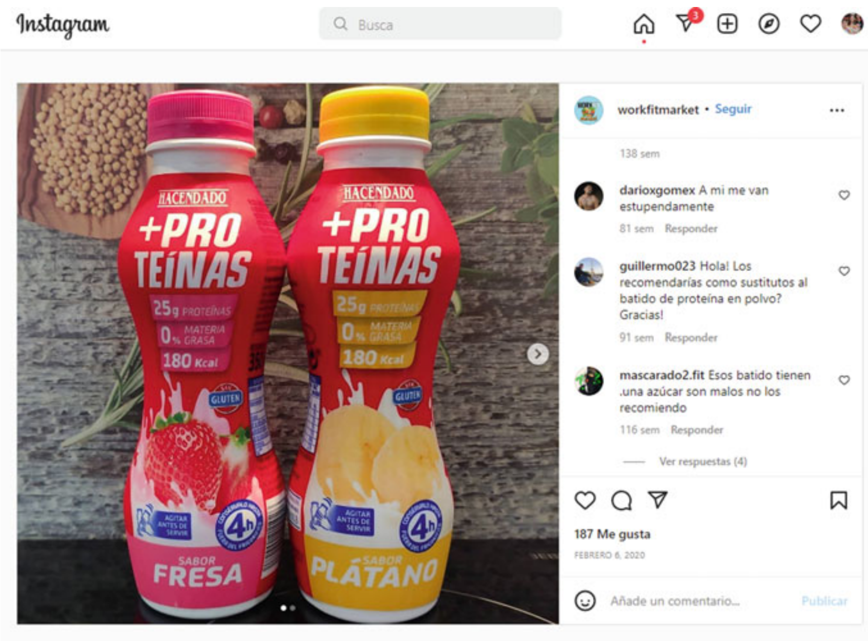


**Fig. 3** Type of milkshake packaging post used for sentiment analysis

### 4.2 Study 2

After performing the sentiment analysis through machine learning algorithms, 448 messages were obtained that expressed types of polarity (see Tables 1 and 2). The rest of the comments were discarded because they did not contain sentiment, or because they were not related to the products to be analyzed.

We found that users who post feedback on their opinion after trying these products are widely satisfied and consider these packaging as a faithful transmitter of what they find afterwards when they try it. As shown in Table 2, 68% of buyers are satisfied with the cereals, and 68% with the milkshakes.

However, there are also negative comments. Specifically, 28% of users criticize that cereal packaging does not inform about the gluten content of the product, and 38% of users indicate that the taste was not what they expected after having seen the packaging (see Table 3). In addition, 18% of users also criticize that cereals include sugar. This is in line with Study 1 results, where people are not unconsciously aware of sugar claims. Furthermore, 9.6% of users criticize the texture of cereals.

> *"They are inedible. They look like cardboard."*

Regarding milkshakes, 85% of users criticize that the amount of sugar contained in the product is not indicated in the packaging, leading to confusion for users. In addition, 8% of users criticize the taste of these products.

> *"A lot of sugar, not even a joke, it's for after training! 😳😳"*

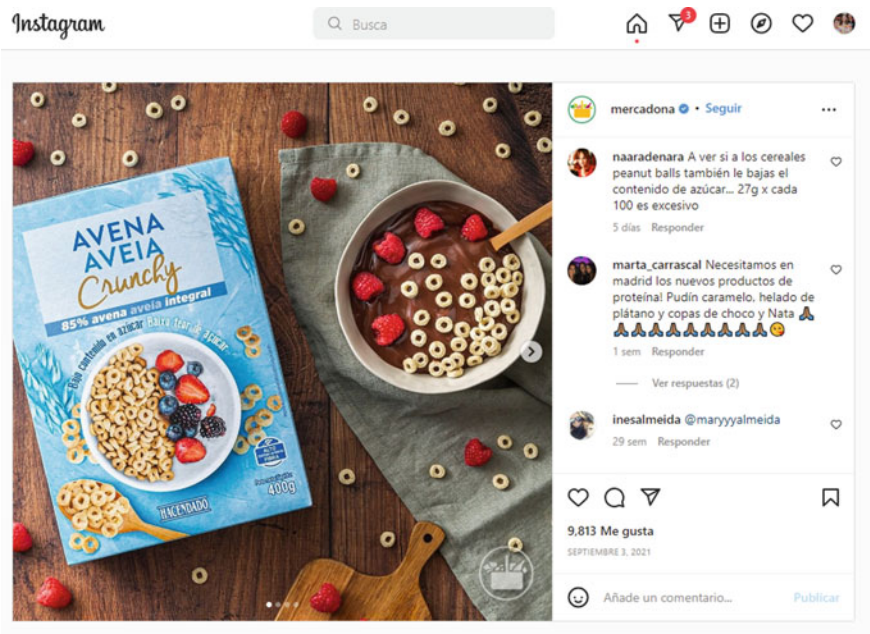


**Fig. 4** Type of cereal packaging post used for sentiment analysis

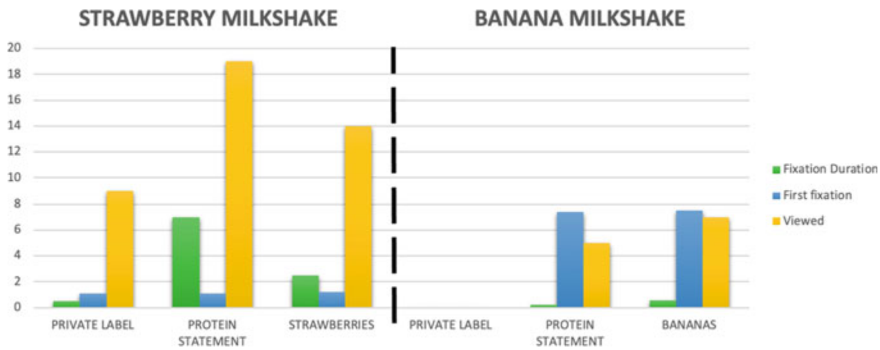


**Fig. 5** Milkshake packaging analyses with eye-tracking technique

In addition, we discovered that Spanish and Portuguese Instagram users generally do not interact through comments, but rather through another type of interaction such as likes, as can be seen in Table 4. The analyzed posts currently have 1054 comments compared to 25,805 total likes on the posts (data collection: October 1st, 2022).

We have also discovered that generally, the more positive the sentiment, in the case of the protein shake, the more likes and replies it accumulates. However, in the case of cereals, this effect is not so evident (Table 4) since the negative comments accumulate 54% of responses and 37% of likes. Therefore, negative comments about aspects such as taste, gluten, sugar or texture have a stronger impact than positive ones among critics of

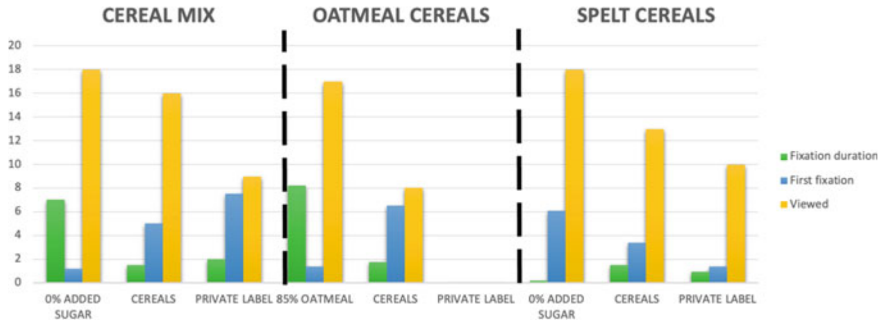


**Fig. 6** Cereal packaging analyses with eye-tracking technique

**Table 1** Classification of analyzed posts, along with their total likes and comments

| Posts analyzed | Type | Comment count | Like count |
|---|---|---|---|
| https://www.instagram.com/p/B8Ob7aiINnv/ | Protein | 19 | 187 |
| https://www.instagram.com/p/CiyPdTkKTxc/ | Protein | 4 | 359 |
| https://www.instagram.com/p/BhbXGGtlutu/ | Protein | 13 | 156 |
| https://www.instagram.com/p/B1bRQsoozwi/ | Protein | 32 | 2012 |
| https://www.instagram.com/p/But8vhBAPMU/ | Protein | 173 | 2451 |
| https://www.instagram.com/p/B5nEXQao3y8/ | Cereal | 56 | 792 |
| https://www.instagram.com/p/CRBo--0jcws/ | Cereal | 78 | 2947 |
| https://www.instagram.com/p/CY2DjuoLVWd/ | Cereal | 14 | 304 |
| https://www.instagram.com/p/CdBr-2ctS_2/ | Cereal | 7 | 93 |
| https://www.instagram.com/p/CgxNBCOgJyw/ | Cereal | 12 | 362 |
| https://www.instagram.com/p/CamHweBNGQa/ | Cereal | 151 | 4793 |
| https://www.instagram.com/p/CTWh1BWIBiL/ | Cereal | 462 | 9818 |
| https://www.instagram.com/p/CTRl-MfoACL/ | Cereal | 33 | 1531 |
| Amount | | 1054 | 25,805 |

cereals. In both cereals and shakes, no relationship has been found between the intensity of the feeling, that is, whether it is more positive or negative, and the number of likes or replies received.

Healthy claims on food packaging are not enough to achieve consumer satisfaction after purchasing the products, but companies must make an effort to communicate truthfully, without omission of information, as well as improve important aspects for the consumer such as the taste and texture.

**Table 2** Sentiment analysis by polarity of the analyzed comments

| Polarity | Cereal | Percentage (%) | Protein | Percentage (%) | Amount |
|---|---|---|---|---|---|
| Very negative | 32 | 9 | 10 | 13 | 42 |
| Negative | 82 | 22 | 16 | 20 | 98 |
| Neutral | 3 | 1 | 0 | 0 | 3 |
| Positive | 136 | 37 | 48 | 60 | 184 |
| Very positive | 115 | 31 | 6 | 8 | 121 |
| Amount | 368 | | 80 | | 448 |

**Table 3** Sentiment analysis by topic of the analyzed comments

| Type | Comments count |
|---|---|
| CEREAL | 114 |
| Taste | 43 |
| Gluten-free | 32 |
| Sugar-free | 21 |
| Texture | 11 |
| Closeness | 2 |
| Size | 1 |
| Price | 1 |
| Nutrients | 1 |
| Availability | 1 |
| Packaging | 1 |
| PROTEIN | 26 |
| Sugar-free | 22 |
| Taste | 2 |
| Price | 1 |
| Size | 1 |

## 5 Conclusions

Messages on food packages convey the healthiness of food and are important in consumers' food choices, but companies cannot forget to convey through their packaging what really matters to users, and they must avoid omission of information that can mislead buyers.

Despite the importance that healthy habits are gaining momentum in our lives, very few studies have examined how users perceive healthy packaging, and how that first impression later affects their culinary experience. Our study is one of the first to analyze

**Table 4** Relationship of sentiment analysis of comments with likes and replies obtained

| Polarity by type | Like count | Percentage (%) | Reply count | Percentage (%) |
|---|---|---|---|---|
| *Cereal* | | | | |
| Very negative | 50 | 8 | 9 | 7 |
| Negative | 178 | 29 | 59 | 47 |
| Neutral | 2 | 0 | 0 | 0 |
| Positive | 190 | 31 | 52 | 42 |
| Very positive | 187 | 31 | 5 | 4 |
| *Protein* | | | | |
| Very negative | 4 | 2 | 7 | 8 |
| Negative | 16 | 7 | 12 | 14 |
| Positive | 219 | 92 | 67 | 76 |
| Very positive | 0 | 0 | 2 | 2 |

how people perceive unconsciously and consciously healthy products, and how they talk after trying them. To this end, physiological objective measures and data analysis techniques have been used. We have examined first fixations and fixations durations of healthy packaging statements with an eye-tracking technology and we have also explained how users on social media online communities communicate their opinions about healthy products with each other. These issues allow us to understand food consumption patterns and food preferences.

In general, marketing managers should avoid omitting information on the packaging which is relevant to the target audience. For instance, if a milkshake intended for athletes is not communicating in an easy way the amount of sugar contained, or if this information is omitted, it can confuse consumers and they are not willing to buy the product. In the case of cereal products, it is important not only to focus all efforts on an attractive packaging, but also on the taste and texture of the product itself. If there is an absence of that, the consumer experience may not be entirely satisfactory.

As we try new products and talk about food daily with other users through social media, this type of communication is gaining more popularity, so there are still many unanswered questions about the effects of healthy issues in food product packaging.

We hope that future studies delve into the cultural differences that affect packaging designs, and therefore the perception of consumers, just as these cultural differences affect cognitive processes and post-purchase behavior in social media.

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# AppPopuli: Web Application for Real-Time Damage Report in Poplar Plantations Using Citizen Science

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**Abstract.** AppPopuli is a citizen science project developed by a multidisciplinary team, in the fields of forest health and computer science. The core of the project was to develop a web application that allows both foresters and ordinary citizens to inform, in real-time, about damages in hybrid poplar plantations (*Populus* spp.) caused by pests or diseases. The damage report is done individually by the user through a form that they fill in with information related to the damaged tree, such as, for example, the name of the pathogen causing the damage (if known), the geographical location, photographs, etc.; so that this data is stored in a database. The database aims to monitor the status of poplar plantations and provide feedback to the app users about the damage they have reported. On the other side, the application also includes a help section with information about the pests and diseases that could damage poplar trees, so that non-experts in the field are able to identify damages found in poplar trees correctly; and an explore section with a table that contains some of the data of the reports sent by the users with their location marked on a world map. The application is focused on its use using mobile devices (but not limited to), which has been kept in mind while designing the user interface in order to guarantee a good user experience, no matter the device you are using and the size of its screen. This application will contribute to sustainable and responsible wood production, providing more resilient poplar plantations and promoting the early control of potential pests and diseases.

**Keywords:** App · Web responsive · Forest health · Monitoring


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# 1 Introduction

## 1.1 Forest Health Monitoring and Citizen Science

In forestry, the possibilities of eradicating or minimizing the effects of a new plague or disease depend to a large extent on the speed with which the problem is detected, in order to stop or slow down its progress. Early detection therefore becomes a key element, which has led several countries to define early warning systems such as Early Warning System (EWS) in the United States, Tree Health Action Plan (THAP) in the UK or the future Tree Health Early Warning System (THEWS) in Europe [1]. These systems are based on four key aspects to detect and respond to environmental threats [2]: (1) Identify potential threats, (2) Detect actual threats, (3) Assess impacts, and (4) Provide a response.

Regarding the second aspect, to detect existing (real) threats, it is necessary to carry out surveillance and monitoring tasks, carried out by specialists in forest health (forestry administration, universities, research centres, forestry associations), forest managers, nursery workers, as well as society in general. In this area, it can be highlighted the "Observtree" initiative [3] of the Forestry Commission of the United Kingdom, which tries to establish a new system for early detection of the health status of forests based on "citizen science", where citizens who participate voluntarily report the location of a forest pest or disease as soon as they see it, through the "Tree Alert" mobile application. This maximizes the chance of eliminating or controlling future outbreaks/infestations. These volunteers receive prior and ongoing training to increase their effectiveness in detecting pathogens, and this information is passed on to forest health specialists for verification. AlertaForestal [4] is a similar project that seeks to collect data on phenomena that affect the health of forests by citizens who do not have to be forestry experts. In addition to sending alerts, it allows the alerts sent by users to be viewed on a world map. iNaturalist [5], Pl@ntNet [6] and BiodiversidadVirtual [7] are citizen science websites that collect data on observations made by users, of living beings in the case of the former and of plants in the case of the latter. These applications are citizen science projects in which citizens are encouraged to be part of by sending data that will be very useful for researchers and, in the case of AlertaForestal, spreading the importance of maintaining healthy forests to the population, since they provide maximum economic, social and environmental benefits, as well as warnings about the impact of climate change on forests.

## 1.2 Real-Time Damage Report in Poplar Plantations

Sustainable production of wood is threatened over the world by the increase in biotic damages, caused by pests and diseases that attack these trees and slow down their growth or, worst case, kill the plant. These issues affect as well commercial poplar plantations which account for 7.6 million ha in China, followed by France (236,000 ha), Turkey (125,000 ha), Spain (105,000 ha), and Italy (101,430 ha) [8]. In Spain there is no general database that collects information about poplar trees damaged by these agents. For this reason, and in collaboration with the poplar value chain, the objective was to design a system that would allow reporting, in real-time, the health status of the poplar trees, based on symptoms observed in the field. Such a system would give both companies in the wood industry and small owners the possibility of managing their poplar plantations much more efficiently, locating possible damage found in the trees early. In addition, one of the aims was that the population in general would participate in the project, sending data about damages found in the field. In this way, much more information would be collected and the idea of how important it is to maintain healthy forests and the economic and environmental benefits that this entails would spread.

## 2 Objective

The objective was to develop AppPopuli, a web application that allows both foresters and ordinary citizens to inform, in real-time, about damages in hybrid poplar plantations (*Populus* spp.) caused by pests or diseases, and integrate that information into a database that can be used by forest managers for monitoring forest health status.

## 3 Material and Methods

### 3.1 Contents

The contents and functionalities that should be included in the application were set considering the feedback from two companies from the poplar sector and the forest administration. The main requirements are listed below:

1. Sending reports with the following data regarding the forest health issue:

   - Geographical location of the damage
   - Date the damage was identified
   - Identification of the pest or disease causing the damage
   - Photographs of the damage (if any)
   - User comments
   - Extent of damage
   - Severity of damage

2. User contact information
3. User help section with:

   Information on the most common pests and diseases that can attack poplars, including photographs and files in PDF format for download.
   A user guide on how to use the application, submit a damage report and take photographs so that the damage is correctly displayed.
   Training videos complementary to the user guide.

4. Storing the information of the reports in a database.

### 3.2 Prototype

The prototype was designed using the tools provided by the Moqups website [9], which has a wide variety of entirely free design options to obtain a layout that is as close as possible to the interface of a real system. As well, the principles that characterize a quality user experience were reviewed [10].

### 3.3 Database Design

To design the database, it was necessary to identify the data that must be stored and the relationships that may exist between them. Given the information that needs to be stored, four tables were necessary (Fig. 1): one for the damage reports, one for users (contact information, to later login with that data), one for the list of pests and diseases (information is available in the help section), and another for the listed symptoms (information is available in the help section).

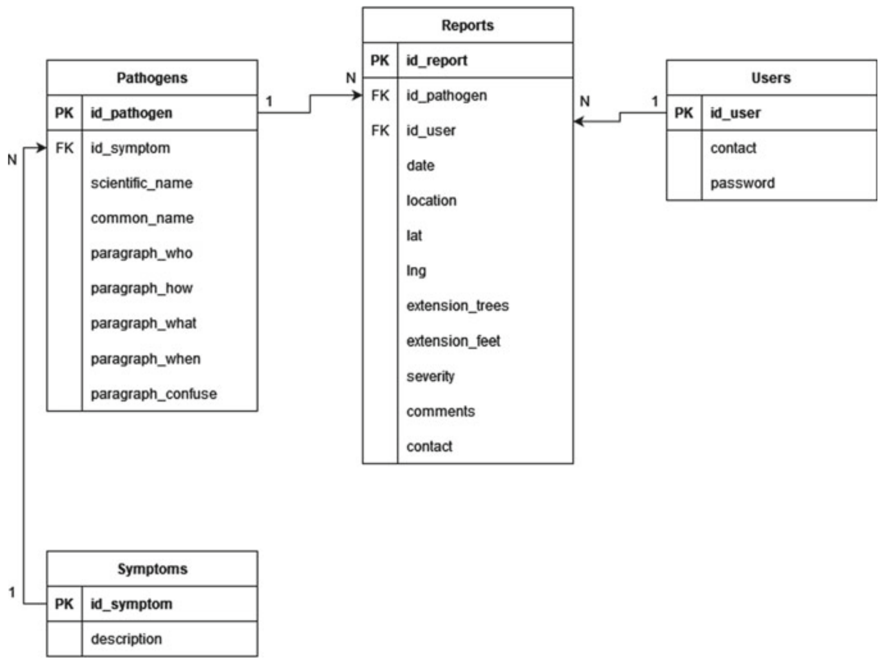


**Fig. 1** Relational diagram of the database of AppPopuli

### 3.4 Tools

The following tools were used to develop the application:

- **Plesk**, a secure and easy-to-use web server control panel. This tool allows, through its graphical interface, to manage the domains hosted on a web server, including transferring files to it, databases (through phpMyAdmin), integration of extensions, traffic statistics and space used, etc.
- **phpMyAdmin** is a free tool that allows the management of MySQL through a graphical interface on the Web. In our case, we used MariaDB, another database management system with which it shares many of its features instead of MySQL. Thanks to phpMyAdmin (which is integrated in Plesk) we were able to create databases, manipulate tables and carry out CRUD (create, read, update, and delete) functions on the data simply and effectively.
- **XFTP** allowed the transfer of files with a server remotely, being able to use the SFTP protocol in the connection for the encryption of the transferred traffic or FTP for traffic without encryption, but at the maximum connection speed. Through this tool, the necessary files to start the application will be sent to the server.
- **Postman** is an application dedicated to the use of APIs (in English 'application programmatic interface'), application programming interfaces for the connection between a client and a server, so that when a client makes a request to the server, it has a specific communication endpoint configured for the said call. The application was used to send requests, both locally to the computer from which we work and remotely to the web server, to the API which was configured to receive the requests of the GET and POST methods, and thus verify that these are they carried out correctly.
- **Node.js** is an asynchronous object-oriented JavaScript runtime environment (https://nodejs.org/en/about/) designed to build scalable web applications. This tool served as the backend of the application. It has the ability to serve many connections simultaneously and independently thanks to the event loop it uses as execution runtime. It was used to execute code written in JavaScript on the web server.
- **Express** is a fast, minimalist, and flexible framework for Node.js web applications [11]. Express provided the following mechanisms to the application [12]: handle requests received on the server with different HTTP versions on different routes, integration with view rendering engines, and add additional processing on requests.
- **Vue.js** is a JavaScript framework designed to create user interfaces [13]. This environment allowed us to create the views that were designed for the prototype.
- **Visual Studio Code** is a source code editor with support for JavaScript, HTML and CSS, although not for Vue.js, at least not natively, so it was necessary to install the official Vue extension, Volar.

## 4 Results

### 4.1 Backend and Frontend

The development of the application was divided into two parts: the first one focused on the backend and the second on the frontend. To develop the first, and for it to be able to communicate with the second, the guide provided by BezKoder [14] was used as a reference, in which the process of creating and deploying a web application with Node is explained step by step. js, Express, MySQL and Vue.js.

Regarding the backend, in order to interact with the database, a REST API was created, where the routes to access the data and the methods to be used were specified. In this case 10 actions were included in the REST API. We verified that the API worked correctly with the Postman program by making HTTP requests of different types to the different routes of the server that we previously defined in the files of the routes folder.

For the frontend, Vue.js was the primary tool used to develop the application interface [13]. The BezKoder guide used to build the backend was needed to learn how the interface should communicate with the API [14].

### 4.2 Appearance and Final Content of the Application

With all of this we would have the application ready for use through the following link: http://test.apppopuli.es. The application is focused on its use through mobile devices (but not limited to), which has been kept in mind while designing the user interface in order to guarantee a good user experience (Fig. 2), no matter which device you are using and the size of its screen.

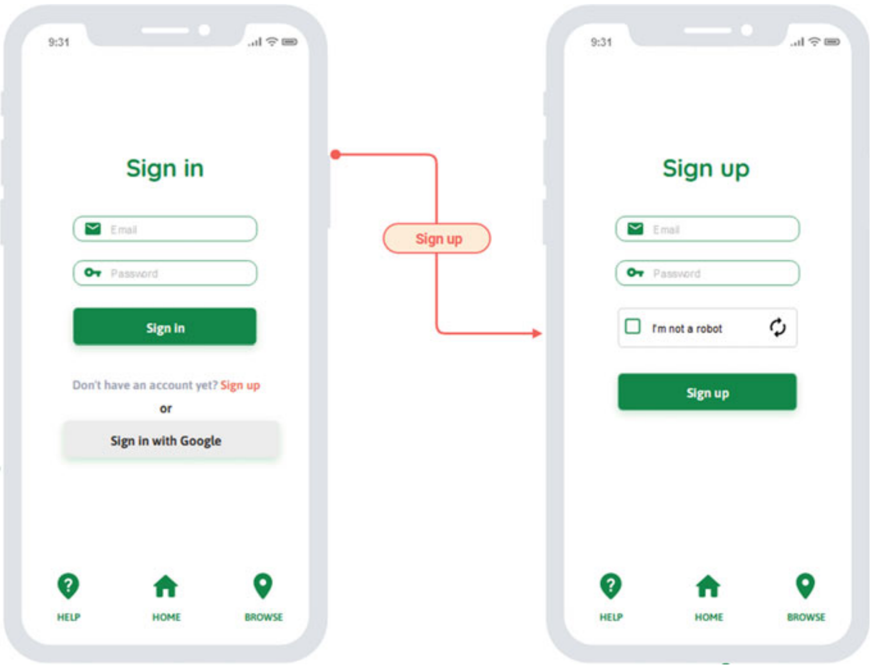


**Fig. 2** Screenshots of the login and signup sections of AppPopuli

As an example, Fig. 3 shows the information collected by AppPopuli for the report, while Fig. 4 shows the list of reports already stored in the database. The database aims to monitor the status of poplar plantations and provide feedback to the app users about the damage they have reported. The owners of poplar trees will also be able to store their damage reports and view those from other areas, contributing to the digitization and progress of the poplar sector.

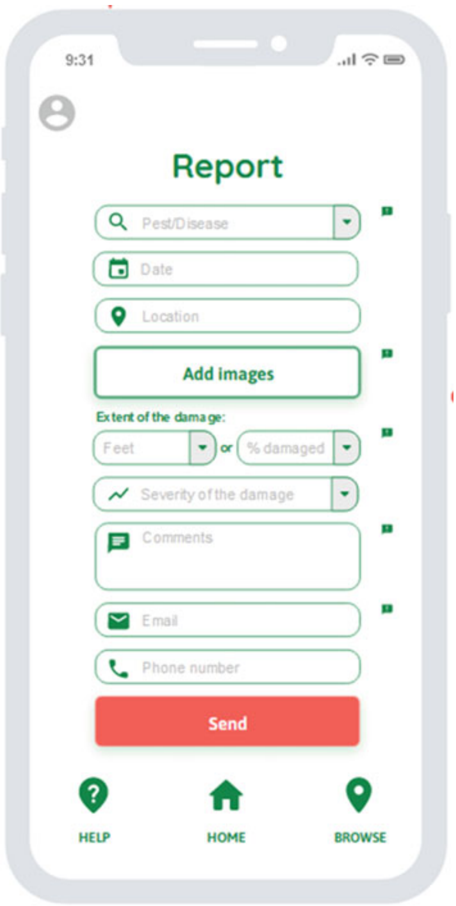


**Fig. 3** Information collected by AppPopuli for the report

The application also includes a help section with information about the most common pests and diseases that could damage poplar trees, so that non-experts in the field can correctly identify damages found in poplar trees. This contributes to raising awareness among the population about the importance of maintaining healthy forests as well as the benefits that it entails.

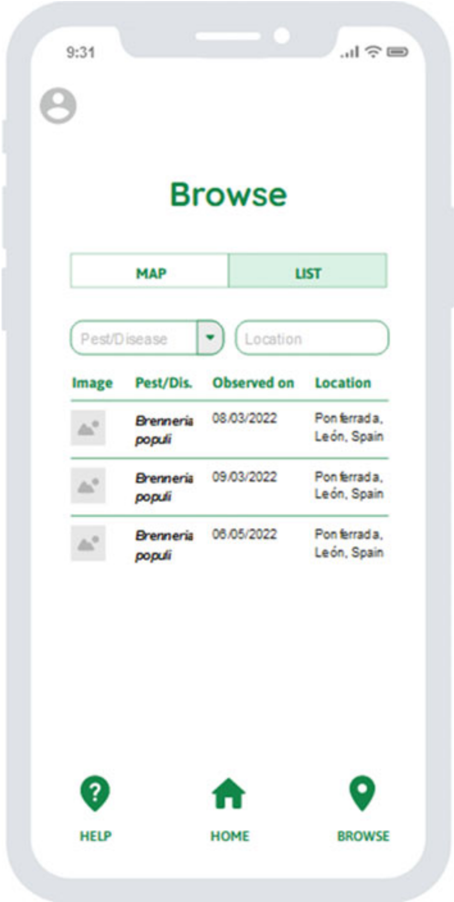


**Fig. 4** Example of list of reports stored in the database and collected by AppPopuli

## 5 Conclusion

The main objective of the application, which was to create a responsive web application to report in real time about damage found in poplar trees, has been satisfactorily fulfilled, as well as the adaptive design that was sought to achieve to offer an optimal user experience regardless of the device from which it was accessed. Early identification of damaged areas using AppPopuli will contribute to sustainable and responsible wood production, providing more resilient poplar plantations and promoting the early control of possible pests and diseases. It is expected that events will be held to present the application to potential users and make use of it, in order to receive feedback that will help us improve the application.

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# Biodeposition of Diatoms in Recycled Aggregates

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**Abstract.** This work studies the behaviour of diatoms in artificial culture environments and analyses the biodeposition of diatom frustules in different sizes of mixed recycled aggregates. In order to be able to use this biodeposition as a surface treatment and improve the properties of this material for its effective use in recycled concrete. Surface analyses show that the density of diatoms in biofilm formation depends on the aggregate size, being better in smaller aggregates of 4–6.3 mm diameter. However, the diversity of diatoms is higher in aggregates with fractions of 8–12.5 mm. The combination of these tests demonstrates that diatom biodeposition is feasible in artificial environments for possible use as a protective surface treatment of cement-based building materials.

**Keywords:** Biogenic silica · Construction and demolition waste (CDW) · Surface treatment

## 1 Introduction

The demand for building materials is increasing in many countries of the world, where the processes of urbanisation and industrialisation are intense. This is causing environmental damage over the last few decades, with the consumption of natural resources and the large amount of waste generated in the construction industry. Over time, this type of industry has focused on linear production models, without considering waste recycling [1], but now it is focusing on models linked to the concept of circular economy [2]. One of the techniques able to link the construction with the concept of circular economy is the use of recycled aggregates (RAs) from construction waste to produce new concrete, reducing the use of natural gravel and the amount and surface area of landfill sites, thus protecting the natural environment and economic development.

These RAs from construction and demolition waste (CDW) are characterised by higher porosity, high water absorption capacity and lower abrasion resistance [3], which can decrease the durability of the constructions made with this material. Therefore, new techniques are being investigated to improve the properties of these aggregates. To date, several researchers are working on the use of bacterial calcium carbonate biodeposition


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[4–6], including the direct application of nano-silica [7–9] as protective in RAs. In this study a new technique, based in the diatoms as biotreatment is proposed.

Diatoms might be applied as a biotreatment for surface of RAs as waterproofing and surface improvement treatment, immersing RAs in aqueous environments with diatom algae for as long as it takes for Bacillariophyceae community growth to cover the surface and partially fill the outermost pore network with a layer of $SiO_2$.

Thus, this study presents an artificial culture technique to develop the biodeposition of diatoms and the characterization of the biofilm formed in RA. Suggesting that this coating could be a practical way of improving the properties of this recycled material and avoiding the overexploitation of raw materials in the construction industry.

## 2 Objectives

The objectives of this work are:

- To analyse the behaviour and growth of diatoms in artificial environments.
- To compare and analyse the biodeposition of diatom frustules in different aggregate sizes in order to improve cultivation techniques.
- To explore the possibility of applying diatom shell biodeposition as a protective or reparative seal in RAs to obviate the need for the raw materials traditionally used in the repair and maintenance of such materials.

## 3 Materials and Methods

The materials that were considered for this research were typical mixed recycled aggregates from crushed concrete and ceramic elements, supplied by the CDW management company, TEC-REC, Tecnología y Reciclado S.L., located in Madrid (Spain). This RAs were characterised in terms of particle density and water absorption ($WA_{24}$) using the standard tests recommended in EN 933-1:2012 [10] and EN 1097-6:2014 [11], showed in Table 1.

**Table 1** Aggregate characterization

| Aggregate | Fraction (mm) | D/d Ratio | Density $\rho_p$ ($Mg/m^3$) | $WA_{24}$ % |
|---|---|---|---|---|
| RA | 2–12.5 | 7.67 | 2.53 | 4.4 |

Furthermore, it was necessary to assess the particular characteristics of these aggregates. The classification of its composition was determined with EN 933-11:2009 [12], from which the results shown in Table 2, based on the works García-González et al. [6] and of Serrano-González et al. [13].

**Table 2** Composition of RAs

| Parameter | Value |
|---|---|
| *Composition* | *(%)* |
| Unbound aggregate (natural aggregate with no attached cement mortar) | 17.5 |
| Masonry and fired clay (bricks, tiles, stoneware, sanitary ware, etc.) | 33.6 |
| Concrete and mortar (natural aggregate with bound cement mortar) | 44.1 |
| Asphalt | 0.4 |
| Glass | 0.8 |
| Calcium sulphates (gypsum) | 3.5 |
| Other impurities (wood, paper, metals, plastic, etc.) | 0.1 |

The samples were sorted and divided into four fractions, 2–4, 4–6.3, 6.3–8 and 8–12.5 mm, with three replicates of 50 g for each fraction type, in order to establish aggregate size influence on diatom biodeposition.

In this work, diatom biodeposition was used as a biological agent for the surface treatment of RAs. This biodeposition known as biogenic silica [14], is based on the adhesion of diatom frustules to the surface of the concrete, forming coatings called biofilms.

For the formation of this biofilm, the different replicate fractions were immersed in beakers (100 ml) with water for one month, since according to Lacoursière et al. [15] the colonisation of diatoms on a substrate develops over a period of 4 weeks.

In terms of the culture medium characteristics, it was composed of river water, live diatom inoculum (from brushing the surface of river stones) and sodium metasilicate (40 ppm) as food for the diatoms. In addition, the samples were exposed to controlled laboratory environmental conditions with 22 ± 2 °C and direct sunlight during the month of March, when the photoperiod starts to become positive, that is, when the number of daylight hours increases.

For biodeposition analysis, periphyton samples were collected on the experimental substrates, following the standard Spanish protocols for the collection of benthic diatoms EN 13946:2014 [16], adapted for lentic media. Furthermore, the aggregates were also analysed according to standard protocols for counting and identification of diatoms EN 14407:2015 [17], quantified and identified to the lowest possible taxonomic level in the sample, following standard taxonomic literature of Hofmann et al. [18]. Numerical results were processed with OMNIDIA v. 4.2 [19] in order to classify individual species according to their ecological guilds (life forms). Finally, whole biofilm production was evaluated using chlorophyll a concentration as a proxy, analyzed following ISO 10260:1992 [20].

## 4 Results

After one month of biofilm growth, the samples were removed and prepared for testing. Four fractions of the prepared samples were characterised in terms of chlorophyll concentration, diversity and preference types of diatom guilds.

To determine the diatoms in the biofilms formed, the chlorophyll concentration (µg Chla/g) of the replicates per gram of substrate was measured. Figure 1 shows that the 2–4 and 8–12.5 mm fractions obtained the largest variability between their replicates, with maximum values of 1.5 µg Chla/g (2–4 mm) and 1.3 µg Chla/g (8–12.5 mm). However, if the average of each type of fraction is analysed, the highest concentration of diatoms in the biofilms belonged to the 4–6.3 mm fraction with average of 0.72 µg Chla/g and 2–4 mm with 0.65 µg Chla/g. The other fractions present, in decreasing order of concentration, were the 8–12.5 mm and 6.3–8 mm. Nevertheless, the treatments did not differ statistically (Kruskal–Wallis test, $p > 0.05$).

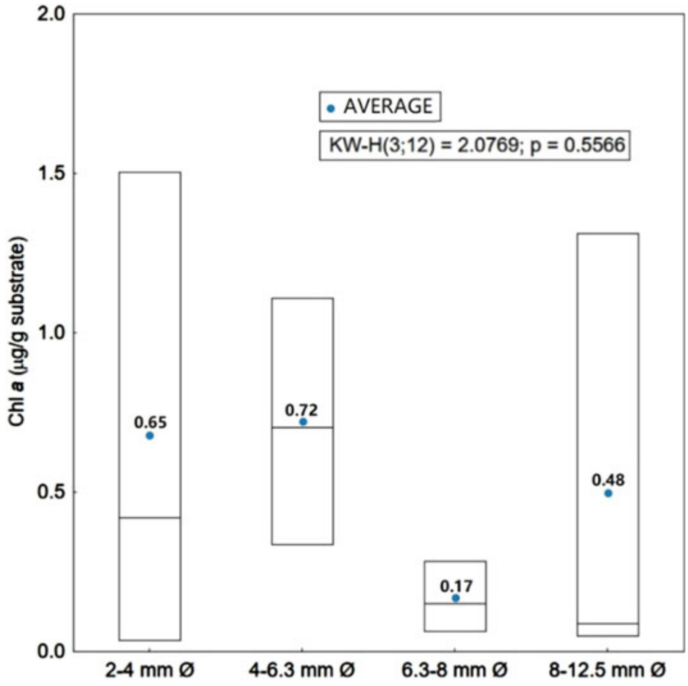


**Fig. 1** Boxplot showing Chl a deposition per surface unit in the different substrata. Blue dots denote average values

In terms of diatom species diversity (Shannon's H index), Fig. 2 shows more similar results between the different aggregate sizes. Nevertheless, diversity increases proportionally as size is larger, with the 8–12.5 mm fraction showing the highest diversity of diatoms.

Diatom species found growing on the different substrata were classified according to their ecological guilds. Figure 3 shows the percentages of these diatom guilds. Although

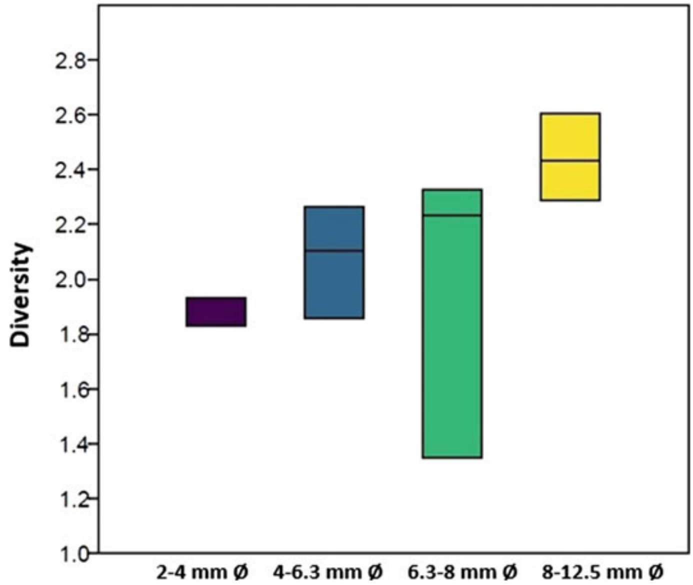


**Fig. 2** Diatom diversity

there was an enormous variety of other species, the most important guilds were epontic (planktonic), benthic (benthic guilds) and Epontic and Bentic (both life forms), for each sample type. Noticeably, the proportion of exclusively planktonic taxa increases monotonically with aggregate size. This implies that substrata with large granulometries are more prone to harbor nonperiphytic algae, that is, species that live in the water column and eventually occur in the biofilm by mere passive deposition after death.

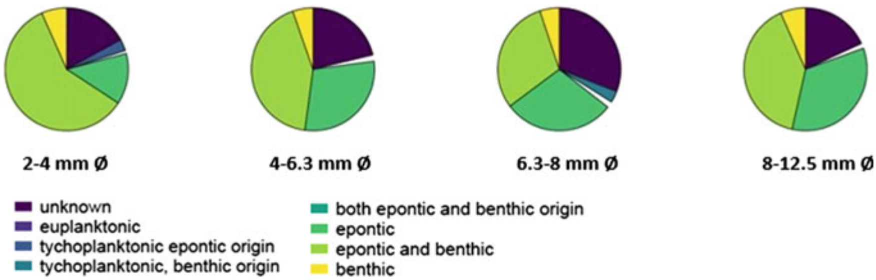


**Fig. 3** Distribution of the different diatom guilds

## 5 Discussion

Silica biodeposition on RAs showed better results for smaller fractions, this is because larger aggregates present difficulties for diatoms to grow on their entire surface, as diatoms grow best in light-exposed areas [21] and due to the surface/volume ratio of aggregate particles, which is higher in small aggregates, because there is more surface area per unit volume and therefore more surface available for diatoms growing. Although the mechanisms of colonisation involved have yet to be categorised [22].

In general, diatoms appear to initiate surface colonisation and biofilm formation, although the exact mechanisms involved are unidentified [22]. But diatoms are known that initiate surface colonization with an initial phase includes the development of a primary coating formed by colloidal organic matter, polysaccharides and proteins. This is immediately followed by the accumulation of microorganisms (bacteria, diatoms, fungi and other microalgae) and the secretion of EPS (Extracellular Polymeric Substances) on their cell surfaces during attachment, colonization and population growth [23].

Thus, the distribution of diatoms in the biofilm develops heterogeneously, with microscale variations affecting the diversity of the population. As in this case, an increase in diversity was obtained in the 8–12.5 mm fraction, given that these aggregates have a larger surface area and allow different types of colonies to be generated, but it is also likely that the diatom community of the biofilm has shown a variation mainly linked to physical and chemical changes in aggregate morphology [23].

In addition, it should be noted that the finding of more planktonic forms as particle size increases may be due to the larger aggregates having more surface area available for passive deposition of silica frustules. In contrast to the benthic guild that actively participates in biofilm formation on the aggregate surface.

## 6 Conclusions

The research was based on the biodeposition of diatom frustules, to observe the behaviour of diatoms in artificial culture environments and to analyse the biofilm formed in different RA sizes, obtaining the following conclusions:

- Cultivation of diatoms in an artificial environment is fully feasible.
- The highest diatom concentrations were obtained in the smaller diameter aggregates (4–6.3 mm and 2–4 mm) because larger aggregates have more surface area without light contact and due to the surface/volume ratio of aggregate.
- Larger diameter aggregates allow for a greater diversity of diatoms, because there is more surface area for the different species to colonise.

Furthermore, this work proposes that diatoms might be applied as a biotreatment whose coating effect might provide sealing or reparative properties to these materials. This could avoid the use of traditional raw materials in repair or maintenance operations. This is an area in which there is hardly any work, so its research and application potential is currently promising.

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# Web Application Based on Sentinel-2 Satellite Imagery for Water Stress Detection and Monitoring in Poplar Plantations

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**Abstract.** Clonal poplar plantations under conditions of water stress are more susceptible to pests and diseases, in addition to having lower growth rates than in optimal conditions of water availability. Likewise, water management is essential to guarantee responsible and sustainable wood production, with a minimum water footprint. The aim of this paper was to develop a user-friendly online system based on satellite imagery to detect and monitor damages caused by water stress in poplar plantations, so it could be used by the poplar owners/managers without previous knowledge of remote sensing. PoplarAlert is a free online web application which was developed using Sentinel-2 MSI imagery, Google Earth Engine, Python. It allows the user to obtain, through the application, clear and immediate information on the probability that damage due to water stress has occurred (in- formation in the form of an image, graph, vector or table). In addition, this tool allows the temporary reconstruction of a damage that is detected (to go back in time and try to identify the trigger). The results of testing it in two different plantations confirmed the capability of PoplarAlert to detect water stress once there was some leaf loss and/or drier/yellower leaves still on the tree (previously or during the leaf loss).

**Keywords:** App · Web responsive · Forest health · Monitoring

## 1 Introduction and Objectives

Biotic (such as those caused by pests and diseases) or abiotic (caused by wind, snow, or water stress) damages in clonal poplar plantations (Populus x spp) cause a decrease in growth, which has an impact not only on the economic value of the plantation due to the amount of wood that can be obtained but also in the ecosystem services provided by the poplars.

Forests in general, and clonal poplar plantations in particular, under conditions of water stress, are more susceptible to pests and diseases than healthy ones, in addition to


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having lower growth rates than in optimal conditions of water availability. If prolonged and repeated, it can compromise the survival of the plantation. Likewise, water management is essential to guarantee responsible and sustainable wood production, with a minimum water footprint. It is necessary to have a tool that allows for the detection and monitoring in almost real time of hydric stress phenomena that can cause a pause in growth and a weakening of the ecosystem. As well, it is required that that this tool can be applied to large areas, which cannot be monitored every week in the field by the owners/managers.

Systematic damage detection campaigns can be carried out using field data, remotely sensed data, or a combination of the two. Remote sensing was first used in the Canadian and US forest monitoring systems in the 1970s, through the use of airplane and satellite imagery. [1] presented a review of the work carried out in Spain in the field of forest health using remote sensing. The most general campaigns can be complemented with others that are more specific and aimed at monitoring a specific pest/disease (as has happened in the Basque Country with *Lecanosticta acicolala* (pine brown band). The use of images from the same area on different dates is a very useful tool for locating the origin of the pest/disease and its evolution. For example, with images from the RapidEye sensor, from which the vitality index was calculated and the initial focus of the disease was located the evolution of the plague of *Lymantria dispar* in El Bierzo (León) [2] could be examined. Regarding poplar health monitoring, [3] have developed PRECISIONPOP, a multi-scale monitoring system for poplar plantations integrating field, aerial, and satellite remote sensing which allows for the detection of early warning poplar stress, which are suitable for variable rate irrigation and cultivation operations scheduling. That system is not fully operational yet and is being calibrated in Northern Italy. The most widely applied and promising approaches to map land cover and land cover changes are ensemble methods and deep learning [4]. An advantage of deep learning models compared to other machine learning methods is their greater ability to characterize the diversity in big data and the fact that a variable selection is not required [5]; however deep convolution neural networks require large and reliable training datasets [6]. D'Amico et al. [7] used a deep learning approach for automatic mapping of poplar plantations using Sentinel-2 imagery.

The aim of this paper was to develop a user-friendly online system based on satellite imagery to detect and monitor damages caused by water stress in poplar plantations, so it can be used by poplar owners/managers without previous knowledge of remote sensing.

## 2 Material and Methods

### 2.1 Contents

The contents and functionalities that were included in the application were set considering the feedback from some agents from the poplar value chain (forest managers and owners). The development of the following two functionalities were requested:

(i) Functionality PolyPop. The user enters the location of their forest plots (as a file or by drawing the áte of interest in the application itself) and the time period of interest (last months, weeks, days) and obtains, in real time, the likelihood that damage has occurred in that áte of interest. The technology developed was áteron the calculation and optimization of the thresholds of the GNDVI spectral index [8] for the detection of damage due to áter stress in poplars, so that each square of 10 m × 10 m of the plot is classified as "No stress", "maybe stress" or "stress", and is shown georeferenced on the map with a color scale. This information is downloadable as a vector file, as a table (CSV) and as an image.

(ii) Functionality PointPop. Once PolyPop has been run, the user marks a point on the plot (drawing the location of interest in the application itself) and obtains in real time the weekly variation of the GNDVI for the chosen period of time and also from 2017 to the present, in order to be able to rule out false positives (anomalous values that do not correspond to changes) and to temporarily reconstruct a damage that is detected now (go back in time and try to identify its onset and cause). That information is downloadable as a table (CSV) and as an image (PNG).

## 2.2 Input Data and Tools

PoplarAlert, a free online tool that integrated PolyPop and PointPop was developed using Google Earth Engine and Python (Fig. 1).

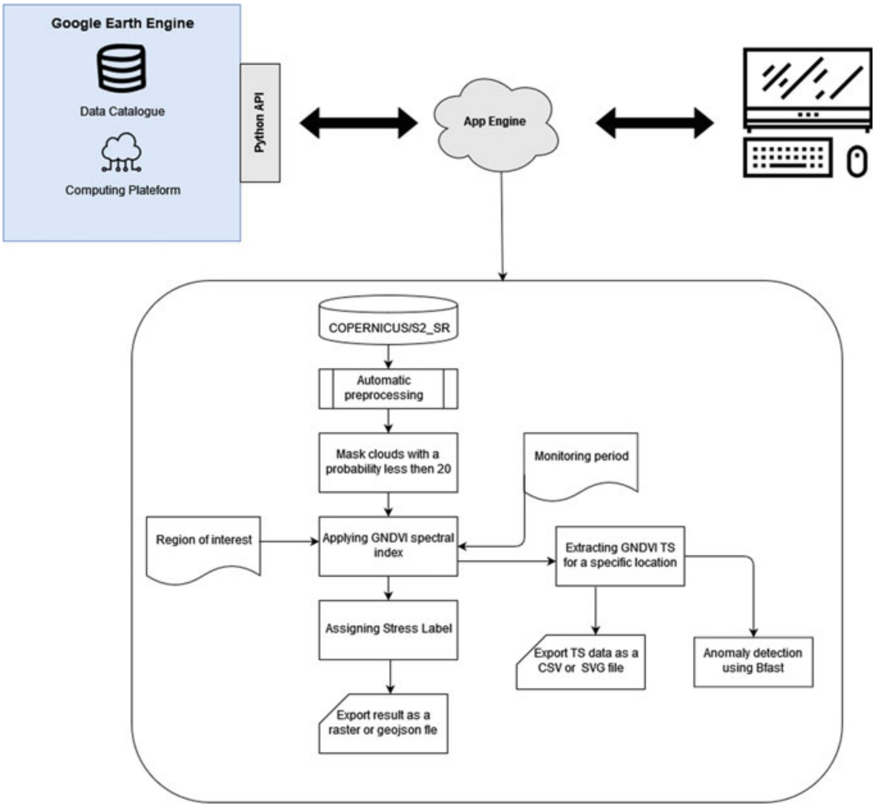


**Fig. 1** AppPopuli workflow

The input satellite data used to calculate the vegetation index GNDVI and its temporal series was the image collection 'COPERNICUS/S2_SR', corresponding to images captured by Sentinel-2 MSI with a processing level L2A [9]. This free imagery has a temporal resolution of 5 days and has been used in other near real time forest monitoring systems ([10, 11]). Clouds were removed using the Sentinel-2 Cloud Probability dataset [12].

The technical part of this tool was based in *Python*, which is a high-level, multi-purpose programming language, designed to support various programming paradigms, counting structured, object-oriented, and functional programming. The main code was executed in a Jupyter *Notebook* environment, that can be used to create and share documents that contain live code, equations, and visualizations as an open-source web application.

First and foremost, the tool was developed by combining functional and modular programming paradigms, in order to enable users to analyze and visualize Earth Engine datasets dynamically, Geemap a Python package for interactive mapping with Google Earth Engine was used, which is built upon ipyleaflet and ipywidgets [13]. Dealing with geospatial vector data in Python is quite complex but Geopandas extends the data types used by pandas to allow for spatial operations in an easy way. On the other hand, Rasterio reads and writes geospatial raster data and provides a Python API based on numpy multi-dimensional arrays and geojson formats.

When using the PoplarAlert system to visualize health changes of a specific location in poplar plantation, the tool offers numerous results among them is a Break Detection for Satellite Time Series data, this data is generated from PointPop. For detecting changes in the GNDVI trend, the BFASTmonitor algorithm was used. This algorithm provides functionality for monitoring disturbances in time series models [14], for this particular application, the time series data was collected for a two-year period to find meaningful anomalies, which can correspond to a health issue in the forest plantation.

## 3 Results

The web-based application PoplarAlert was developed and deployed on a local server, and it is available in both Spanish and English.

Figure 2 shows the interface of PoplarAlert, where the user can choose the language (English or Spanish), the start and finish date for the analysis and the area of interest, which can be drawn or uploaded. As well, different layers can be showed on the display (roads, etc.) to help locate the area.

After activating "Health status" the user will obtain a coloured map with three possible classes "No stress" (in green), "maybe stress" (in yellow) or "stress" (in red). The results are only showed for the selected area (Fig. 3). This information can be downloaded as an image, as a table or as a vector file.

The online tool allows the user to obtain extra information about a point in the study area (Fig. 4), providing the evolution of the GNDVI index for the selected period of time and also for the complete time series since 2017. As an example, Fig. 5 shows the GNDVI time series for a selected point from June 2021 to September 2021. This time series allowed for the identification of abnormal values which were related to water

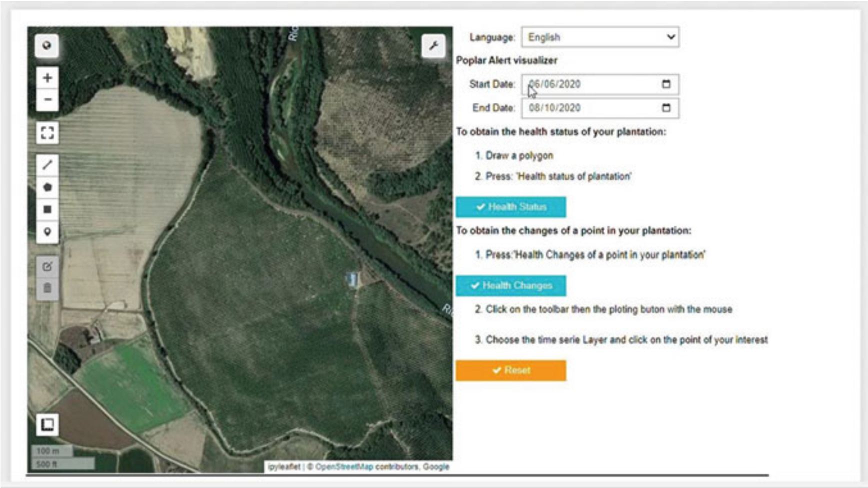


**Fig. 2** Interface for data entering (location, date)

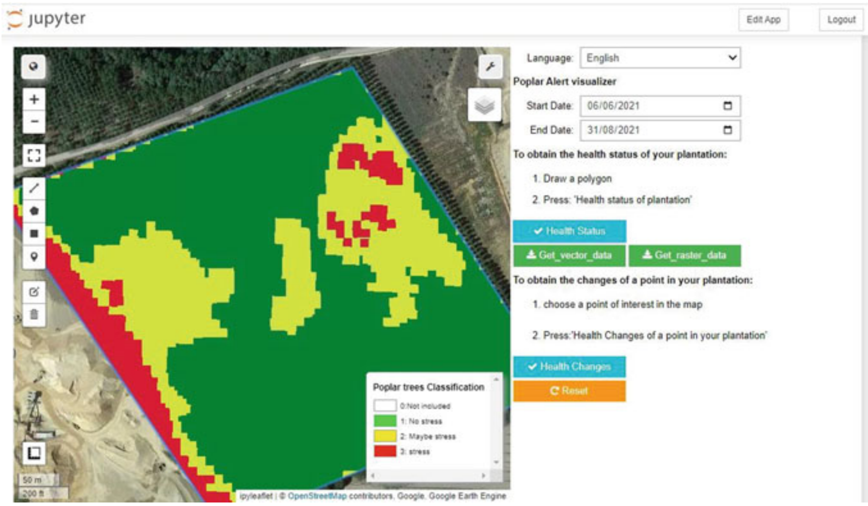


**Fig. 3** Output result for "Health status": three levels of water stress

stress. In the example (Fig. 5) a problem was detected on August 17th 2022 (GNDVI $< 0.5$), and was tracked back to see when it started (two weeks (red dots) earlier) and it was confirmed that it was a real issue and not an area with a typically low GNDVI.

This tool was tested in two poplar plantations, in two different locations in the province of León, comprising ca. 20 ha and more than 20 different clones. Overall, 5000 trees were monitored in the field, by assessing visually symptoms of water stress on a weekly basis from July to September, in 2021 and 2022 (Fig. 6). In addition, radial growth was monitored for 64 trees in those locations on a weekly basis during the same


**Fig. 4** Point locator for tracking changes in time

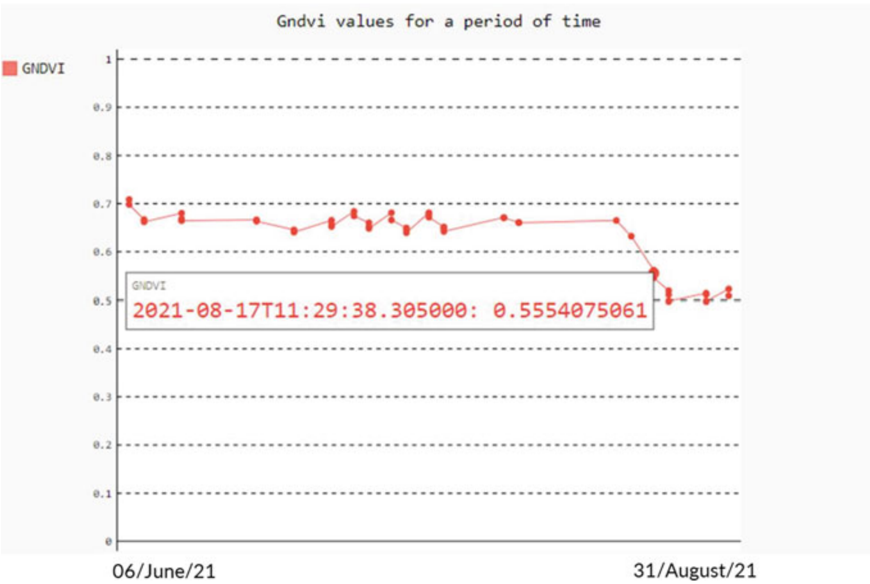


**Fig. 5** Example of time series of GNDVI, used to identify abnormal values which can be related to water stress. The problem detected on August 17th 2022 (GNDVI $< 0.5$). It was tracked back to see when it started (two weeks (red dots) earlier)

period of time, by using permanent dendrometers. The decrease in the radial growth rate was used as an early warning for water stress. The results confirmed the capability of PoplarAlert to detect water stress once it involves some leaf loss and/or drier/yellower leaves still on the tree (previously or during the leaf loss).

**Fig. 6** Water stress effects in one of the field plots where the performance of PoplarAlert was tested

## 4 Conclusion

PoplarAlert allows a user who is not an expert in remote sensing to obtain, through the application, clear and immediate information on the probability that damage due to water stress has occurred (information in the form of an image, graph, vector or table). It allows for the temporary reconstruction of a detected issue, going back in time and try to identify the start of it, and also, in some cases, going into the future to track the possible recovery. This tool is also applicable over large areas without increasing processing costs. Finally, PoplarAlert implies a substantial reduction of costs for poplar plantation monitoring, as a permanent network of field plots requires a larger effort and frequent visits to assess damage.

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# Influence of Ground PV Glass Addition on Selected Properties of Geopolymer Mortars

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**Abstract.** The Alkaline Activated Binders are a hope and a necessity to reduce the carbon footprint of the building materials industry. Many waste and recycled materials can be reused. In our work, we used activators and geopolymerization precursors: slag, waste concrete, metakaolin and glass from photovoltaic panels. We added a little glass, 1.1%, but even this amount has an impact on the microstructure of the mortar. The porosity decreased and the strength increased with the addition of the pulverized glass from the photovoltaic panels. A low Si/Al ratio, around 1, of the mortars cured in room conditions allowed to achieve compressive strength, around 12–14 MPa, open porosity was around 20%. The compressive strength of the geopolymer paste is slightly lower than that of geopolymer mortars. Permeability of mortars without glass increased almost 3 times. Phases changes after 2 and 4 months focused on strong carbonation reactions, what entitles to draw the conclusion of double decarbonizing properties of geopolymers.

**Keywords:** Geopolymers · Porosity · PV glass

## 1 Introduction

The main goal of many researchers from various fields is climate protection. The huge demand for building materials, in particular concrete, makes us think about more ecological solutions. As it is known, concrete is the second most widely sold product worldwide. There has been more and more research in recent years, as we are increasingly focusing on reducing equivalent $CO_2$ emissions, which is caused mostly by the production of a cement clinker. Geopolymer binders can be used instead of cement. Despite the fact that it is not a zero-emission product, because it requires the use of activators, it is still more ecological. Geopolymer is a commercial name for the alkali-activation of kaolinite/limestone/dolomite [1]. A 1908 patent of Kuhl (US Patent 900,939) was recognized as the first on the alkali activation of aluminosilicate precursors in order to obtained an ordinary Portland cement alternative material [2]. Many authors claim that Davidovits is considered the precursor of this field of science even before the 80's, while Provis and Van Deventer [3] noticed that the nomenclature introduced by Davidovits implies certain aspects of the geopolymer gel structure which do not correspond to reality. Therefore, due to the fact that this field is intensively developing now, clear rules should be introduced. However, based on the assumptions of Davidovits we prepared mixtures with a


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low Si/Al ratio, around 1, which gives mechanically not very strong geopolymers, with addition of glass.

The PV panels waste problem is serious [4]. According to the IRENA report [5] 1.7 to 8 million tonnes of cumulative PV panels waste will be generated by the end of 2030 and 60 to 80 million tonnes by the end of 2050. One of the elements of the panels is glass, which is considered to be chemically active when properly ground in the presence of appropriate activators [5–7]. Many studies have been conducted on reactive glass manufacture for possible use as Alkali Activated Binder (AAB) precursors with (variable) compositions located on the $Na_2O–SiO_2–Al_2O_3$ and $CaO–SiO_2–Al_2O_3$ ternary diagrams [6]. In geopolymers, high alkalinity and low calcium content favored the formation of N–A–S–H and N–(C)–A–S–H gels, unlike in the case of hydrated cement, where the C–S–H phase is the leading one. This material would have a polymerized tetrahedral coordinated network of silica and alumina. The sodium and calcium cations would act as lattice modifiers via ionic bonds, the weakest part of the structure, and the reactivity of the glass would depend on the degree of polymerization. According to some researchers, the most reactive glass compositions are influenced by the content of CaO, and according to others the presence of $Al_2O_3$ in the glass structure as essential for reactivity [6].

We would like to focus on PV glass (PVG), because there are is not too many articles concerning the application of powdered PVG in geopolimer matrices; although it was added only in small amount into our mortar specimens. Works on geopolymers with glass are very diverse due to different types of glass, different additives and the curing process [6–9]. However, quite decent strength values can be obtained, for example Hao et al. [10] examined the compressive strengths of metakaolinite-based geopolymer with solar panel waste glass after 28 days of curing. The geopolymer samples contained solar panel waste glass in the amount of 10 and 20% of the total mass. The strength was higher, 63 Mpa, when 10% of glass was used and 49 Mpa when 20% of glass was used. Besides the strength, another important property of geopolymers is heavy metal immobilization. They are able to stabilize hazardous and radioactive wastes better than Portland cement [11]. Słomka-Słupik et al. [9] detected that the presence of PV glass in mortars contributed to better binding properties of mercury and arsenic, but other metals were released.

In this work we studied alkali-activated mortars produced with photovoltaic glass powder in 5%; kaolin clay in 15%; ground granulated blast furnace slag in 30%; alumina-lime cement in 30%; and granulated autoclaved cellular concrete in 5%. The activator was sodium metasilicate with sodium hydroxide. The strength and porosity of mortars made with and without ground PV glass, and the main phase changes after the time of hardening of the paste with the glass were compared.

## 2 Materials and Methods

The chemical composition, determined by the XRF method, of the components used to prepare the mortar mixes is shown in Table 1.

The glass from the photovoltaic panels was cleaned of the black layer of encapsulant and solar cells and crushed to pieces up to 1 cm in size by a recycler. Photovoltaic glass

**Table 1** Components for preparation binder mixtures with their chemical composition

| Component | PVG | MK | GGBFS | ALC | ACC |
|---|---|---|---|---|---|
| *Content, wt.%* | | | | | |
| Silica as $SiO_2$ | 72.39 | 47.46 | 40.43 | 3.05 | 67.45 |
| Aluminium as $Al_2O_3$ | 1.10 | 36.75 | 7.88 | 42.52 | 2.32 |
| Sodium as $Na_2O$ | 13.41 | 0.02 | 0.46 | 0.08 | 0.26 |
| Calcium as CaO | 9.01 | 0.23 | 43.27 | 35.87 | 17.26 |
| Iron as $Fe_2O_3$ | 0.05 | 0.92 | 0.81 | 15.31 | 1.00 |
| Magnesium as MgO | 3.09 | 0.24 | 6.97 | 0.50 | 0.29 |
| Potassium as $K_2O$ | 0.02 | 0.88 | 0.29 | 0.09 | 0.60 |
| Titanium as $TiO_2$ | 0.02 | 0.24 | 0.28 | 2.01 | 0.06 |
| Manganese as MnO | $< 0.01$ | 0.02 | 0.16 | 0.07 | 0.02 |
| Phosphorus as $P_2O_5$ | $< 0.01$ | 0.08 | 0.02 | 0.06 | 0.04 |
| Chromium as $Cr_2O_3$ | 0.01 | 0.01 | 0.01 | 0.08 | 0.01 |
| Zirconium as $ZrO_2$ | $< 0.01$ | $< 0.01$ | $< 0.01$ | 0.05 | $< 0.01$ |
| LOI (550 °C) | 0.31 | | | | |
| LOI (1025 °C) | | 13.35 | 0.46 | 0.29 | 10.44 |

(PVG) was ground to make it more reactive and the particle sizes were as follows: $d_{10}$: 4.669 μm; $d_{50}$: 85.67 μm; $d_{90}$: 200.5 μm; mean: 97.19 μm; median: 85.67 μm;.

To prepare metakaolinite (MK), basing on the DTA/TG examination of kaolinite clay, it was calcined at 600 °C for 1 h in a laboratory ceramic kiln. According to XRD results, it contained amorphous phase (92.1%), dehydroxylated muscovite $KAl_3Si_3O_{11}$ (5.1%) and quartz (2.9%). Kaolin was degraded as well, but converted to an amorphous metakaolinite.

Specific surface area, according to Blaine, of GGBFS (ground granulated blast-furnance slag) was 3850 $cm^2/g$. According to X-ray diffraction (XRD), GGBFS was consisted mainly of amorphous phase, in 98%. Other phases: gehlenite and merwinite (melilites) and calcite were detected as well as.

In order to keep the Si/Al ratio around 1 in the mixes, aluminate-lime cement (ALC) was used as the aluminum source. In addition, calcium was needed for the pozzolanic reactions. The aluminate-lime cement consisted of the main CA phase and other phases, such as: C4AF, C12A7, and C2AS (where the abbreviations mean: C = CaO, A = Al2O3, F = Fe2O3, and S = SiO2).

Autoclaved aerated concrete, in other words autoclaved cellular concrete (ACC), is made of cement, lime, gypsum, aluminium powder or aluminium paste as a blowing agent, sand, and water. The production process of aerated concrete consists of exposing it to saturated water vapour in steam autoclaves. Remains of ACC blocks from the construction site, were milled and sieved. The fraction less than 65 μm was used to prepare mortar mixtures. According to XRD examination, AAC was composed of amorphous phase: 26.6%; quartz: 38.4%; tobermorite: 24.1%; calcite: 4.0%; anorthite: 1.5%; microcline: 2.1%; anhydrite: 2.0% and gypsum: 1.5%.

In order to prepare beams of mortars with dimensions of 4 cm × 4 cm × 16 cm for binder strength test, according to PN-EN 196-1 [12], standard sand was used, as well.

To prepare alkali activated mortars, an activating solution (activator) was prepared. Sodium metasilicate pentahydrate $Na_2SiO_3{\cdot}5H_2O$, sodium hydroxide NaOH, and distilled water (0.06 μS) were mixed in 1: 2: 10.2 mass proportion, respectively. Firstly metasilicate was dissolved using a magnetic stirrer and then sodium hydroxide was added, so that the temperature of the solution was not too high [13] (Activators are indicated in Table 2).

**Table 2** Composition of mixtures, in $\%_{mass}$

| Component | Designation of mixture and components amount. % | | |
|---|---|---|---|
| | M.6.1 | M.6.1.1 | M.6.1z |
| PVG | 1.1 | – | 3.3 |
| ACC | 1.1 | 1.1 | 3.3 |
| MK | 3.2 | 3.3 | 9.9 |
| GGBFS | 6.5 | 6.5 | 19.7 |
| ALC | 6.5 | 6.5 | 19.7 |
| $Na_2SiO_3{\cdot}5H_2O$ | 1.1 | 1.1 | 3.3 |
| NaOH | 2.2 | 2.2 | 6.6 |
| Standard sand | 67.2 | 68.0 | – |
| Distilled water | 11.2 | 11.3 | 34.2 |

## 3 Results with Analysis

### 3.1 Porosity (M.6.1 and M.6.1.1 Specimens)

Mortars of the same composition were tested for porosity (see Fig. 1), but no PV glass was added to the M.6.1.1 mortar. The graph shows that the porosity of the mortars is characterized by two main peaks, while the graph of the porosity of the mortar without PVG (M.6.1.1) is shifted towards the higher porosity values. The preliminary analysis therefore suggests that ground glass from PV panels seals the structure of geopolymer mortars. However, there may be an explanation as to the increased proportion of sand in the mass of the mixture M.6.1.1. increasing the number of larger pores: 0.5–2 μm. In addition, after removing the glass, the permeability slightly increased and the tortuosity of the pores decreased (see specimen M.6.1.1. in Table 3), also less mercury was injected while the open porosity was lower.

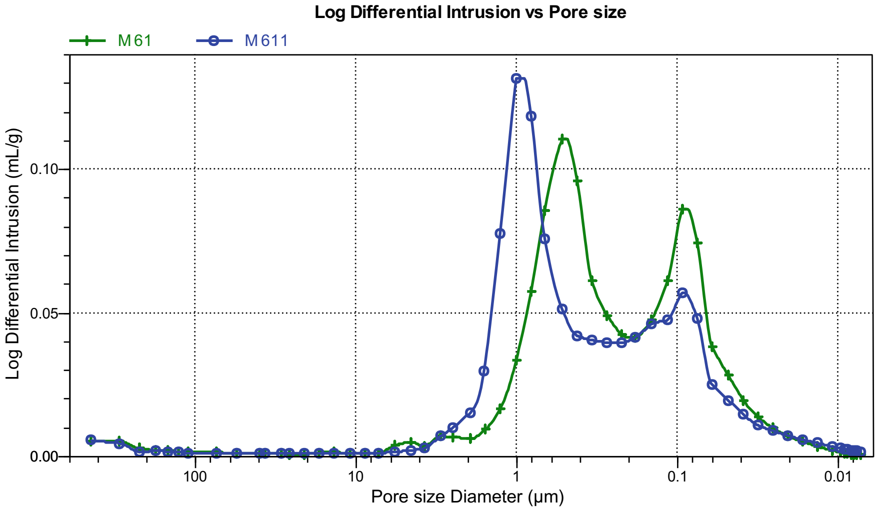


**Fig. 1** Porosity comparison of M.6.1 and M.6.1.1 specimen

**Table 3** Selected porosity parameters

| Parameter | unit | Specimen M.6.1 | Specimen M.6.1.1 |
|---|---|---|---|
| Mercury intrusion volume | ml/g | 0.100 | 0.099 |
| Real density | g/ml | 2.55 | 2.55 |
| Open porosity | % | 20.31 | 20.17 |
| Permeability | mdarcy | 0.06 | 0.19 |
| Tortuosity | – | 397.8 | 214.4 |

### 3.2 Phases (M.6.1z Specimen)

Hardened paste of specimen M.6.1z was examined after 2 (Fig. 22 in [9]) and 4 months of curing in room condition (Fig. 2). The main phase was the amorphous phase (60.7%), silicated katoite (10.2%), sodalite (6.3%), katoite (5.4%), quartz (4.8%), calcite (2.9%), aragonite (2.4%) and others, as shown in Fig. 2. It was noticed that the composition of the mortar had changed, mainly in terms of carbonation. During these 2 months, carbonate phases such as hydrotalcite, aragonite, calcite were formed. The influence of PV glass on this process has not been detected here. However, it can be assumed that calcium escapes from the glass truss (due to the dissolution of the glass in a highly alkaline environment) and further as free lime reacts with atmospheric $CO_2$.

### 3.3 Strength After 28 days

Table 4 shows the results of the bending and compressive strength tests of the analyzed samples. All mortars were cured in laboratory room conditions: 25 ± 2 °C and humidity:

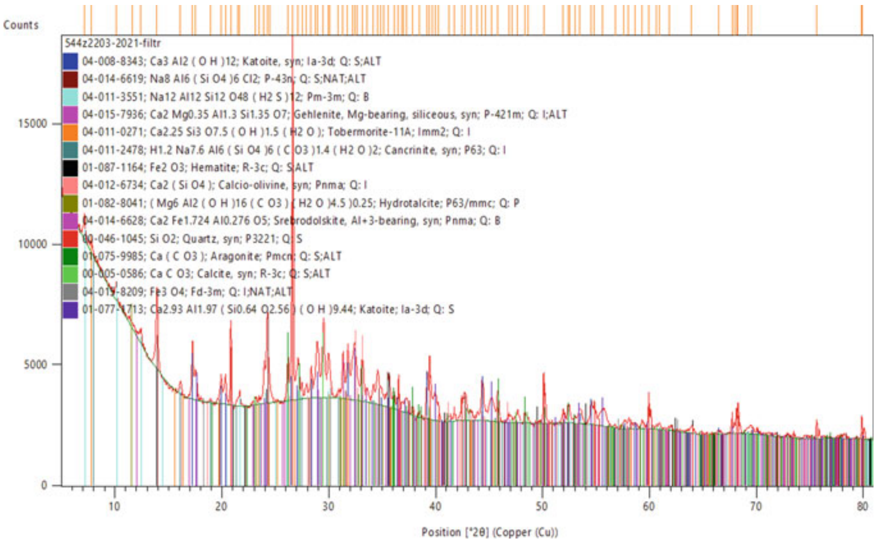


**Fig. 2** Phase composition of M.6.1z specimen, after 4 months

60%. As this was a pilot study, unfortunately only one sample from each series was tested. The mortar without glass (M.6.1.1) showed a slightly lower strength compared to the mortar with ground PVG (M.6.1). Thus, glass had a positive effect on the mechanical properties of the analyzed mixture. Generally, however, its grain size and activation conditions are very important [6–8]. Palomo et al. [6] also indicates that synthetic glasses, depending on the CaO content, are possible to generate geopolymers with compressive strengths even to 60 MPa.

**Table 4** Strength values after 28 days of hardening in room conditions of specimens M.6.1, M.6.1.1 and M.6.1z

| Type of geopolymer mixture | | Strength, MPa | |
|---|---|---|---|
| | | Bending | Compressive |
| Mortar | M.6.1 | 3.83 | 14.45 |
| Mortar | M.6.1.1 | 3.28 | 12.37 |
| Paste | M.6.1z | 1.30 | 11.43 |

Unfortunately, the strength of the paste (M.6.1z) cannot be compared with the strength of the mortars, although the results are also presented in Table 4. It should be noted, as well, that the paste was very wet, so after 14 days of hardening it was placed in an oven for 14 days in 105 °C. As can be seen, the content of standard sand in the mortars increased bending strength and slightly increased compressive strength, comparing with M.6.1z.

## 4 Conclusions

It is difficult to compare the own research presented in this work with the multitude of studies presented in the literature, due to the lack of repeatability of the composition used. Therefore it must be stated that the literature analyzes and the presented research show that in the field of geopolymers (alkaline activated binders) there are many possibilities for scientific development, opening to market needs and, above all, ecological solutions. The research presented here shows as below.

After removing a small amount (1.1%) of the ground PV glass panels from the geopolymer mortar, the permeability and the largest pores content (from 0.5 to 2 μm) increased.

The results of the phase composition tests confirmed that after a longer period of storage of the slurry samples in room conditions, quite strong carbonation took place. Therefore, it can be safely stated that Geopolymers are materials with *double decarbonizing properties*. They lead to decarbonisation due to the reduction of the cement clinker production amount and due to their reactivity with the surrounding natural environment. Thus, they can serve as filters and it is necessary to test the porosity after different hardening times.

Even a small amount of ground glass increased the mechanical strength of the mortars. Thus, it can be argued that it is reactive. Therefore another direction of research should be the observation of the contact zone of the ground glass with the binder matrix.

Glass PV content has an effect on metal bonding, as shown by literature studies, but research needs to be continued to draw a more detailed conclusion.

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# Production of Nanobiochar from Sewage Sludge for the Adsorption of Emerging Contaminants (ECs) from Water and Wastewater

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**Abstract.** Biochar is the solid product of biomass pyrolysis. Nanobiochar is a new concept that combines biochar technology with nanotechnology in order to create advanced adsorptive and sustainable materials. This can be achieved by using waste materials as feedstock for nanobiochar production. Emerging Contaminants (ECs) contain of a list of organic pollutants that get increasingly detected in surface waters during recent years, causing harmful effects to the recipient organisms. These contaminants cannot be removed conventionally by WWTPs resulting to the search for efficient solutions to resolve this problem. For this purpose, nanobiochar was produced from sewage sludge combined with two nanomaterials, Graphene Oxide (GO) and Carbon Nanotubes (CNTs). Nanobiochars were physicochemically characterized and then applied as adsorbents for the removal of six organic micropollutants listed as ECs from water and wastewater samples. Results showed that CNTs were the best choice of nanomaterial to enhance sewage sludge by effectively removing at least 80.8% of all contaminants from water and wastewater during the first 5 min of contact time, while GO nanobiochars required higher contact times (up to 60 min) in order to remove most pollutants sufficiently, except for 2.4D, which was difficult to remove in this case.

**Keywords:** Nanobiochar · Emerging contaminants · Waste reuse

## Abbreviations

| | |
|---|---|
| **2.4D** | 2,4-Dichlorophenol |
| **ADT** | Androsterone |
| **BPA** | Bisphenol A |
| **CNTs** | Carbon NanoTubes |
| **EC** | Electrical Conductivity |
| **ECs** | Emerging Contaminants |
| **E1** | Estradiol |
| **EE2** | Ethinyl Estradiol |
| **GO** | Graphene Oxide |
| **MSW** | Municipal Solid Wastes |
| **NOR** | Norethindrone |
| **SS** | Sewage Sludge |


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| | |
|---|---|
| SS_CNT_600 | CNT doped nanobiochar from Sewage Sludge, produced at 600 °C |
| SS_GO_600 | GO doped nanobiochar from Sewage Sludge, produced at 600 °C |
| WWTP | Wastewater Treatment Plant |

## 1 Introduction

Biochar is the solid product of biomass pyrolysis and can be used as an adsorptive material for the decontamination of polluted waters, among other uses. Combining biochar technology with nanomaterials, in order to improve the properties of the final product, results in the creation of a concept called nanobiochar [1]. It is important that the feedstock used for the creation of such product is waste biomass of any type (agronomic origin, sewage sludge, manure, MSW), which is reused by being converted into biochar for further anti-pollution purposes, highlighting its sustainability [2]. Emerging Contaminants (ECs) contain of a list of organic pollutants that get increasingly detected in surface waters during recent years, causing harmful effects to the recipient organisms because they usually are resistant to biodegradation and can easily bioaccumulate in living organisms, which can cause various consequences such as hormonal disfunction, genetic mutations, cancer etc. to the recipients [3]. These contaminants get found in low concentrations in water and wastewater and cannot be removed conventionally by WWTPs resulting to the search for efficient solutions to resolve this problem [4].

In this work, nanobiochar was produced from sewage sludge combined with two nanomaterials, Graphene Oxide (GO) and Carbon Nanotubes (CNTs), at 600 °C pyrolysis temperature. The produced materials were physicochemically characterized and then applied as adsorptive materials for the removal of six organic micropollutants listed as Ecs (2,4-Dichlorophenol, Bisphenol A, Norethindrone, Androsterone, Estradiol, Ethinyl Estradiol) from water and wastewater samples.

## 2 Materials and Methods

Anaerobically digested dewatered secondary sewage sludge (SS), collected from the Psyttalia Wastewater Treatment Plant, located in Athens, Greece was used as feedstock for the production of nanobiochar. The samples were initially oven-dried at 90 °C for 48 h and then pulverized to a particle diameter $< 0.5$ mm. Two nanomaterials were implemented into the biomass to improve the final product properties, Graphene Oxide (GO) produced in our laboratory and –COOH functionalized graphitized multi-walled Carbon Nanotubes (CNTs) with 99.99% purity and 28–48 nm outside diameter (Nanografi S.A.). Nanomaterial implementation into the biomass samples was performed using the dip-coating procedure [5]. Briefly, CNT and GO suspensions were prepared by adding 4 g nanomaterial in 400 mL double-de-ionized water (1% nanomaterial w/v). The suspensions were then ultra-sonicated at 25 kHz for 1 h, in order for the nanomaterials to disperse in water. After this step, 40 g of the pre-treated sewage sludge was added to the suspensions and then homogenized at 800 RPM, using a mechanical stirrer, resulting to 10% w/w nanomaterial-doped biomasses. After the homogenization stage, samples were oven-dried at 80 °C for 48 h and then placed in air-tight sealed crucibles for pyrolysis. Nanobiochar production took place in a muffle furnace (Linn High Therm) at 600 °C using a heat rate of 6 °C $min^{-1}$. Samples stayed in the pyrolysis chamber for 60 min at the desirable temperature, while 99% pure Nitrogen gas was being supplied at a 200 L $h^{-1}$ rate.

Several analyses were performed in order to assess the physicochemical properties of the produced nanobiochars. Ash content was determined by dry combustion in a muffle furnace at 750 °C for 6 h. Organic carbon ($C_{ORG}$) content was determined using the SSM-500A solid sample module of a Shimadzu Total Organic Carbon analyser. Specific surface area was determined by using a NOVA 2200, Thermo Scientific Surfer gas sorption analyzer (samples were de-gasified at 200 °C), by applying the BET (Brunauer-Emmet-Teller) method. pH and electrical conductivity (EC) values were determined using a multi-meter Crison Instruments (micropH 2202), after shaking biochar with de-ionized water, in a 1:20 ratio, for 90 min [6].

Six organic micro-pollutants were selected for the conduction of the adsorption experiments; two phenols, 2-4D and BPA, two estrogens E1 and EE2, and two androgens, ADT and NOR. These compounds have been identified as Emerging Contaminants (ECs) and are being found in WWTP effluents, in concentrations of ng $L^{-1}$ to μg $L^{-1}$ [7]. The following initial concentrations were selected to produce the polluted mix: 2-4D and BPA: 20–40 μg $L^{-1}$, E1 and EE2: 40–60 μg $L^{-1}$, ADT and NOR: 70–90 μg $L^{-1}$. The mentioned pollutants were spiked into 500 mL of table water and secondary wastewater (before the chlorination stage), acquired from the Municipal Water and Sewerage Company of Chania, creating the initial polluted mixes. The adsorption experiments took place in light-protected conical flasks, at 22 ± 1 °C, in duplicate repetition. 50 mL of the aqueous polluted sample and 0.15 g of biochar (equal to a dose of 3 g $L^{-1}$) were added in the flasks. Three adsorption residence times were investigated for each sample type, 10, 30 and 60 min concerning the GO nanobiochars and 5, 10 and 30 min for the CNT nanobiochars. After the adsorption experiments, samples were filtered with 0.45 μm PVDF Whatman filters.

The acquired samples were analyzed using Solid Phase Micro-Extraction (SPME) followed by GC–MS analysis, according to a modified method developed by Antoniou et al., (2009) [8], which is described thoroughly in our previous work [6].

## 3 Results and Discussion

The results concerning nanobiochar physicochemical characterization are presented in Table 1.

**Table 1** Nanobiochar physicochemical characterization

| Sample ID | pH | EC (μS·$cm^{-1}$) | Ash (%) | $S_{BET}$ ($m^2$·$g^{-1}$) | $C_{org}$ (%) |
|---|---|---|---|---|---|
| SS_GO_600 | 7.9 | 326.3 | 60.4 | 55.2 | 36.5 |
| SS_CNT_600 | 7.6 | 380.3 | 53.1 | 58.1 | 39.7 |

Based on the data of Table 1, it is clear that there were no significant differences between the two samples, which was expected since the major parameter affecting biochar structure is biomass type and pyrolysis conditions [9]. pH values were neutral for both samples (7.9 and 7.6), while EC values were 326.3 $\mu S \cdot cm^{-1}$ and 380.3 $\mu S \cdot cm^{-1}$ for SS_GO_600 and SS_CNT_600 accordingly. The expected high inorganic content of sewage sludge was depicted by the ash content analysis of nanobiochar, where values ranged between 53.1% and 60.4%. This is normal for waste based biochars, due to the nature of the biomass, while agronomic waste biomasses (lignocellulotic) show much lower percentages of ash in their structure [10]. Similar behaviour was observed for the specific surface area and organic C content of both nanobiochars. $S_{BET}$ values were in the range of 55.2 $m^2$ $g^{-1}$ to 58.1 $m^2$ $g^{-1}$, while $C_{org}$ content was 36.5% and 39.7% accordingly. These values are normal for sludge based biochars, but lower than biochars produced by agronomic biomasses [11].

Figures 1 and 2 contain the adsorption kinetic results of nanobiochar SS_GO_600 in Table water and secondary wastewater effluent accordingly. The investigated pollutants were removed by 37.1–97.5% after 60 min of contact time in Table water, while in wastewater adsorption rates also ranged between 29.3% and 97.5% after 60 min of contact time. The main difference between the two figures is that all pollutants except for 2.4D were removed by higher than 59% after the first 10 min of contact time in Table water, while in wastewater 60 min of contact time were necessary for most pollutants to be removed sufficiently. This behavior was expected since wastewater may contain other organic or inorganic substances in low concentrations that could provoke an antagonistic effect concerning the adsorption of the investigated pollutants [12]. 2.4D was proven to be the most difficult to remove pollutant, providing slow removal rates of 37.1 and 29.3% in Table water and wastewater accordingly. This was explained in our previous work, where because of the low pka value of 2.4D the ion exchange adsorption mechanism is limited [6].

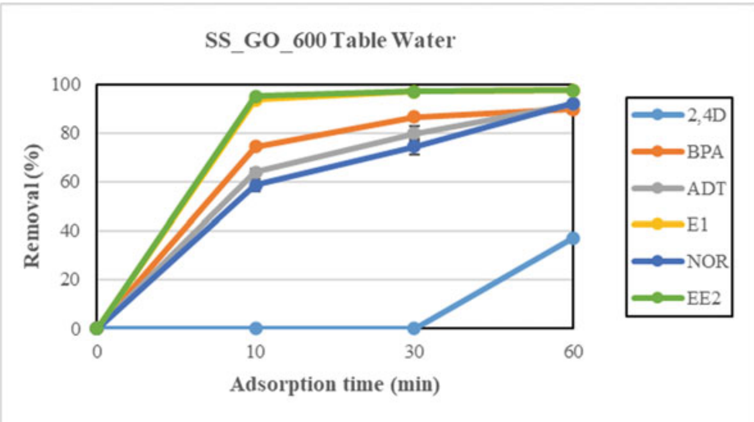


**Fig. 1** Adsorption kinetics of SS_GO_600 in table water

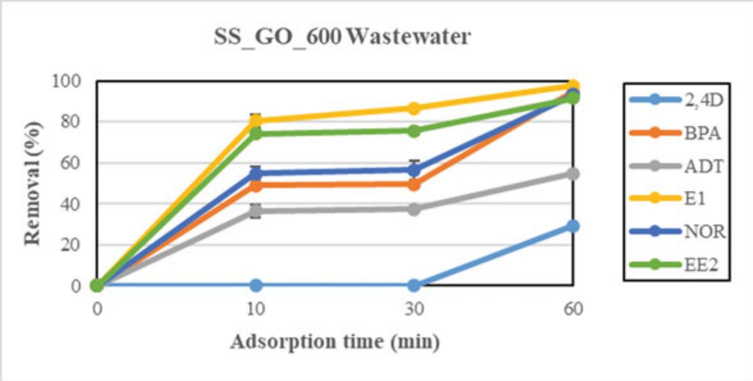


**Fig. 2** Adsorption kinetics of SS_GO_600 in secondary wastewater

The results concerning the adsorption experiments on SS_CNT_600 in Table water and wastewater are depicted in Figs. 3 and 4 accordingly. It is clear that this nanobiochar was significantly more effective than the GO-doped one, providing removal rates of 83.6% up to 92.8% in Table water and 80.8–94.2% in wastewater, after just 5 min of contact time. This was the reason why shorter contact times were studied in the case of CNT nanobiochar. All pollutants, including 2.4D, were efficiently removed after just 5 min which was attributed to the important −COOH functional groups of CNTs that efficiently resolved any previous problems concerning the polarity of some investigated pollutants [1].

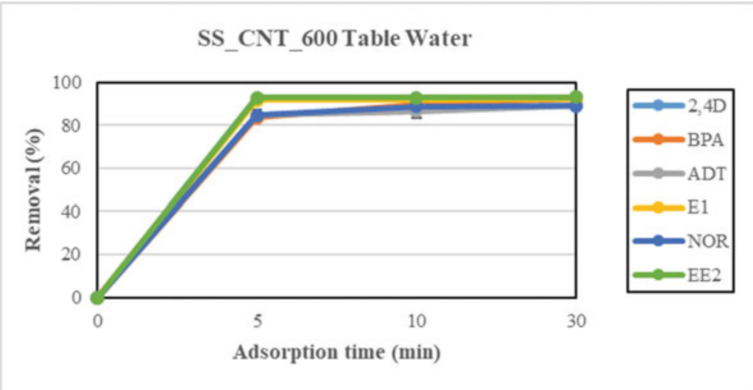


**Fig. 3** Adsorption kinetics of SS_CNT_600 in table water

## 4 Conclusion

The results of this work showed that despite the fact that the two nanobiochars did not have any significant differences between them in terms of physicochemical structure,

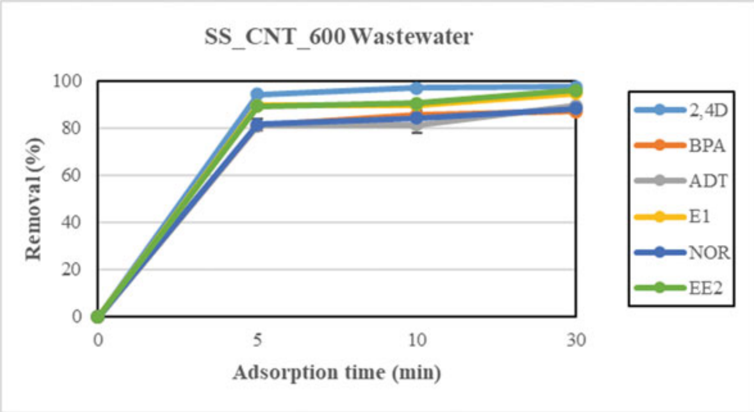


**Fig. 4** Adsorption kinetics of SS_CNT_600 in secondary wastewater

they behaved differently concerning the adsorption of six organic micro-pollutants from water and wastewater. SS_CNT_600 biochar was more efficient than SS_GO_600 by at least 40% after 10 min of contact time in water and wastewater, which was attributed to the vital -COOH functional groups on CNT surface. These findings suggest that CNTs can be used in low dosages to upgrade a difficult to manage waste biomass like sewage sludge and convert it into a material that can be used further for its anti-pollution properties, in filter production.

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# Near-Real Time Forest Health Monitoring Using Ecophysiological Sensors and the Internet of Things (IoT). A Study Case for Water Stress in Sustainable Poplar Plantations

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**Abstract.** Having a damage/stress detection and monitoring system in semi-real time will allow a quantitative improvement in the poplar (*Populus* spp.) sector, from the point of view of sustainable and responsible wood production. The aim of this work was to develop a near-real-time system for monitoring water stress in poplar clone plantations using the sap flow density measured by ecophysiological sensors and transmitted by the Internet of Things (IoT). Results showed a high correlation between the sap flow density and the growth in diameter measured weekly in the field for trees under water stress (Pearson's r > 0.81) and confirmed the suitability of this variable as an early warning indicator of damage to poplars due to water stress. In an early warning system for water stress, an average sap flux density value of 0.7–0.8 between 12 and 3 pm could be used as a threshold, since sap density fluxes under that value have showed weekly growth values of zero or close to zero.

**Keywords:** Sap flow · IoT · Forest · Early warning

## 1 Introduction and Objectives

### 1.1 Introduction

In recent years, technologies have been developed that allow forest ecosystems to be monitored in real time using intelligent systems that use the "Internet of Things" (IoT). The term "Internet of Things" was first used in 1999 by British technology pioneer Kevin Ashton to describe a system in which objects in the physical world were able to connect to the Internet via sensors without the need for human intervention [1]. Thus, IoT tools provided new ways to connect ecosystems to smart monitoring systems, therefore these technologies have been used in environmental management, such as mapping changes


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in the composition and structure of vegetation [2, 3], monitoring urban tree ecosystem services [4] or parameters in precision agriculture [5], as well as in the detection of fires, pollution sources and monitoring of illegal deforestation [6]. In addition, by monitoring the functional characteristics of trees (such as sap flow or relative humidity of the trunk) and their response to biotic and abiotic factors, the aim is to improve the management of these stands and their resilience [7].

Based on these IoT systems, a low-cost multifunctional device has been developed for the real-time observation of physical and biological parameters of trees applicable to forest monitoring called "TreeTalker" (now TreeTalker+ version 3.3; TT+). This device was developed by Nature 4.0 [8] and is capable of hourly collecting and measuring several tree parameters, such as water transport in the trees (through a sap flow sensor), the spectral characteristics of the electromagnetic radiation received under the tree canopy (through a spectrometer), the stability of the trees (through an accelerometer), microclimatic parameters such as the air temperature and humidity, as well as wood humidity and temperature in near-real time [4, 7, 8]. The availability of these data helps to make informed decisions in almost real time to improve the management of forests while considering their physiological condition [8].

On the other hand, Spain is the third country in Europe with the largest number of poplars, with Castile and León being the first European region in production of poplar wood. It is estimated that there are around 44,000 ha of poplar plantations in the region, which account for 60% of the cultivated area at the state level [9]. From a point of view of sustainable and responsible wood production, having a damage/stress detection and monitoring system in semi-real time would allow a quantitative improvement in the poplar sector in Castile and León, in terms of productivity. In addition to the commercial aspects, it must be considered that detecting early and monitoring damage to poplars supports the success in the management of existing plantations, making them healthier, more resilient, and therefore capable of growing at a higher rate, producing more wood. Also, this will provide greater benefits in ecosystem services such as carbon sequestration, alongside other aspects aligned with the 2030 Sustainable Development Goals, such as decent work and economic growth, production and responsible consumption and climate action [10].

### 1.2 Objective

The goal of this work was to develop a near-real-time system for monitoring water stress in poplar (*Populus* spp.) clone plantations using ecophysiological sensors and the Internet of Things (IoT). For this, our aim was to determine the suitability of the density of the sap flow measured by the ecophysiological sensor as an indicator to detect damage due to water stress in poplar plantations.

## 2 Material and Methods

### 2.1 Study Area and Sensor Network

Considering the importance of the poplar industry in the region of Castile and León, the province of León was chosen as the study area. The study sites were established in two plantations of hybrid poplar clones, respectively located in the municipalities of Villamañán and Villasabariego (Fig. 1). The plot located in the municipality of Villamañán (VM), is at 744 m above mean sea level (mamsl), with an average annual rainfall of 556 mm and an average annual temperature of 10.9 °C. This plot is in a deep-rooted poplar plantation established in 2011 with an area of 18.1 ha and a plantation frame of 6 m × 6 m. The plot located in the municipality of Villasabariego (VS) has climatic characteristics similar to VM, located at 798 mamsl. It is poplar plantation established in 2012 with deep-root planting, with an area of 7.89 ha and a plantation frame of 6 m × 6 m.

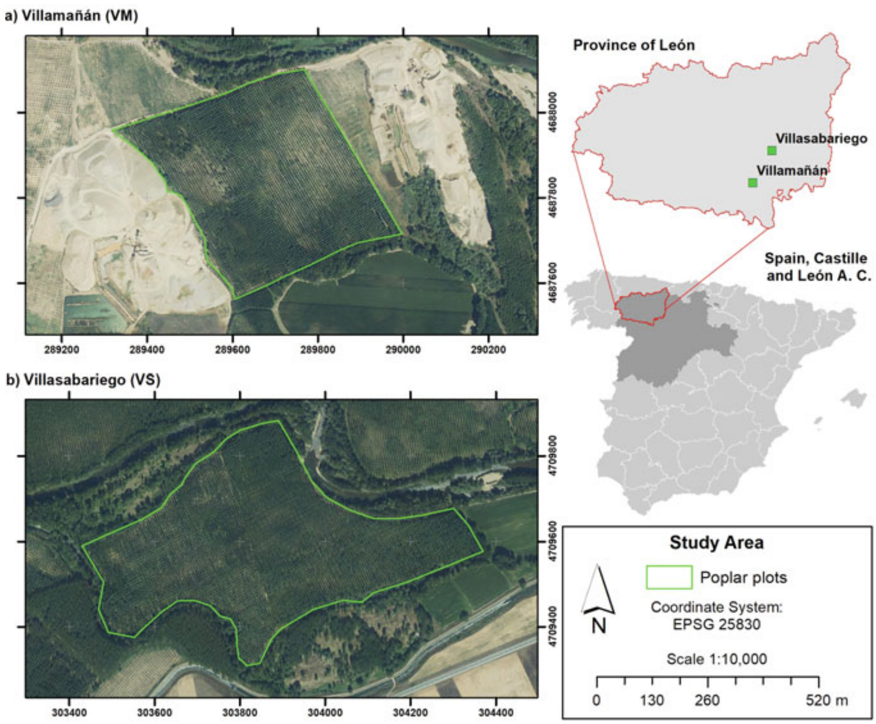


**Fig. 1** Study area in the two plots (**a** and **b**) of poplar plantations in the Province of León

A total of five TreeTalkers (TT+) version 3.3 [8] were installed. They are ecophysiological sensors which record data every hour. Figure 2 shows the setup of these devices in the field. They were identified by a TTid assigned by the site and tree inventory number, and the TTsn which corresponds to the serial number from its factory (Table 1). These sensors use a low power chipset LoRa for data transmission, to communicate with the TTcloud [8]. LoRA is a long distance and slow speed wireless protocol which allows the connection among several sensors using a minimum amount of energy. The TTCloud is connected to the internet via the GPRS network and sends data to a computer server (Altervista), provided by Nature 4.0.

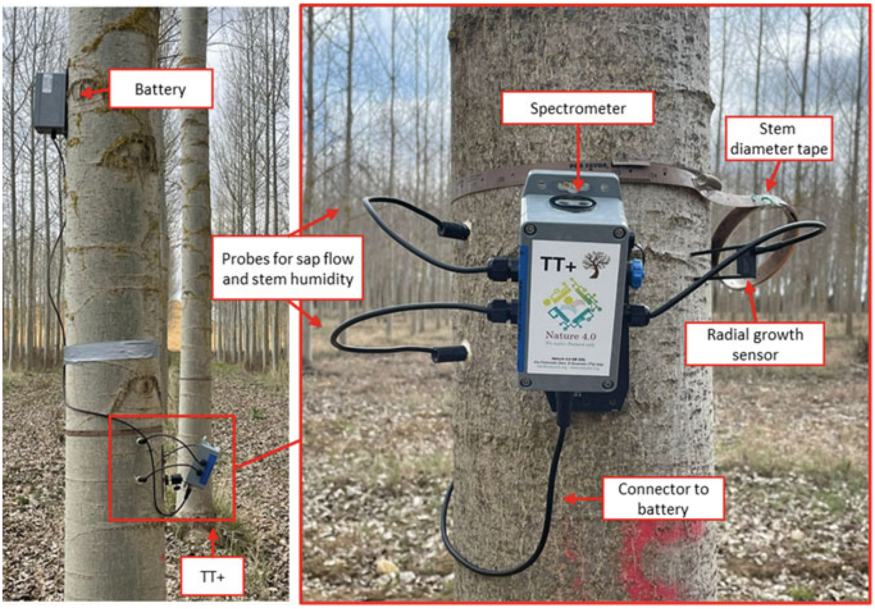


**Fig. 2** Feature parts of TT+ installed on VM_PIE20 (left) and VM_PIE15 (right)

**Table 1** Information about the sensors installed in the field, trees and locations

| TTsn | TTid | TTCloud | Clon | Age in years | Municipality | Installation date |
|---|---|---|---|---|---|---|
| 621B0392 | VM_PIE20 | C0210043 | Raspalje | 12 | Villamañán | 03/23/2022 |
| 621B0393 | VM_PIE22 | C0210043 | Beaupre | 12 | Villamañán | 03/23/2022 |
| 621B0394 | VM_PIE15 | C0210043 | I-214 | 12 | Villamañán | 03/23/2022 |
| 621B0396 | VS_PIE12 | - | Raspalje | 11 | Villasabariego | 03/23/2022 |
| 621B0397 | VS_PIE33 | - | USA 184/411 | 11 | Villasabariego | 03/23/2022 |

## 3 Ecophysiological Data Gathering and Processing

Among the different variables measured by the TT+ 3.3., two were analyzed in this work: sap flux density and electromagnetic radiation under the canopy. After this data was recorded by the sensors, it was sent to the server and stored in the database. This database was defined by records displayed as digital numbers (d.n.) and distinct types of string data, and then converted into measurable physical variables. In this case, the R programming language [11] in RStudio (v. 2022.07.1 + 554) was used for this task, using an in-house code, since there was no code available to process the TT + 3.3. data. The procedure to collect and process the sap flux density is described below.

Sap flow methods can be applied to analyze diurnal seasonal patterns of transpiration and stomatal conductance, as well as to quantify their responses to hydroclimatic variability [12]. Then, in estimating sap flow density with TT+, this uses a thermal dissipation method with repeated heating cycles—through two probes, the reference probe (Ref) and the Heater probe—, known as Granier's method [13], who found an empirical relationship between the sap flow density (Js; l dm–2 h– 1) and an index of change in the temperature difference, called the alternative flow index (Ka; dimensionless) [14].

Thus, the sap flux density was calculated by firstly converting the d.n. into temperature (°C), then applying a Savitzky-Golay smoothing filter, and lastly using the following calibration formula from Nature 4.0 (2021) TT+ manual [15] (Eqs. 1 and 2).

$$\Delta T_i = T_{on} - T_{off} \tag{1}$$

$$Sap\,flux\,density\left(ldm^{-2}h^{-1}\right) = 4.79 * \frac{\Delta T_{max(24hrs)} - \Delta Ti}{\Delta Ti} \tag{2}$$

where $\Delta T_{\mathrm{i}}$ is the temperature difference of the probe after cooling for 50 min and heating for 10 min, that can be evaluated based on both heater and reference probes or only the heater probe data; and $\Delta T_{\mathrm{max(24hrs)}}$ is the maximum temperature difference during one day for $\Delta T$.

Sap flux density was calculated for each hour for each tree, but only the values registered between 12 and 3 pm were used in this analysis, since that time period showed the maximum values in the time series, and they should correspond with the maximum in stomatal activity. Then, the moving average for a period of 5 days was calculated for each tree for July and August 2022. Data from March to June was not used in this work since there were no water stress events during that period. Data for VS_PIE33 could not be used since the sensor had an anomaly during some periods.

## 4 Other Field Data

Growth in diameter at 1.30 m was measured weekly for each tree, using permanent dendrometers, with a measurement resolution of 100 μm. The measurements in Villamañán and Villasabariego were conducted from March 23rd, 2022 until August 1st, 2022. In addition, the health status of each tree was assessed once a week (leaf, bark, and stem diseases/pests). VM_PIE20 showed no radial growth since June 29th, VM_PIE15 since July 6th and VM_PIE22 since July 20th. It was verified that this lack of growth was due to water stress, since no other pathogen/pest were detected, and other trees in the plot, closer to the water table, were still growing (Fig. 3). VS_PIE12 and VS_PIE33 did not stop growing during June or July.

## 5 Water Stress Detection

During previous years it was observed that very low radial growth values (close to 0) in the growing period (June/July) were related to water stress, as a previous phase to leaf loss. The hypothesis was that, in trees affected by water stress, there was a correlation

**Fig. 3** Poplar trees close to the water table and with no water stress issues (above) and trees affected by water stress (leaf loss and no radial growth) (below) in the Villlamañán site

between radial growth and sap flux density, and that there was a threshold value in the sap flux density below which the growth was zero or very close to zero in the growing season. In order to confirm this hypothesis, the Pearson product-moment correlation coefficient between the moving average of the sap flow between 12 and 3 pm for each tree and the weekly growth in diameter was calculated. Moreover, the existence of a threshold value in the sap density, which could be used as an alert to detect water stress which involved no growth was tested.

## 6 Results and Discussion

### 6.1 Sap Flux Density for Water Stress Detection

The results of the correlation analysis between the sap flow density measured by the TT+ and the growth in diameter measured weekly in the field, confirmed the suitability of this variable as an early warning indicator of damage to poplars due to water stress. Pearson's correlation values were 0.89, 0.88 and 0.81 for VM_PIE15, VM_PIE20 and VM_PIE22, respectively, at the 95% confidence level. For VS_PIE12, which did not show symptoms of water stress or no growth, there was no significant correlation ($r = -0.41$, p-value $= 0.30$). For VM_PIE15 and VM_PIE20, which were the fist to show symptoms of water stress, the lines which show the linear correlations between the variables (Fig. 4) are very similar and almost overlap. VM_PIE22 followed a different pattern and also one date has no data, since the battery level of the TT+ was too low to register the values. Regarding the sap density flux value to use as a threshold for an early warning system for water stress, 0.7–0.8 could be used, since sap density flux under that value have showed growth values of zero or close to zero.

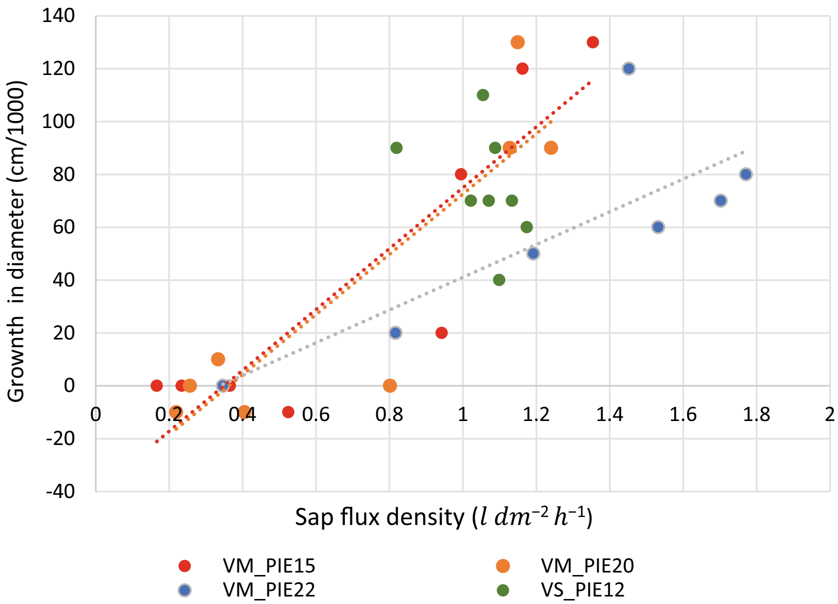


**Fig. 4** Relationship between the sap flux density (weekly mobile mean) and weekly radial growth

The results show as well that the time interval during the middle of the day was adequate to identify anomalous values in the sap flux density, since the mean density values of the sap flow of trees VM_PIE20 and VM_PIE15 were lower than the ones corresponding to VM_PIE22, which was reflected in the weekly diameter measurements. Subsequently, VM_PIE15 stopped growing, the leaves turned yellow, and finally suffered total leaf loss in mid July. In the case of VM_PIE20, there was a 75% leaf loss in late July. It should be highlighted that they are all different clones and they might have different tolerances to water stress.

Mencuccini et al. [16] showed as well that the use of dendrometers and sap flow sensors can be useful to quantify the use of water and the health of plants in terms of growth. In this way, the daily fluctuations of the sap flow must be understood and also identify the “normal” trends that show the development of the tree throughout the seasons of the year; the deviations between the expected (“normal”) values and those recorded is the basis for an early detection of a physiological problem or damage.

## 7 Conclusions

The combined use of ecophysiological sensors, sap flow density and IoT has been effective for the early detection and in almost real-time of water stress in poplar plantations. This early detection of water stress was recorded even prior to it being reflected in leaf loss. It is considered necessary to have a longer time series with more trees with sensors installed to determine the usefulness of this variable in the case of heat stress and in the case of pests/diseases (bark beetles, aphids, leaf rust, etc.).

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# Energy Saving Technology Integration into the Transport Sector; The Influence of Years of Driving and Gender on Electric Vehicles

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**Abstract.** The study sought to investigate if gender and years of driving can be used to predict whether electric vehicles can fully be integrated into the transport sector. The transport sector was the center of focus as it is connected to almost all production branches. The use of electric vehicles was one of the energy-saving technologies identified. The paper discusses five different types of electric vehicles: the hybrid electric vehicle, the plug-in electric vehicle, the plug-in hybrid electric vehicle, the fuel cell electric vehicle, and the ultracapacitor electric vehicle. Drivers around car dealerships, parking lots, hotels, supermarkets, shopping malls, and bus service centers in Lithuania were recruited using random sampling n = 100. Data was collected using a simple questionnaire that was provided to the sample population. The methods of data analysis included descriptive statistics, chi-square, and predictive analysis. The results indicated that years of driving affect people's preference for electric vehicles over traditional combustion engine vehicles. There was no significant relationship between gender and preference for electric vehicles.

**Keywords:** Gender · Electric vehicles (EVs) · Years of driving · Preference for Evs · Traditional vehicles

## 1 Introduction

Energy is the basis of all human activities as we use it to perform various daily tasks such as moving around, cooking, and as a source of electricity. The transport sector is connected to almost all production branches, making the need to come up with energy saving technologies that allow for responsible consumption an important factor [1]. The increase in prices of fuel, as well as the need to reduce the world's carbon footprint, have led to the increase in innovative technological practices that reduce both fuel consumption and ensure that the carbon emissions from vehicles are low [2].

The dramatic change in transportation dynamics worldwide has led to an increase in energy-saving technologies that help reduce fuel consumption. There are three main types of technologies that are rampantly being used in vehicles to reduce fuel consumption: the use of hybrid electric vehicles, plug-in electric vehicles, and plug-in hybrid


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electric vehicles. Hybrid electric vehicles have a combination of the combustion engine, which uses fuel such as diesel and petrol, and an electric motor that is powered by batteries. The electric motor cannot be charged directly. Instead, it is charged through regenerative braking by the combustion engine. The extra power provided by the electric motor allows for a smaller engine, and also powers auxiliary loads. The electric motor also reduces engine idling when stopped. The hybrid vehicle saves up to 60% of energy in comparison to traditional vehicles and emits up to 70% less carbon [3].

Plug-in electric vehicles on the other hand are charged by plugging into a charging point. Plug-in electric vehicles store their energy in rechargeable batteries. These batteries then charge the electric motors which then turn the wheels on a vehicle. Plug-in electric vehicles can accelerate faster than traditional vehicles and are also lighter. They have no carbon emissions produced from burning fuel in combustion engine vehicles, the reason being that plug-in electric vehicles run on electric motors powered by batteries [4].

Plug-in hybrid electric vehicles mainly run on electricity as their source of energy but also have the traditional combustion engine. The traditional combustion engine provides an alternative source of power when the electric motor battery runs out. When the vehicles run on the traditional fuel combustion systems, they emit carbon but when they run on electric motors, they have no carbon emissions [5, 6].

Other forms of energy-saving technologies for responsible consumption include the use of fuel cell electric vehicles. The fuel cell electric vehicles use electricity to charge their electric motors just like the electric vehicle. The difference is that the fuel cell electric vehicles produce electricity using fuel cells that are powered by hydrogen. This means that electric motors do not draw their power from only a battery but also use fuel cells that are charged by hydrogen [7]. The vehicle, much like the hybrid vehicle, does not have plug-in charging capabilities. Instead, the vehicle uses the fuel cells as its main power source and has a hydrogen fuel tank that is used to charge the fuel cells. The battery is mainly used to provide power during short acceleration events, smoothen out the power delivered from the fuel cells, and can be used as an alternative to the fuel cells as the cars can idle or turn off completely the fuel cells. The amount of energy produced by the fuel cell is heavily determined by the hydrogen fuel tank capacity [8]. The use of ultracapacitor electric vehicles is also a new form of electric vehicle technology that is being adopted for responsible energy consumption. The ultracapacitor or a double-layered capacitor is an energy storage system that is a cross of the capacitor and battery. The cars utilize ultracapacitor cells that have both positive and negative electrodes which are separated by an electrolyte. The ultracapacitor car has a lower energy storage capacity and it loses its stored energy fast. The ultracapacitor stores static charge as opposed to the electrochemical reactions gotten from batteries [9]. The supercapacitor is usually fitted into super sports cars like the Lamborghini Sian due to its capacity to provide boosts of energy in a short time. The ultracapacitors are also very light which is mainly useful in ensuring that the super sports cars are very light [10]. Other transportation providers like the town service buses have also adopted the use of ultracapacitors in their electric buses. The ultracapacitors are charged every time they stop as these buses only move for short distances before they have to stop [3].

The preference for electric vehicles (EVs) has been a major concern as electric vehicles are the future of the transport industry and learning whether the shifts in dynamics of preferences for combustion cars will affect the integration of EVs is necessary. Major concerns raised that attribute to the preferences for EVs is their range [11]. Electric vehicles are seen to cover shorter distances before requiring them to be recharged [6]. The availability of fast-charging electric stations is also another factor that affects preference for EVs. Many countries do not have access to electric charging stations and fast charging stations. This is a major factor affecting the preferences for EVs as it only takes a few minutes to fuel combustion vehicles and fuel stations are universally available [12].

## 2 Objectives

The most common type of energy-saving technology used for responsible consumption in the transport sector is the use of electric vehicles. The main objectives of the paper are to:

1. Analyze the preference for using electric vehicles as compared to traditional combustion engine vehicles.
2. Analyze how years of driving affect preference for using electric vehicles as compared to traditional combustion vehicles
3. Analyze whether gender plays a role in preferences for using electric vehicles as compared to traditional combustion vehicles.
4. Determine how years of driving and gender will dictate the future of electric vehicles as a source of energy saving technology in the transport sector.

## 3 Methods

This research utilized a quantitative research methodology for data collection and analysis. Quantitative research mainly utilizes empirical analysis through the collection of statistical data which form the basis for making conclusions on the research question. It mainly involves the technical evaluation of data to derive conclusions [13]. As it is empirical in nature, quantitative research mainly analyses the correlation between variables in research. These variables are usually classified into dependent and independent variables [14]. The data collection strategy utilized was a simple questionnaire.

### 3.1 Sample

Random sampling was used to recruit Lithuanian drivers for the study. We visited several car dealerships, parking lots, hotels, supermarkets, shopping malls, and bus service centers in Lithuania with the questionnaires which were to be filled by drivers on whether they preferred electric vehicles over traditional combustion engine vehicles. The sample population was only a small proportion of the drivers in the country. The inclusion criteria for selecting the participants consisted of any driver who was willing to answer the questionnaire we provided. The study took count of the years a driver had been driving, the driver's gender, the type of car they were using, the technology of the car used, and their preference between electric vehicles and traditional combustion engine vehicles. 120 questionnaires were disseminated, and we retrieved 100 valid, 50 male and 50 female responses from the sample.

### 3.2 Internal Consistency

The questionnaire was tested for internal consistency using Cronbach's alpha reliability analysis. The test was conducted on gender and preference of driving variables. The value of the Cronbach's alpha was 0.082. Since this value is greater than 0.05 alpha level, it can be concluded that there is a significant level of internal consistency. The following Table 1 gives a summary of the reliability analysis.

**Table 1** Reliability statistics

| Cronbach's alpha | Number of items |
|---|---|
| 0.082 | 2 |

## 4 Results

The participants were all asked to provide the number of years that they have been driving and their gender before being asked to state their preference for either electric vehicles or traditional combustion engine vehicles.

### 4.1 Analysis of How Years of Driving Affect Preference for Electric Vehicles

The count of the responses of the survey participants indicated that drivers with fewer years of driving experience preferred electric vehicles as compared to the more seasoned drivers. There was only one driver with an experience within 31–40 years who preferred electric vehicles as opposed to traditional combustion engine vehicles. Drivers with 1–20 years of experience had a higher preference for electric vehicles over traditional vehicles. The results are provided in Table 2.

A chart was developed to better understand the distribution of the preferences according to the years of driving the participants had. The chart shows a higher frequency of drivers with fewer years of driving preferring electric vehicles over traditional combustion engine vehicles (see Fig. 1).

A regression analysis was performed to predict whether years of driving and preference for electric vehicles can be used to analyze future preferences for electric vehicles (EVs). The hypothesis for the analysis was H1: years of driving has a significant impact on preference for electric vehicles. The dependent variable, preference for EVs, was regressed on predicting variable, years of driving, to test hypothesis H1. Years of driving

**Table 2** Preference for electric vehicles according to the years the driver has been driving

| Years driver has been driving | No. | Yes | Total | Years driver has been driving | No. | Yes | Total |
|---|---|---|---|---|---|---|---|
| 1 | | *1* | 1 | 20 | *1* | | 1 |
| 2 | | *3* | 3 | 22 | | *3* | 3 |
| 3 | | *4* | 4 | 24 | *2* | *1* | 3 |
| 4 | | *4* | 4 | 25 | | *3* | 3 |
| 5 | *1* | *3* | 4 | 26 | | *1* | 1 |
| 6 | | *4* | 4 | 27 | | *1* | 1 |
| 7 | | *1* | 1 | 28 | | *1* | 1 |
| 8 | | *2* | 2 | 30 | *3* | *1* | 4 |
| 9 | *1* | *2* | 3 | 31 | *1* | | 1 |
| 10 | *1* | *1* | 2 | 33 | | *1* | 1 |
| 11 | *2* | *5* | 7 | 34 | *1* | | 1 |
| 12 | *1* | *2* | 3 | 35 | *1* | | 1 |
| 13 | *6* | *5* | 11 | 36 | *1* | | 1 |
| 14 | *1* | *5* | 6 | 37 | *1* | | 1 |
| 15 | *1* | *8* | 9 | 38 | *1* | | 1 |
| 16 | *1* | *2* | 3 | 40 | *1* | | 1 |
| 17 | *3* | *2* | 5 | 42 | *1* | | 1 |
| 19 | | *2* | 2 | | | | |
| Total | 18 | 56 | **74** | | 14 | 12 | **26** |

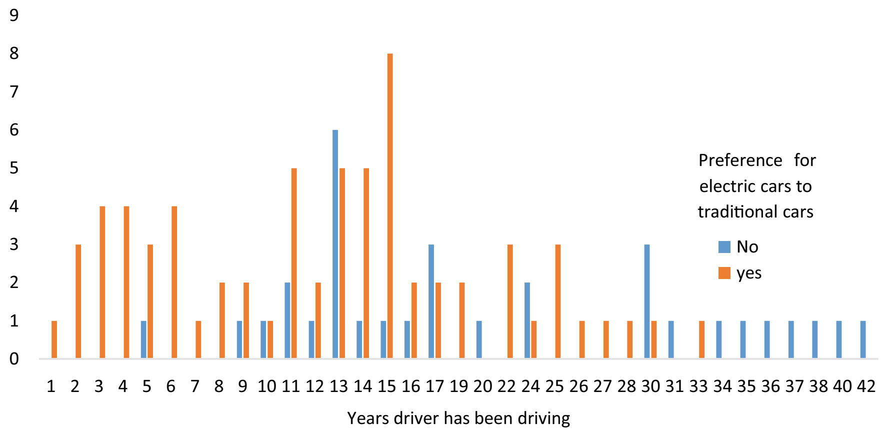


**Fig. 1** Distribution of preference for electric vehicles according to years driver has been driving

significantly predicted preference for EVs, $F(1,99) = 20.265$, $p < 0.001$, which indicates that years of driving can play a significant role in preference for EVs ($b = 1.007$, $p < 0.001$). The results clearly direct the positive effect of the preference for EVs. Moreover, the $R^2 = .171$ depicts that the model explains 17.1% of the variance in preference for EVs (see Table 3).

**Table 3** Regression hypothesis test

Model summary

| Model | R | R square | Adjusted R square | Std. error of the estimate |
|---|---|---|---|---|
| 1 | .414[a] | .171 | .163 | .429 |

*ANOVA*[b]

| Model | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 3.729 | 1 | 3.729 | 20.265 | .000[a] |
| | Residual | 18.031 | 98 | .184 | | |
| | Total | 21.760 | 99 | | | |

*Coefficients*[b]

| | | Unstandardized coefficients | | Standardized coefficients | | |
|---|---|---|---|---|---|---|
| Model | | B | Std. error | Beta | t | Sig. |
| 1 | (Constant) | 1.007 | .082 | | 12.337 | .000 |
| | Years of driving | .020 | .004 | .414 | 4.502 | .000 |

[a] Predictors: (constant), years of driving
[b] Dependent variable: preference for electric vehicles to traditional vehicles

## 4.2 Analysis of How Gender Affects Preference for Electric Vehicles

This part of the research was based on these hypotheses; H1: gender provides a basis for the preference for electric vehicles as opposed to traditional combustion engine vehicles. H0: gender has no basis for the preference for electric vehicles as opposed to traditional combustion engine vehicles. The count of the responses of the survey participants indicated that more females preferred electric vehicles to males as shown in Table 4 and Fig. 2.

To clearly identify the relationship between gender and preference for electric vehicles, a chi-square test was performed with a p-value significance of 0.05. A chi-square test analyzes whether there is a correlation between two variables by comparing responses provided in a survey to the expected responses if the variables were fully independent of each other [15]. The results of the analysis are shown in Table 5.

**Table 4** Preference for electric vehicles according to gender

| Gender | No | Yes | Total |
|---|---|---|---|
| Female | 15 | 35 | 50 |
| Male | 17 | 33 | 50 |
| Total | 32 | 68 | 100 |

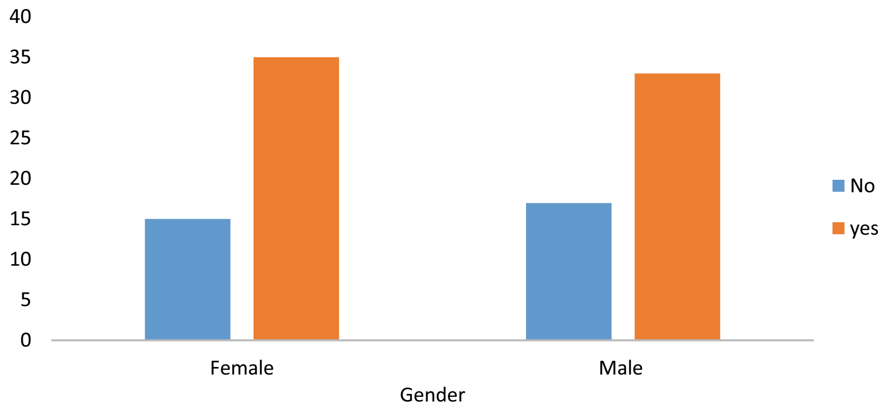


**Fig. 2** Preference for electric vehicles according to gender

## 5 Discussion

Although electric vehicles seem to be the future of vehicles, there have been barriers to the adoption of this futuristic method of transportation. One of these very significant barriers is age. In England, older drivers are seen to be less inclined to buy electric vehicles than younger drivers [16] (see Fig. 3).

Other factors that act as barriers to the adoption of electric vehicles are reliance on fossil fuels, alienation of electric vehicles, and policies that are unfavorable to electric vehicle purchase such as pricing [17]. The results of our analysis show that drivers with fewer years of driving are more inclined to make the move towards driving electric vehicles as opposed to drivers with more years of driving. The hypothesis for the analysis, H1, is therefore true, implying that years of driving has a significant impact on preference for electric vehicles.

The relationship between preference for electric vehicles and gender from the chi-square test indicated that there is no relationship between gender and preference for electric vehicles. Even though women are more likely to prefer electric vehicles due to their environmental safety and friendly attributes, there are more complex social constructs such as their geographic positions, income, education, and household size that dictate their preferred vehicles [18]. The null hypothesis from the research, H0, thus is true as the p-value from the test was 0.73 which is significantly higher than the

**Table 5** Chi-square test

| Observed frequencies | | | |
|---|---|---|---|
| Count of preference for electric vehicles | | | |
| Gender | No | yes | Total |
| Female | 16 | 35 | 50 |
| Male | 17 | 33 | 50 |
| Total | 32 | 68 | 100 |
| *Expected frequencies* | | | |
| Count of preference for electric vehicles | | | |
| Gender | No | yes | Total |
| Female | 16 | 34 | 50 |
| Male | 16 | 34 | 50 |
| Total | 32 | 68 | 100 |
| | $f_0 - f_e$ | $(f_0 - f_e)$ | $(f_0 - f)_e^2/f_e$ |
| | 0 | 0 | 0 |
| | 1 | 1 | 0.0625 |
| | 1 | 1 | 0.029411765 |
| | -1 | 1 | 0.029411765 |
| | | Chi-square | 0.121323529 |
| | | P-value | 0.727603425 |

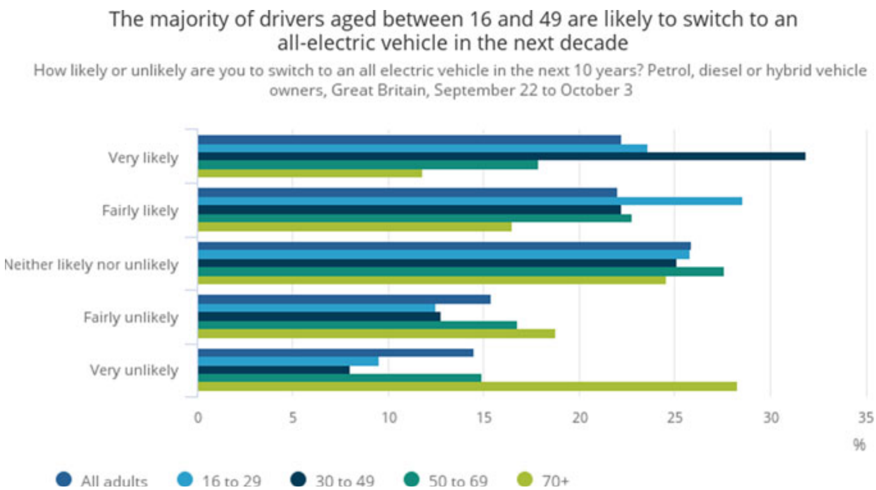


**Fig. 3** Preference for an all-electric vehicle in England

significance p-value of 0.05. This indicates that gender does not influence preference for electric vehicles.

## 6 Conclusion

The increase in prices of fuel, as well as the need to reduce the world's carbon footprint, have led to the increase in innovative technological practices that reduce both fuel consumption and ensure that the carbon emissions from vehicles are low. The use of electric vehicles has proven over the years to be the better choice as they have reduced greenhouse gas emissions and also utilize energy-saving technologies for responsible consumption. Although the use of electric vehicles seems to be the best choice, their adoption in everyday life has become difficult due to certain barriers such as years of driving experience (or age) and policies. Our research showed that drivers with more years of driving are less inclined to use electric vehicles than drivers with fewer years of driving. While years of driving is seen to play a significant role in predicting the preference for electric vehicles, gender does not significantly affect the preference for electric vehicles. This means that in the next few years, more drivers will be inclined to buy electric vehicles. Energy sustainability in the transport sector is more likely to be accomplished by drivers who have driven for fewer years.

## Appendix 1: Questionnaire

Electric vehicle Survey Questionnaire

Thank you for taking the time to answer these questions. The following questions will help to answer how well electric vehicles as a form of energy sustainability measure is preferred by the public.

1. What is your gender?

   ◯ Male
   ◯ Female

2. What type of car do you drive? [ ]
3. How many years have you been driving? [ ]
4. Do you prefer Electric vehicles or traditional combustion engine cars that use petrol or diesel?

   ◯ Electric vehicles
   ◯ Traditional combustion engine cars

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# Energy Analysis of a Wastewater Treatment Plant

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**Abstract.** The paper focuses on a case-study that deals on biogas capitalization by means of a cogeneration group that employs the biogas coming from treatment plants. The energy, economic and environment effect resulting from the biogas supplying of such a group has been determined quantitatively. An energy and financial determination of the predicted savings as well as the determining of the investment recovery time and the decrease of the impact upon the environment have also been carried out. The obtained results confirm the opportunity of valorizing the biogas from the treatment plants from an energetic, economic and ecological point of view.

**Keywords:** Diesel motor · Cogeneration · Energy efficiency · Environmental impact · Foot print.

## 1 Background

Cogeneration represents a type of valorization of secondary energy resources that regards thermal power installations. In Romania biogas share within the energy potential of the biomass employed represents 7.7%, and that which comes from wastewater treatment is 3.84% [1]. In the EU, 13% of the biogas produced comes from the wastewater treatment plants. Currently, a lot of EU countries such as Germany, Austria, Netherlands, Belgium, Denmark and Sweden have complex systems of biogas, using waste to provide energy. Beginning with year 2000, modern treatment plants have been built in Romania, too, which employ biogas as a secondary energy resource and valorize it through cogeneration. The calculations and experimental determinations carried out on site at a wastewater treatment plant in the Jiu Valley highlight the fact that the most efficient way to capitalize biogas is through electric and thermal energy cogeneration [2]. In general, the use of cogeneration becomes efficient from an economic and energetic point of view when 35–50% of the thermal energy obtained from the combustion of biogas is provided [3]. In [4] we display a series of analytical models for simulating the operating modes of cogeneration systems and define a series of quantity and quality indicators that measure the contribution of the electrical and thermal component to the energy efficiency of the installation. In [5] we assess, from an energy and exergy point of view the performance of a series of cogeneration plants equipped with steam turbines and internal combustion engines. The results given through the energy approach (maximal


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thermal performance) and the exergy approach (maximal electrical performance) are worth mentioning. The studies focusing on the building and functional performance of cogeneration installations with internal combustion engines have been carried out by various manufacturers, research entities and universities. In [6, 7] we specify the energy performance and the analytical relations required with a view to quantify the opportunity of adopting the cogeneration method as well as the investment and maintenance values for various charges. In [8] we comparatively analyze the performance of various systems of cogeneration, while insisting on solutions employing internal combustion engines, using natural gas and various types of biogas.

In order to account for the opportunity and topicality of the study, let us remember the specific advantages of cogeneration use: energy advantages, advantages in the domain of environment preservation, economic and social advantages.

Biogas production in the Jiu Valley, a mountainous area of Hunedoara County, located in the province of Transylvania, can be increased by modernizing the treatment plants and by capitalizing on the resources in cattle breeding and mountain agriculture specific to the area. The availability, in the Jiu Valley, of an important amount of biogas resulting from the processes of wastewater treatment has determined us to carry out an energy and financial assessment of the biogas, while checking the opportunity for capitalizing it as well as the recovery time of the investment.

## 2 Problem Formulation

Owing to the fact that in the Jiu Valley there are two plants that treat methanogen wastewater and considering the perspective of modernizing the water supply and sewage system in all the communities in the Jiu Valley, we have carried out a case-study that focuses on biogas valorizing by means of electro—energy cogeneration groups.

In accordance with a series of feasibility studies for increasing energy efficiency, they have decided the installing of certain generating groups that aim at valorizing thermal energy through cogeneration [9].

The cogeneration installation, supplied with biogas coming from technological processes or with natural gas from the supply network of the plant is meant to provide the self-consumption of thermal energy required for generating biogas, to heat administrative locations and to generate electrical energy.

The installation includes two Lindenberg generators with Diesel Guascor engines type SFGLD 180 and a power of 304 kW each (two groups). The generators operate in nominal mode while using gas fuels: biogas produced in the methane tankers and stored in gasholders, respectively methane gas from the supply network of the treatment plant.

The generators are meant to warm the heat carrier provided at the heat exchanger that has to warm the mud in the annex building of the methane tanker and to produce the electrical energy used for a part of the installations of the treatment plant.

The heat exchange at the generator occurs within the heat exchanger with combustion gases, where, they recover the thermal potential of the exhaust gas by means of cooling water.

In case of potential electrical energy disruptions from the main source, the electrical energy provided by the two generating sets is going to provide the consumption of the main vital users at the treatment plant.

The data concerning the nominal parameters and the energy performance are synthetically exhibited in Table 1.

**Table 1** Building and functional performance of the generating set with cogeneration

| Type of diesel internal combustion engine | | SFLGD 180 | |
|---|---|---|---|
| Fuel | | Natural gas | Biogas |
| Engine power | kW | 315 | 315 |
| Speed | $min^{-1}$ | 1500 | 1500 |
| Average effective pressure | bar | 14 | 14 |
| Exhaust temperature | °C | 372 | 374 |
| Exhaust mass flow of humid gases | kg/h | 1638 | 1660 |
| Combustion air flow | kg/h | 1581 | 1517 |
| Temperature projected on combustion air | °C | 25 | 25 |
| Ventilation air flow | $m^3/h$ | 22,050 | 22,050 |
| Type of exhaust manifold | | Humid | Humid |
| Levels of intercooler | | Solitary | Solitary |
| *Engine parameters* | | | |
| Inner diameter of the cylinder | mm | 152 | 152 |
| Piston stroke | mm | 165 | 165 |
| Cylinder displacement | $dm^3$ | 18.0 | 18.0 |
| Number of cylinders | | 6 | 6 |
| Compression ratio | | 11.8:1 | 11.8:1 |
| Average speed of the piston | m/s | 8.3 | 8.3 |
| Content of lubricating oil | $dm^3$ | 70 | 70 |
| Average consumption of lubricating oil | g/kWh | 0.35 | 0.35 |
| Electric generator | | | |
| Performance | % | 96.4 | 96.4 |

The main diagram of the cogeneration installation by means of a generating set is displayed in Fig. 1.

## 3 Results

Relying on the analytical calculation relations of the components of the heat balance [10], on the data provided by the beneficiary and on the measurements in situ, the building and functional performance of the generating set with cogeneration have been determined and are displayed in Table 2. With a view to account for the advantages of using biogas from the treatment plants to supply a series of electro-energy cogeneration groups, we

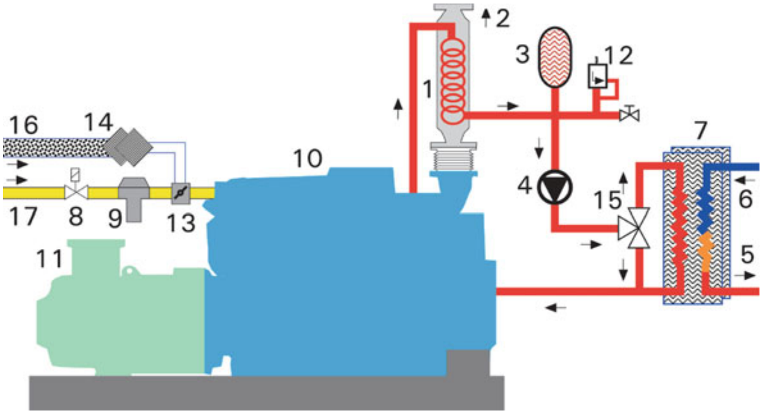


**Fig. 1** Diagram displaying the principle of the cogeneration installation by means of a generating set. (1)—heat changer water—combustion gases; (2)—exhaust pipe; (3)—expansion tank; (4)—pump; (5)—warm water output; (6)—cold water input; (7)—water—water heat changer; (8)—shut-off valve on the gas fuel circuit; (9)—pressure regulator; (10)—internal combustion engine; (11)—electric generator; (12)—safety valve; (13)—carburetor; (14)—air filter; (15)—thermo regulator; (16)—combustion air input point; (17)—combustion air input

have quantitatively determined the energy, economic and environmental effects having resulted from the implementation of the proposed solution. The economic performance is expressed through the investment recovery time for biogas use in relation to the lifespan of the installations.

By means of using the calculation data extracted from Table 1 and Table 2 we have calculated the energy and financial estimated savings as well as the recovery time of the investment and the decrease of the environment impact.

The thermal power of the biogas consumed:

$$P_{tbg} = 781\,\text{kW} \cdot 2groups = 1562\,\text{kW} \tag{1}$$

Power of electric generator:

$$P_{ge} = 304\,\text{kW} \cdot 2groups = 608\,\text{kW} \tag{2}$$

Recovered heat

$$P_{t.rec} = (188 + 76 + 135)\,\text{kW} \cdot 2groups = 798\,\text{kW} \tag{3}$$

- Total efficiency

$$\eta_{total} = \left(P_{ge} + P_{t.rec.}\right)/P_{tbg} = (608 + 798)/1562 = 0.9001 \tag{4}$$

Supplemental calculation data

The yearly functioning duration has been deducted from the data provided by the beneficiary for year 2020, which show that the maximal biogas production is provided

**Table 2** Heat balance of the analyzed system

| Heat balance | Unit | | Value | |
|---|---|---|---|---|
| Fuel | | | Natural gas | Biogas |
| Electrical power | kW | | 304 | 304 |
| Heating power of hot water | ± 8% | kW | 191 | 188 |
| Heating power of cooling water | ± 8% | kW | 74 | 76 |
| Heating power of exhaust gases at 120 $^{0}$C | ± 8% | kW | 132 | 135 |
| Heating power radiated by the internal combustion engine | kW | | 16 | 17 |
| Heating power radiated by generator | kW | | 11 | 11 |
| The power related to the fuel consumption | ± 5% | kW | 778 | 781 |
| Mechanical efficiency | % | | 40.5 | 40.3 |
| Electrical efficiency | % | | 39.0 | 38.9 |
| Thermal efficiency | % | | 51.0 | 51.1 |
| Total efficiency | % | | 90.1 | 90 |
| *Parameters of the system* | | | | |
| Minimal flow of hot water | $m^3$/h | | 25 | 25 |
| Minimal / maximal flow of cooling water | $m^3$/h | | 15/30 | 15/30 |
| Amount of heating water | $dm^3$ | | 50 | 50 |
| Maximal temperature of hot water | °C | | 90 | 90 |
| Temperature of cooling water | °C | | 55 | 55 |
| Maximal exhaust backpressure | mbar | | 45 | 45 |
| Maximal pressure loss at air filter | mbar | | 5 | 5 |
| Minimum gas pressure | mbar | | 50 | 50 |
| Maximum gas pressure | mbar | | 240 | 240 |
| Starter battery 2 × 12 V, required capacity | Ah | | 280 | 280 |

for the months of June, July and August, which represents 2208 hours/year, months in which the temperature is favorable for carrying out the process. During this period of time, the groups work 24 h a day [11].

With a view to drawing up the energy and financial quantification and to decrease the impact upon the environment we have used the data in Table 3.

Energy quantification of estimated savings

- Savings of electrical energy

$$E_{electric} = P_{ge} \times \tau_{an} = 608 \times 2208 = 1342464 \frac{\text{kWh}}{year} = 1342.46 \frac{\text{MWh}}{year} = 115.45 toe/year \quad (5)$$

**Table 3** Quantification calculation data [12, 13]

| No. | Denomination | Value | Unit |
|---|---|---|---|
| 1 | Price of 1 kWh of electrical energy | $p_{el} = 0.31$ | Lei/kWh |
| 2 | Price of 1 kWh of gas thermal energy | $p_{gaz} = 0.15$ | Lei/kWh |
| 3 | Ton oil equivalent | $1toe = 11.627$ | MWh |
| 4 | Average value of $CO_2$ exhaust factor for gas fuels in Romania | $f_{CO_2} = 0.205$ | kg/kWh |
| 5 | Cost of investment | $C = 3 \times 10^6$ | Lei |

- Savings of thermal energy

$$E_{thermal} = P_{t.rec} \times \tau_{an} = 798 \times 2208 = 1761984 \frac{\text{kWh}}{year} = 1761.98 \frac{\text{MWh}}{year} = 151.53 toe/year \quad (6)$$

- Total yearly energy savings

$$E_{total} = E_{electric} + E_{thermal} = 115.45 + 151.53 = 266.98 toe/year \quad (7)$$

Financial quantification of estimated savings.

- Savings of electric energy

$$E_{felectric} = P_{ge} \cdot \tau_{an} \times p_{el} = 608 \cdot 2208 \cdot 0.31 = 416164 Lei/year \quad (8)$$

- Savings of thermal energy

$$E_{fthermal} = P_{t.rec} \cdot \tau_{year} \cdot p_{gas} = 798 \cdot 2208 \cdot 0.15 = 264298 Lei/year \quad (9)$$

- Total savings

$$E_{f.total} = 416164 + 264298 = 680462 Lei/year \quad (10)$$

Recovery time of the investment

$$R = C/E_{ftotal} = 3000000/680462 = 4.408 years = 53 months \quad (11)$$

Owing to the fact that the estimated functioning duration of the engine is 10 years, during the next 5.5 years considerable savings are going to result, which might be corrected upwards due to the upward trend of fuel price.

Decreasing the impact upon the environment

The reduction of the impact on the environment refers to the annual electricity savings for which the carbon factor related to the gaseous fuel (regardless of whether it is natural gas or biogas) is $f_{CO_2} = 0.205$. Therefore:

- Yearly emissions of $CO_2$ are going to decrease as follows:

$$\Delta Em = f_{CO_2} \cdot E_{electric} = 0.205 \cdot 1342464 = 275205\,\text{kg}\,CO_2/year \quad (12)$$

## 4 Conclusions

The valorizing of biogas by means of a cogeneration group at treatment plants proves to be a feasible solution from a technical, energy, economic and ecologic perspective. The study confirms the opportunity of valorizing the biogas from wastewater treatment plants as the energy, economic an ecology potential is quite significant. From an economic point of view, important savings might result during the 5.5 years of functioning, the recovery time of the investment representing 53 months, the calculations point decrease in annual $CO_2$ emissions by 275,205 kg $CO_2$/year. The obtained results show a fit within the limits known in the specialized literature regarding the savings recorded in terms of energy and economy, as well as a significant reduction of the impact on the environment. This points a correct assumption of the working assumptions and in the management of the processes from an energetic and ecologic point of view.

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# Increasing the Elastic Properties of Gypsum Materials by Reinforcing with Terephthalate Polyethylene (PET)

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**Abstract.** The paper studies the possibility of using strips obtained from plastic bottles through mechanical processes, which by creating nets from this material could be armed and cast in three samples. The paper presents the mechanical tests that were carried out on the three gypsum samples, one without insertion and two with one and two layers of insertion. The values obtained as a result of the mechanical process of breaking by bending demonstrated that the PET reinforcement sample increased its elasticity. The mechanical recycling of plastic bottles transformed in sheets can be used in increasing the elasticity coefficient of gyp- sum based construction materials in the future.

**Keywords:** Terephthalate polyethylene (PET) · Recycling · Gypsum · Reinforced · Mechanical test · Elasticity

## 1 Introduction

### 1.1 Overview

Starting with 1950, the world production and consumption of plastic materials increased by about 9% per year, reaching from 1.5 million tons (1950) to 245 million tons (2008) (Fig. 1). In 2009, the production and consumption began to decrease, due to the global economic and financial crisis that affected all fields of activity.

In Europe, the production of plastic materials was about 60 million tons (2008), then decreasing to 48.5 million tons (2009).

The problem of recycling plastic materials has been raised since the beginning of the 1960s, constantly developing, so that today over 20% of them are recycled, and about 30% are converted into energy. There are still technical, economic and structural problems to be solved, but the possibilities are vast. Compared to other recyclable materials, such as metal materials or glass, polymers are much more difficult to recycle, due to the content of auxiliary materials (stabilizers, dyes, fillers) [1].


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Springer Proceedings in Earth and Environmental Sciences, https://doi.org/10.1007/978-3-031-25840-4_44

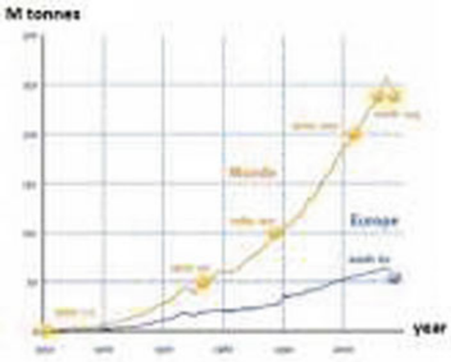


**Fig. 1** The evolution of the production of plastic materials [1]

## 1.2 Recycling Procedures

Plastic materials are usually used in our lives. Once consumed, they generate bulky waste, relative to their weight. Dispersing them in the environment is sustainable and unsightly and therefore recycling is very important.

Although many plastics appear to be identical, they actually have different molecular structures. Recycling depends on the separation process which can only be done efficiently in specialized factories. Recycling changes the mechanical properties of plastic materials, so their immediate reintegration in the same production process is not possible. The cost of collecting materials in small quantities from a multitude of sources is the main obstacle in boosting the recycling process. As a result, recycling only becomes profitable when a certain type of plastic material is widely used among consumers. This is the case of PET bottles which are used in large quantities for bottling different types of drinks, as well as of the other families presented in Table 1. Figure 2 shows the options for managing plastic waste: some can be reused, others are recycled, others are burned, and others are thrown away. Those that are reused or thrown away are out of the question. Incineration ensures the recovery of the energy released during combustion and its transformation into heat and electricity. Also, metals and glass are recovered after burning.

At the same time, burning is polluting, but this inconvenience is also removed by using extremely sensitive devices that limit the spread of polluters in the atmosphere. The most important option for managing plastic waste therefore remains recycling. Of the more than 5000 types of plastic materials known, only about 50 are of economic importance, and of these 7 families lend themselves to recycling [2, 3].

## 1.3 Material Recycling

Mechanical recycling is a process that consists in the physical transformation of plastic waste into products. It is very simple when the plastics contain only one resin. The waste is ground and by adding fresh resin it can be plasticized and processed into products. But recycling poses problems when the waste is not of the same nature, having different

**Table 1** Mechanical recycling of plastic materials

| Material/ simbol | Properties | Applications | Products from recycled material |
|---|---|---|---|
| Polyethylene terephthalate  | Good transparency, resistance, durability and tenacity, low gas and moisture permeability | Bottles for mineral water, juice, beer, soda, oil and ketchup. Jars for pickles, jellies and jam. Foils and boxes for food. Tapes for tying parquet floors or containers | Bottles for drinks, foils and boxes for food, tapes for tying, foils for the protection of seedlings, bags for the transport and storage of clothing, filters |

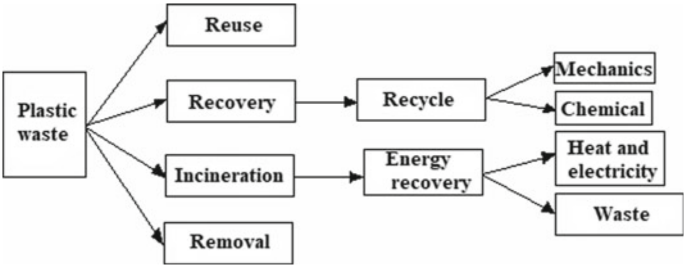


**Fig. 2** Options for plastic waste management

transformation temperatures. Even if the polymers are of the same chemical nature but have different configurations, they may be incompatible, such as milk bottles and high-density polyethylene detergent bottles. The sorting of waste of the same nature can be done either manually, according to configuration and color, or automatically, using various techniques (X-rays or infrared, spectroscopy).

Next, fine particles and labels are removed, after which the waste is ground, washed and separated by flotation or by cyclone. The obtained sequins are dried, hot extruded and passed through a water-cooled die where they turn into granules. The granules constitute the secondary raw material for obtaining new plastic products. Figure 3 shows the technological flow diagram of polyethylene terephthalate waste recycling [4–6].

The mechanical recycling of plastic materials is presented synthetically in Table 1.

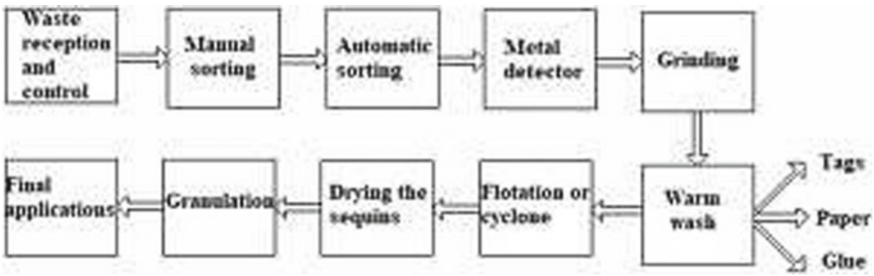


**Fig. 3** Recycling of PET waste

# 2 Methodology and Work Processes

## 2.1 Preparation of Samples

In order to highlight the applicability of the work, three plaster samples were made with and without (pet) insert. The first reference sample was made without insertion, called sample 0, a sample with one row of insertion, called sample 1 and a sample with 2 rows of insertion called sample 2.

When plaster is mixed with water, the water reacts with the semi-hydrated calcium sulfate in a solid state, which it turns into dehydrated calcium sulfate, which begins to crystallize. At first, the crystals being very small, the mixture of plaster and water acquires the plasticity necessary for the work. Through the continuous growth of the crystals, they solidify and form a rigid mass, completely devoid of plasticity.

The amount of water required to prepare a good workable paste is 50–60% of the weight of the plaster, with which it is to be mixed. The plaster is sprinkled over the water, mixing energetically, until the resulting paste acquires a usable consistency. After finishing these operations, it is not allowed to liquefy the paste with water. The paste is prepared in small quantities, in order to have the possibility to be completely put into the work before it starts to harden (maximum 10–15 min). The paste is prepared in an easy-to-handle container so that the paste can be easily poured into the mold. After pouring the first layer of paste, the first layer of reinforcement is placed, which is pressed into the mold with the help of a plate or parallelepiped that fits perfectly into the mold. The next layer of paste is poured and the second layer of reinforcement is placed. When the mold is completely filled with paste, a mechanical vibration of the mold is also carried out so that the material sits perfectly and at the same time.

The precision and accuracy with which one works will later determine the quality of the sample. The mold must have all perfectly straight surfaces and must be designed in such a way that no mechanical shocks occur when the sample is removed, which can damage the integrity of the sample. The mold must be reusable so that later cast samples have the same dimensions. The dimensions of the sample are 100 × 50 × 50 mm (Figs. 4 and 5).

After finishing the casting, the mold is placed on a perfectly horizontal surface so that the paste hardens uniformly in the mold, with equal dimensions over its entire surface. The accuracy of the tests to which the sample is subjected depends on the quality of the sample manufacturing process. The samples were dried for 28 days, after which they were subjected to mechanical tests, to determine the different resistance values [7–10].

## 2.2 Interpretation of Results

See (Fig. 6) (Tables 2, 3 and 4).

# 3 Test Results and Data Discussions

In the first sample, taking into account the measurements in Table 5, a tensile breaking strength value of 2.745 daN/cm$^2$ was obtained, and the value of the deformation during


**Fig. 4** Samples subjected to mechanical testing at breaking

stretching was 0.000153%, the modulus of elasticity being 23,684.21 daN/cm$^2$ (Fig. 7 and 8).

In the second sample with a single layer of PET insert from Table 6, a value of the tensile breaking strength of 1,290 daN/cm$^2$ was obtained, and the evaluation of the deformation during stretching of 0.000173%, the modulus of elasticity being 11,320.75 daN/cm$^2$.

In the third sample that contains three layers of PET insert from Table 7, a value of the tensile breaking strength of 1260 daN/cm$^2$ was obtained, and the value of the tensile deformation of 0.000198%, the modulus of elasticity being 7692,308 daN/cm$^2$ (Fig. 9).

## 4 Conclusions

From the analysis of the values obtained on the three types of material (the sample without PET insert, the sample with one layer of PET insert and the sample with two layers of PET insert) it can be seen that the smallest deformation is registered by the sample without insert, and the highest deformation value is given by the sample with 2 Pet inserts. The values of the modulus of elasticity obtained on the 3 types of samples show that the sample with 0 Pet is more homogeneous, homogeneity given by the lack of Pet inserts.

In this case, the values obtained for tensile strength are significantly higher than in the other 2 cases.

Although the values recorded for the first sample are superior compared to the 2, the insertion of 1 and 2 layers of Pet gives these materials a higher degree of deformation. Although the material breaks at a lower value than in the first case, these inserts ensure a fixation of the material, behaving as in the case of secured ge-arms. Although the flexural tensile strength was lower for the samples with one and two layers of PET insert, the material rupture was a slow rupture supporting plastic behavior compared to the first

**Fig. 5** Detail with and without PET inserts

sample without PET insert, the rupture of which was explosive with the frag- mentation of the material.

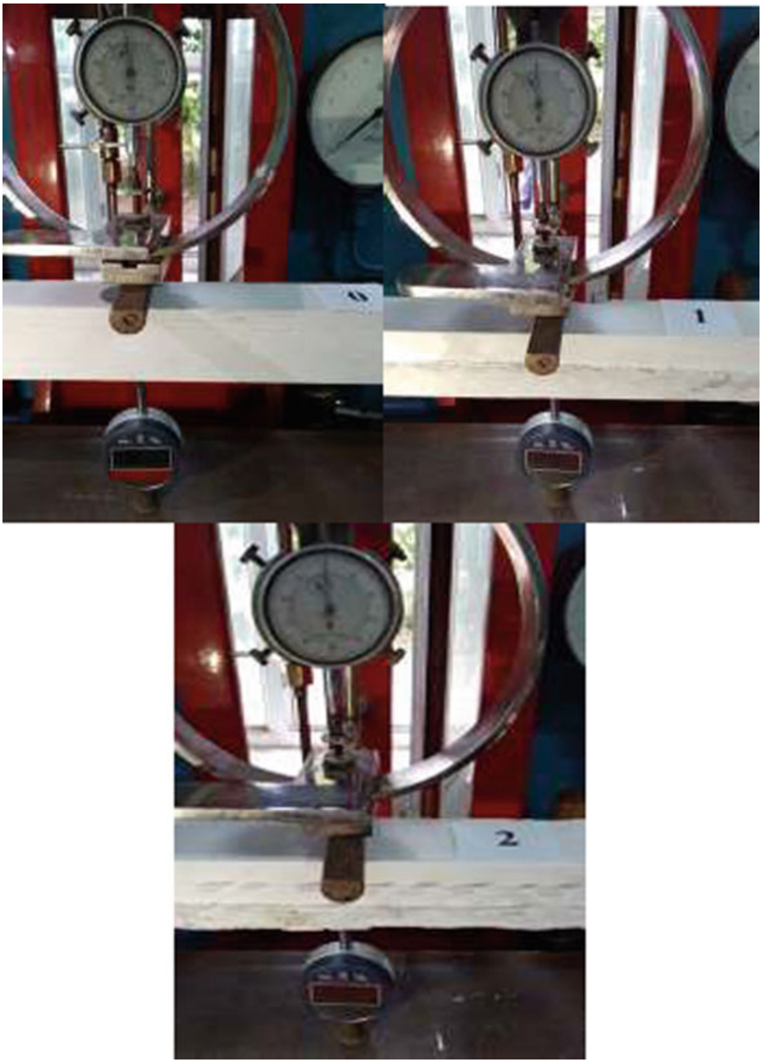

**Fig. 6** The samples introduced in the press

**Table 2** The input data of the first sample

| Sample | b [cm] | l [cm] | h [cm] | $F_{ri}$ [daN] | $\Delta h_{comp}$ [mm] | $\Delta h_{intin}$ [mm] |
|---|---|---|---|---|---|---|
| 0 Pet | 10 | 80 | 10 | 0 | 0 | 0 |
| | 10 | 80 | 10 | 2.5 | 0.1 | 0.2 |
| | 10 | 80 | 10 | 7.5 | 0.3 | 0.31 |
| | 10 | 80 | 10 | 10 | 0.4 | 0.45 |
| | 10 | 80 | 10 | 12.5 | 0.5 | 0.61 |
| | 10 | 80 | 10 | 15 | 0.6 | 0.76 |
| | 10 | 80 | 10 | 17.5 | 0.7 | 0.93 |
| | 10 | 80 | 10 | 20 | 0.8 | 1.1 |
| | 10 | 80 | 10 | 22.5 | 0.9 | 1.27 |
| | 10 | 80 | 10 | 22.75 | 0.91 | 1.44 |
| | 10 | 80 | 10 | 22.875 | 0.915 | 1.53 |

**Table 3** The input data of the secound sample

| Sample | b [cm] | l [cm] | h [cm] | Fri [daN] | $\Delta h_{comp}$ [mm] | $\Delta h_{intin}$ [mm] |
|---|---|---|---|---|---|---|
| 1 Pet | 10 | 80 | 10 | 0 | 0 | 0 |
| | 10 | 80 | 10 | 2.5 | 0.1 | 0.24 |
| | 10 | 80 | 10 | 5 | 0.2 | 0.53 |
| | 10 | 80 | 10 | 7.5 | 0.3 | 0.78 |
| | 10 | 80 | 10 | 10 | 0.4 | 1.05 |
| | 10 | 80 | 10 | 10.75 | 0.43 | 1.73 |

**Table 4** The input data of the third sample

| Sample | b [cm] | l [cm] | h [cm] | Fri [daN] | $\Delta h_{comp}$ [mm] | $\Delta h_{intin}$ [mm] |
|---|---|---|---|---|---|---|
| 2 Pet | 10 | 80 | 10 | 0 | 0 | 0 |
| | 10 | 80 | 10 | 2.5 | 0.1 | 0.34 |
| | 10 | 80 | 10 | 5 | 0.2 | 0.78 |
| | 10 | 80 | 10 | 7.5 | 0.3 | 1.2 |
| | 10 | 80 | 10 | 10 | 0.4 | 1.67 |
| | 10 | 80 | 10 | 10.5 | 0.42 | 1.98 |

**Table 5** The values obtained by compression and stretching

| Sample | $\sigma_{ri}$ [daN/cm$^2$] | $\varepsilon_{comp}$ [%] | εintindere [%] | E [daN/cm$^2$] |
|---|---|---|---|---|
| 0 Pet | 0.000 | 0 | 0 | 23,684.21 |
| | 0.300 | 0.00001 | 0.00002 | |
| | 0.900 | 0.00003 | 0.000031 | |
| | 1.200 | 0.00004 | 0.000045 | |
| | 1.500 | 0.00005 | 0.000061 | |
| | 1.800 | 0.00006 | 0.000076 | |
| | 2.100 | 0.00007 | 0.000093 | |
| | 2.400 | 0.00008 | 0.00011 | |
| | 2.700 | 0.00009 | 0.000127 | |
| | 2.730 | 0.000091 | 0.000144 | |
| | 2.745 | 0.0000915 | 0.000153 | |

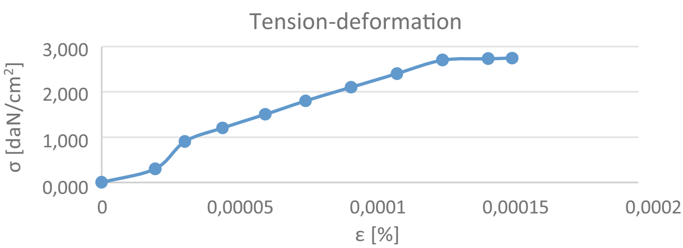


**Fig. 7** Tension diagram

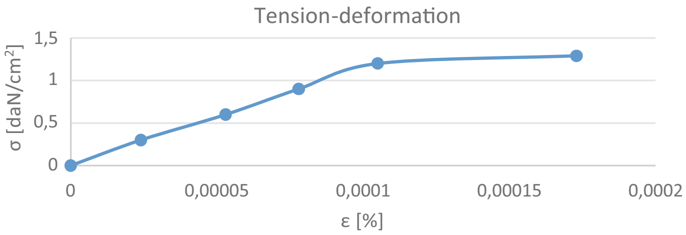


**Fig. 8** Tension diagram

**Table 6** The values obtained by compression and stretching for sample 2

| Sample | $\sigma_{ri}$ [daN/cm$^2$] | $\varepsilon_{comp}$ [%] | εintindere [%] | E [daN/cm$^2$] |
|---|---|---|---|---|
| 1 Pet | 0.000 | 0 | 0 | 11,320.75 |
| | 0.300 | 0.00001 | 0.000024 | |
| | 0.600 | 0.00002 | 0.000053 | |
| | 0.900 | 0.00003 | 0.000078 | |
| | 1.200 | 0.00004 | 0.000105 | |
| | 1.290 | 0.000043 | 0.000173 | |

**Table 7** The values obtained by compression and stretching for sample 3

| Sample | $\sigma_{ri}$ [daN/cm$^2$] | $\varepsilon_{comp}$ [%] | εintindere [%] | E [daN/cm$^2$] |
|---|---|---|---|---|
| 2 Pet | 0.000 | 0 | 0 | 7692.308 |
| | 0.300 | 0.00001 | 0.000034 | |
| | 0.600 | 0.00002 | 0.000078 | |
| | 0.900 | 0.00003 | 0.00012 | |
| | 1.200 | 0.00004 | 0.000167 | |
| | 1.260 | 0.000042 | 0.000198 | |

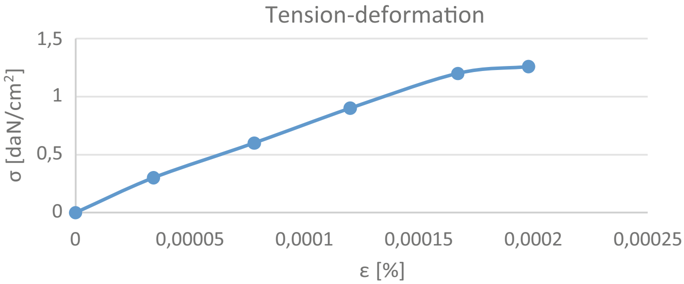


**Fig. 9** Tension diagram

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# Automation of the Assessment and Diagnosis Process in Rehabilitation: A Proposal to Reduce Costs and Optimize the Health Care System

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**Abstract.** The standardization of assessment processes leads to increased efficiency in healthcare practice. Fundamentally, this is due to the fact that it facilitates the application of appropriate clinical reasoning processes and bias-free decision making. As a result of this situation, it is necessary and very useful to develop a multiplatform application to guide physiotherapists in the assessment process as a strategy to facilitate clinical reasoning in rehabilitation. This program will show in an organized way all the validated clinical tests and tests suitable for physiotherapy assessment, will record and compile all the relevant results and will facilitate the selection of the physiotherapy diagnosis. The present project aims to transform a procedure that is currently performed manually (storing all the information on paper and consuming time and resources of health personnel), into a fully automatic and digitized process thanks to the use of disruptive technologies such as computer engineering and engineering and data science through artificial intelligence techniques.

**Keywords:** Automation · Health system · Diagnosis · Clinical reasoning

## 1 Introduction

The standardization of assessment processes leads to increased efficiency in healthcare practice. Fundamentally, this is due to the fact that it facilitates the application of appropriate clinical reasoning processes and bias-free decision making. However, in the specialties, the assessment process is not protocolized, which leads to greater inference of biases and greater probability of errors by physiotherapists in clinical practice [1].

As a result of this situation, it is necessary and very useful to develop a multiplatform application to guide physiotherapists in the assessment process as a strategy to facilitate clinical reasoning in physiotherapy [2]. This program will show in an organized way all the validated clinical tests and tests suitable for physiotherapy assessment in several specialties, will record and compile all the relevant results and will facilitate the


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selection of the physiotherapy diagnosis [3]. In addition, this application will have the implementation of predictive models based on artificial intelligence techniques such as machine learning and deep learning, as well as logical reasoning modules through the use of knowledge graphs. Increasing the efficiency and reliability of the clinical evaluation and diagnosis process also allows early identification of modifiable risk factors for a multitude of chronic diseases that reduce people's quality of life. In this way, it will also facilitate the development of actions related to disease prevention and health promotion. In addition, thanks to the artificial intelligence module, specialized physiotherapists will have predictions of possible diagnoses which, as they use the application, will increase in precision and accuracy [4, 5].

This claim is formulated with the initial hypothesis that the development of this application will promote among physiotherapists specialized the health practice based on objectivity and scientific evidence. This entails a novel component because there is currently no similar product that offers the user all the functionalities described [6].

This project is directly aligned with the Sustainable Development Goals of Health and Well-being (No. 3), Gender Equality (No. 5), Reduction of Inequalities (No. 10) and Responsible Consumption and Production (No. 12). At the same time, this proposal comes to solve a real need of physiotherapists who develop their assistance activity through the care of patients who do not have any objective and scientifically validated assessment and diagnosis tool [7, 8].

The present project aims to transform a procedure that is currently performed manually (storing all the information on paper and consuming time and resources of health personnel), into a fully automatic and digitized process thanks to the use of disruptive technologies such as computer engineering and engineering and data science through artificial intelligence techniques. Therefore, this project is within the framework of the digital transition as it helps the digitization of a part of the health sector, generating a new path related to the new economy of care thanks to the synergy between two different scientific branches that rely on technological development and data management, transforming a procedure that currently consumed resources in an unsustainable way into a sustainable and inclusive process thanks to its own digitization.

## 2 Work Plan

The development of this project is intrinsically related to the development of technologies and the support of the care economy. Furthermore, this proposal implies a series of specific actions that require an inter and multidisciplinary work strategy. In order to achieve them successfully, the following methodology is proposed:

(a) Identify the variables necessary to construct a complete and efficient clinical assessment method for different specialties of physical therapy. Development of a Delphi study to define the assessment variables to be included.
(b) Analyze the functional requirements to be met by the application and design and develop it with guarantees that it works correctly.
(c) Design and develop the multiplatform application.
(d) Creation of predictive models through the use of artificial intelligence based on the available variables collected through the application.

(e) Integration of the predictive models in the multiplatform application.
(f) Detect specific alarm signs according to age, medical-surgical history and presence of chronic diseases to recommend the initiation of treatment and/or referral to the most appropriate health specialist.
(g) Evaluate the usability of the finished application.
(h) To certify the developed application as a medical device.
(i) Collect data that will allow the continued research and exploitation of the multiplatform application.

The authors propose that a reasonable period of time to develop all these actions successfully would involve 18 months of work.

## 3 Scientific-Technical Impact

The multiplatform application obtained will help to make fewer errors and biases in the assessment and clinical reasoning processes by identifying possible incongruities between the assessment items recorded and the Physiotherapy diagnoses selected. All this implies a great social impact by improving people's health care. The feasibility is further consolidated with the possibility of extending the tool to the analysis of other physiotherapy specialties such as neurology, pediatrics, cardiology and pneumology.

Thanks to the research carried out, a tool is provided that will improve the management of the clinical assessment of physiotherapists by reducing the time spent on it, as well as the use of paper, providing a noticeable improvement in the consumption of environmental resources and reducing the carbon footprint. All this thanks to the transformation of procedures that are currently carried out in analogical form, to digital format.

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# The Application of Nanotechnology in the Development of Concrete Coatings

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**Abstract.** In the current scenario, the search for new, more economical and environmentally sustainable approaches that contribute to the circular economy are receiving special attention in all sectors. In the construction sector, the most developed approach is the use of nanotechnology. It is one of the best and most innovative options available to improve performance in this sector. The continuous growth and increasing use of natural resources leads to the search for new materials that are more efficient, sustainable and increase the useful life of materials. In this sense, the use of nanomaterials as surface treatments is one of the fields of research that is evolving the most, since it is possible to prevent deterioration and improve the durability and conservation properties of construction materials, reducing restitution. This article conducts a capillary absorption test, which determines that the graphene oxide used as a protective treatment of the concrete surface decreases capillary water absorption by 15%; this is the beginning of a more exhaustive study to determine the effectiveness of this treatment and to be considered a nano-coating.

**Keywords:** Nanotechnology · Concrete · Surface treatments

## 1 Introduction

During the last decades, in the field of construction, the great concern for the consumption of natural resources and the deterioration of concrete structures has exposed the need to intervene, studying new approaches that are more economical and environmentally sustainable than those traditionally used [1]. Thus, in recent years, the concept of Nanotechnology has started to be used in the construction sector. It is the most recognized concept that correlates the great development in the world of technology and science, discovering new cases of innovation in almost all industry sectors [2]. Therefore, this


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new concept that unites science and technology presents a great economic impact and market potential. Nanotechnology is defined as "*the study, design, creation, synthesis, manipulation and application of materials, devices and functional systems through the control of matter at the nanoscale, and the exploitation of the phenomena and properties of matter at the nanoscale*" [3].

To date, the construction sector has embraced many innovations related to the use of nanotechnology and is also one of the sectors that continues to experiment the most, especially in relation to construction materials [4]. The creation of nanotechnological materials generates a much more sustainable, efficient and less environmentally aggressive construction, thus contributing to the circular economy [5].

Nanotechnology applications offer new opportunities in the construction sector, producing materials with better specific and advanced properties, such as higher durability, higher mechanical strength, corrosion resistance, superhydrophobic materials, etc., [6].

Concrete is the most consumed building material worldwide, and requires continuous improvement in quality, so the application of nanotechnology can be mainly focused on this material. In this sense, nanotechnology is developed in two directions, on the one hand, developing the nano-modification of concrete and on the other hand, the development of nano-coatings [3].

Nano-modification of concrete offers the possibility of developing new concrete admixtures, such as nanoparticles or nanoreinforcements. Some of the main additives based on nanoparticles [7] or nanoreinforcements [8, 9] are nano-$SiO_2$, nano-$TiO_2$, nano-clay, nano-$Fe_2O_3$, nano-$Al_2O_3$, nanotubes/nanofibers (CNT/CNF).

Nanotechnology offers a wide variety of applications in coatings for concrete surfaces, giving the new innovative properties. Nano-coatings are generally solid–liquid coatings, consisting of extremely small particles, which form a protective layer on surfaces. Due to the characteristics of these coatings applications, it has been proven that they are an excellent option as surface protection against moisture, wear, fire, etc. The main nanomaterials studied as protective coatings for concrete have been nano-$SiO_2$ and nano-$TiO_2$, and new nanomaterials such as rapheme oxide (GO) are beginning to be studied [10–12].

The objective is to carry out a small study to observe whether a nanomaterial such as graphene oxide (GO) applied on the surface of concrete produces any improvement in the durability of this, being the beginning for a subsequent more exhaustive study of the treatment on the surface of concrete and thus being able to check some of the properties offered by the application of nanotechnology in materials.

## 2 Experimental Process

For the preparation of the concrete samples, blast furnace slag cement CEM III/A 42.5 N/SR, tap water and natural siliceous aggregates were used; therefore, the concrete to be tested is conventional (HC). The dosage used for the preparation of the concrete is shown in Table 1.

The treatment used as nano-coating was graphene oxide (GO) dispersed in aqueous suspension (0.5 mg $mL^{-1}$), obtained by exfoliation of graphitic oxide. The concrete samples were sprayed with an airbrush, deposited on each concrete sample (21 $\mu g/cm^2$).

**Table 1** Concrete dosage

| | Coarse aggregate (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Cement (kg/m$^3$) | W/C |
|---|---|---|---|---|
| HC | 1030.71 | 650.49 | 390.91 | 0.51 |

The preliminary test performed to check whether the GO surface treatment can generate a protective layer for the concrete is the capillary test. The behavior of concrete against capillary water absorption is evaluated according to UNE 83982 [13]. Three cubic specimens (100 mm × 100 mm × 100 mm × 100 mm) were tested, which were cast and cured for 28 days at a Tª (20 ± 5) °C and RH 100%.

Capillary water absorption is one of the most important durability parameters of concrete, since the capillary suction process is the transport mechanism for the entry of water and harmful substances into the concrete. Initially, the concrete samples are conditioned according to UNE 83966 [14]. In order to ensure that capillary absorption occurs only on the treated surface, the remaining faces of the concrete sample are sealed with kerosene. Once the test room has the appropriate conditions of Tª (20 ± 2) °C and RH (45–15) %, the concrete samples are placed inside a container on a leveling grid that allows the contact of the specimens with deionized water. After given periods of time (5 min, 10 min, 15 min, 30 min, 1 h, 2 h, 3 h, 4 h, 6 h, 24 h, 48 h, 96 h, until the mass is constant), the specimens are removed from contact with the water and weighed.

The test showed the permeability of the concrete, allowing the calculation of the capillary absorption coefficient (K), using Eq. (1):

$$K = \frac{\delta_a \cdot \varepsilon_e}{10 \cdot \sqrt{m}} \tag{1}$$

where K is the capillary absorption coefficient (kg/m$^2$min$^{0,5}$), $\delta_a$ is the density of water (the value of 1 g/cm$^3$ is considered), $\varepsilon_e$ is the effective porosity of concrete (cm$^3$/cm$^3$) and m is the resistance to water penetration by capillary absorption (min/cm$^2$).

## 3 Results and Discussion

The permeability of concrete is represented by a typical water absorption curve, in which mass gain is related to the exposure time of the specimens in water (Fig. 1). The development of the typical curve shows an initial state in which water penetrates through the capillary pores and a second state in which water penetrates through the air pores [15].

The results showed that the concrete specimens with the GO coating absorbed less water, while the control specimens had higher capillary absorption. It can be observed that the surface treatment used improves the protection of the concrete specimens against water penetration, reaching up to a 15% improvement.

To verify that the GO surface treatment produces concrete protection, the capillary absorption coefficient (K) shown in Table 2 was also studied. The results obtained corroborate that the surface treatment with GO creates a protection of the concrete, reducing the capillary absorption coefficient by 7% with respect to the control samples.

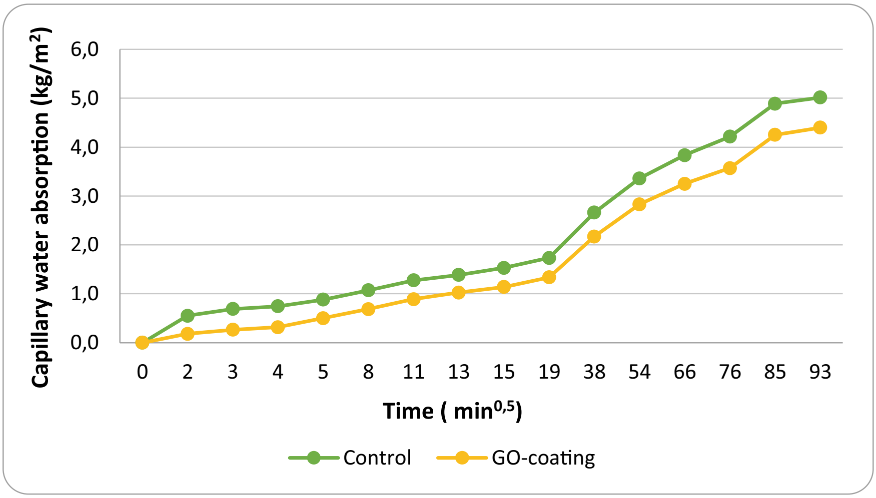


**Fig. 1** Typical capillary absorption curve for GO-coated and control specimens

**Table 2** Capillary absorption coefficient (K)

| Samples | K ($kg/m^2 min^{0.5}$) | Standard deviation |
|---|---|---|
| Control | $5.25 \cdot 10^{-3}$ | $2.16 \cdot 10^{-5}$ |
| GO-coating | $4.90 \cdot 10^{-3}$ | $1.10 \cdot 10^{-4}$ |

## 4 Conclusions

The introduction of nanotechnology in the development of coatings for building materials has led to many innovations and advantages, offering a wide variety of new coatings to alleviate the negative effects on building materials, such as moisture, corrosion, maintenance, etc.

The small study carried out shows that the surface treatment of GO on concrete surfaces reduces water absorption by 15%, so it is proposed that this treatment creates a protective layer on the material. It is necessary to carry out a more exhaustive study of this material applied on the concrete surface to be able to verify its effectiveness with nano-coating, as well as to verify its effectiveness in the protection and prevention against the entrance of substances, and the increase of the durability of the concrete structures.

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# Mapping and Estimation of Carbon Dioxide Storage in Forest Plantations. The Contribution of the Sentinel-2 Time Series in Increasing Estimates Precision

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**Abstract.** Forest restoration activities and tree plantations play an important role in combating global warming. On the other hand, quantifying their carbon storage is a challenging task due to very short rotations and the effort and costs required for field analysis, often in remote and hardly accessible regions. In this context, remote sensing combined with new cloud computing platforms offers unprecedented opportunities for monitoring tree plantations globally. In this study, we implemented and demonstrated over a 20-ha tree plantation in Guatemala an approach that exploits Sentinel-2 imagery time series derived metrics and cloud-free composites for mapping carbon storage. Ground data were collected over 20 plots (10-m radius) to train and validate our model, which performance resulted in high ($R^2 = 0.69$, RMSE = 35%). Plus, we estimated the amount of carbon stored in the study area and the relative confidence intervals. Using exclusively the ground data, we estimated the average net equivalent $CO_2$ as 4.95 Mg $ha^{-1}$ ± 0.9 Mg $ha^{-1}$, with a confidence interval of 95%. Nevertheless, exploiting the herein presented model and statistical procedure, the estimate was much more precise and the ratio between the variances of the design-based and the model-assisted estimates was 7.1, meaning that, by using remote sensing data, it is possible to reduce the ground sample size by a factor of 7.1 while obtaining estimates with the same precision of those do not exploiting remote sensing data. This is a crucial point for meaningful reducing the effort and the cost required for collecting data on tree plantations while still obtaining statistically rigorous estimates.

**Keywords:** Forest · Carbon · Restoration · Remote sensing


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# 1 Introduction

Avoiding dangerous climate change requires the removal of vast amounts of carbon dioxide from the atmosphere, as well as drastic cuts in emissions [1]. Forests must play a part in the climate change battle as they are a critically important component of the global terrestrial carbon cycle [2]. Accordingly, the G20 (Nov. 2021) proposal to plant 1 billion trees by 2030 to fight the climate crisis has been accepted, as trees restoration and emissions reduction have been considered among the most effective strategies for climate change mitigation. Plantations for timber production, such as poplar (*Populus* spp.) in Europe, cedar (*Cedrela* spp.) in Central and South America, and mahogany (*Swietenia* spp.) in Asia, are well suited for climate change mitigation due to their fast-growing performance [3]. They also provide other ecosystem services, such as erosion prevention, soil protection, water quality, and habitat for many species [4], and they are also used for phytoremediation. On the other hand, quantifying and monitoring over time the amount of carbon stored by those plantations is challenging, mainly due to very short rotations, which increase the effort and costs required for field analysis.

In this context, remote sensing satellite missions provide a huge amount of consistent and open access data [5, 6] that can provide detailed information over very large areas [7–9]. In addition, the Copernicus Earth observation program of the European Union recently developed the Sentinel-2 mission, which provides data with 10–60-m spatial resolution and revisits times of 2–3 days at mid-latitudes.

This study exploits the Sentinel-2 time series to predict the amount of carbon stored in forest plantations. Herein, we focus on a study area in Guatemala for which we have ground data collected over 20 plots that were used for model training and validation, and for providing estimates with 95% confidence interval of the total and average amount of carbon stored over the study area.

# 2 Materials

## 2.1 Study Area

The study area consists of a forest plantation of 20.31 ha located in the community of Monte Carmelo in the commune of La Libertad in the Petén department, Guatemala (16° 50′ 59.57″ N; 90° 2′ 39.24″ W). The study area includes 1111 trees per hectare, for a total of about 20.31 * 1111 = 22,564 trees. Each tree is given nine square meters of space. Half of the trees in the study area are cedar (*Cedrela odorosa*) and the remaining half is mahogany (*Swietenia macrophylla*), both species of great cultural and economic importance. The two species are planted alternately with each other across the study area.

## 2.2 Ground Data

For training and validating our models and estimating the amount of carbon in the study area, we constructed a reference sample by randomly selecting 20 plots (10-m radius) within the study area (Fig. 1). For each plot, the species, the height, and the diameter at the breast height (DBH) of each tree were measured. In total, 730 trees were measured on the ground. The surveys were carried out in June 2022, when each tree was of twenty-one months of age.

**Fig. 1** The study area (blue) and sample plots (red)

### 2.3 Sentinel-2 Data

For predicting the carbon storage, we used data from the Sentinel-2 (S2) mission, which has a wide swath (290 km) with a spatial resolution of 10–60-m, depending on spectral bandpass, and a revisit frequency of 2–3-days at mid-latitudes [10]. The S2 Multispectral Instrument (MSI) provides 14 spectral bands: visible (*blue*, *green*, *red*) and *nir* at the 10-m resolution, Red edge (*redE1, redE2, redE3, redE4*), and SWIR (*swir1, swir2*) at the 20-m resolution, three atmospheric bands (*B1, B9, B10*), and a quality assurance band (*QA60*) at a 60-m spatial resolution that was used in this study for mask out clouds from images [8].

An up-to-date S2 image archive can be found in Google earth engine [11], from which we selected all S2 images acquired over the study area between 2020-09-01 and 2022-08-31. For each image, we increased the number of available bands by calculating seven additional spectral indices: (i) the Normalized Difference Vegetation Index NDVI, (ii) the Normalized Burn Ratio NBR, (iii) the Enhanced Vegetation Index EVI, and the Tasseled Cap (iv) Wetness TCW, (v) Greenness TCG, (vi) Brightness TCB, and (vii) Angle TCA. As a result, we obtained a set of 17 predictors for each image, the ten S2 bands at 10–20 m spatial resolution, and the seven additional indices we calculated. All 17 predictors were resampled at the 10-m resolution.

## 3 Methods

### 3.1 Per Plot $CO_2$ Calculation

We calculated the above-ground biomass for each plot using the function presented in Chave et al. [12] for tropical species:

$$Ba = 0.0673\left(\rho D^2 H\right)^{0.976}$$

where $Ba$ is the above-ground biomass, $\rho$ is the species-specific wood density, $D$ is the tree DBH, and $H$ is the tree height. The wood densities of the two species are 0.4 and 0.5 for cedar and mahogany, respectively [13]. For each tree, we then calculated the below-ground biomass by exploiting the Mokany et al. function [14]:

$$Bs = 0.489Ba^{0.89}$$

where $Bs$ is the below-ground biomass and $Ba$ is the above-ground biomass. The constant 0.489 is the root shot ratio commonly used for tree species. Then, the total biomass was the sum of above and below-ground biomass

$$Bt = Ba + Bs$$

The total carbon content was calculated by applying the default carbon fraction factor of 0.5 provided by the IPCC [15]:

$$Ct = \frac{Bt}{2}$$

where $Ct$ is the total carbon content. Finally, the equivalent $CO_2$ content was calculated using a conversion factor derived from the $CO_2$ molecular weight:

$$CO2_{eq} = Ct(3.6667)$$

## 3.2 Sentinel-2 Predictors

The time-series spectral behavior of each pixel can be indeed described by harmonic functions with four parameters (constant, sine, cosine, time). For each pixel and predictor, four harmonic function coefficients were calculated to identify the pixel harmonic trend (Fig. 2). Each pixel harmonic trend function was further used to calculate the amplitude, the phase, and the root mean square error (RMSE). For more details on harmonic predictors calculation see [16].

As a result of this step, we obtained for each pixel a set of 17 (the S2 bands) per 7 (the harmonic function parameters) for a total of 119 predictors from now on referred to as *harmonic predictors.*

To quantify the advantage of using *harmonic predictors*, and thus for comparison purposes, we calculated more standard cloud-free composite predictors too, using all S2 imagery selected (Sect. 2.3). To do it, we used a state-of-the-art cloud-free composites methodology named *medoid* [17]. The Medoid composite processing aims to populate the final image composite with the pixels with surface reflectance values as similar as possible to the median calculated considering the whole image collection. In brief, medoid compares each band's pixel surface reflectance values to the median bands' spectral values of that pixel in all selected images. Then, the bands' spectral values from the pixel closest to that median value (using Euclidean spectral distance) were chosen.

As a result of this step, we obtained a set of 17 (the S2 bands) per 4 (the Medoid seasonal composites) for a total of 68 predictors referred to as *medoid predictors.*

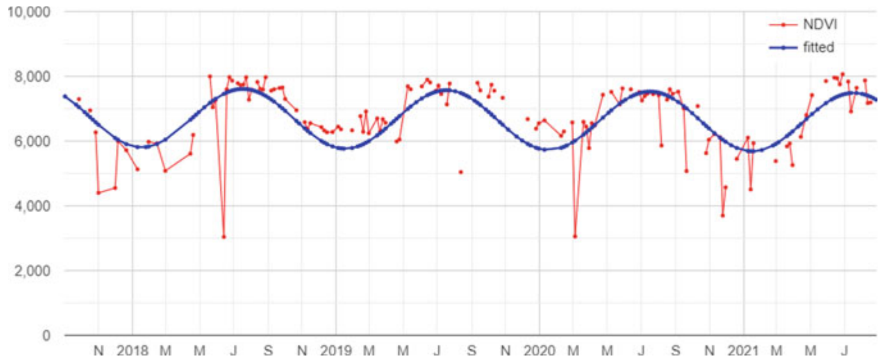


**Fig. 2** Example of NDVI pixel time series (red) and the corresponding fitted harmonic function (blue)

### 3.3 $CO_2$ Mapping

To map carbon storage across the study area by exploiting S2 predictors and the ground data, we used random forests (RF), a well-known supervised machine learning approach [18]. Although RF is known to be insensitive to the number of variables, a variables selection procedure was performed to reduce the burden of data collection and improve efficiency. To do it, we used the VSURF package [19] within the R statistical software. The package implements a stepwise selection procedure that performs a backward elimination and then a forward selection in three steps, based on importance measures and error rate internally calculated by the RF algorithm. Finally, the best set of variables is chosen and the redundancy in the predictors is minimized.

Using the set of variables chosen with VSURF, the RF model is trained with net equivalent $CO_2$ stock as the dependent variable and S2 predictors as independent ones. Other RF tuning parameters were kept with their default values: the number of trees in the forest was 500 and the number of variables chosen at each split was p/3, where p is the number of independent variables.

RF performance was assessed in terms of root mean squared error (RMSE) by using the out-of-bag error (OOB) estimate, which removes the need for a test set and which, unlike cross-validation (CV), performance estimates are unbiased [18]. The internal estimates of OOB were also used to order by importance variables selected using VSURF, using as criteria the percentage increase of mean square error (MSE%) that occurs when that variable is randomly permuted in the model [18]. Finally, to obtain the carbon stock map over the study area, we used the model fitted with the set of predictors previously selected, which obtained the best performance in terms of RMSE. The result was a regular map of predicted carbon stock with a spatial resolution of 10 m.

### 3.4 $CO_2$ Estimation

The mean and total values of net equivalent $CO_2$ stock absorbed in the study area were inferred using the design-based estimators originally proposed by Horwitz and Tompson [20], which permit unbiased estimation of the sampling variance. The Horwitz-Tompson

(HT) estimator for the mean is simply the sample mean:

$$\hat{\mu}_{HT} = \overline{y}$$

where $\overline{y}$ is the sample mean.

The standard error (SE) for the estimator can be expressed as:

$$SE(\hat{\mu}_{HT}) = \sqrt{\frac{\sigma^2}{n}}$$

where $\sigma^2$ and $n$ are the sample variance and size, respectively.

The HT estimator for the total is:

$$\hat{\tau}_{HT} = N\overline{y}$$

where $N$ is the population size, which is typically unknown in forest inventories. A good approximation of $N$ can be given by $A_a/A_{plot}$ where $A_a$ is the area of the study and $A_{plot}$ the area of the field plot. The sampling SE of the total is given by:

$$SE(\hat{\tau}_{HT}) = \sqrt{N^2\frac{\sigma^2}{n}}$$

The mean and total values of net equivalent $CO_2$ stock absorbed in the study area were also estimated by using a model-assisted estimator, which exploits the RF model and remote sensing data used to construct the 10-m resolution net equivalent $CO_2$ stock map. More specifically, model-assisted, generalized regression estimators were used to infer the mean and total value of carbon absorbed in the whole study area [21–23]. From a statistical standpoint, the model-assisted estimator for the mean can be expressed in the following form:

$$\hat{\mu}_{ma} = \frac{1}{N}\sum_{\mathrm{i}=1}^{N}\hat{\mathrm{y}}_{\mathrm{i}} - \frac{1}{n}\sum_{\mathrm{j}=1}^{n}\left(\hat{\mathrm{y}}_{\mathrm{j}} - \mathrm{y}_{\mathrm{j}}\right)$$

where $\hat{\mu}_{ma}$ is the model-assisted estimation of the mean, $N$ is the number of forest pixels in the study area, $\hat{\mathrm{y}}_{\mathrm{i}}$ is the model prediction for the $i$th map unit, $n$ is the field sample size (i.e., 20 plots), $\hat{\mathrm{y}}_{\mathrm{j}}$ is the model prediction for the $i$th field plot and $\mathrm{y}_{\mathrm{j}}$ is the measured value in the $i$th plot.

The model-assisted estimator has two components: the mean of the map-predicted values for the whole study area (leftmost term) and a correction term based on the mean residual of the plot sample (rightmost term). The effect of the latter term is to remove bias from the model, which makes the estimator asymptotically unbiased (i.e., bias goes to zero at large sample sizes). The SE for the estimator is:

$$SE(\hat{\mu}_{ma}) = \sqrt{\frac{1}{n(n-1)}\sum_{j=1}^{n}\left(e_j - \overline{e}\right)^2}$$

where $n$ is the sample size, $e_j = \hat{y}_j - y_j$ and $\overline{e} = \frac{1}{n}\sum_{j=1}^{n} e_j$

Similarly, the model-assisted estimator for the net equivalent $CO_2$ total can be expressed as

$$\hat{\tau}_{ma} = \sum_{i=1}^{N} y_i - \frac{N}{n}\sum_{j=1}^{n}\left(\hat{y}_j - y_j\right)$$

Särndal et al. [21, p. 402] give the SE of the model-assisted estimator for the total:

$$SE\left(\hat{\tau}_{ma}\right) = \sqrt{N^2\left(\frac{1}{n} - \frac{1}{N}\right)\sum_{j=1}^{n}\frac{\left(e_j - \overline{e}\right)^2}{n-1}}$$

which can also be expressed as [21, p. 276]:

$$SE\left(\hat{\tau}_{ma}\right) = \sqrt{\hat{V}\left(\hat{\tau}_{HT}\right)\left(1 - R^2\right)}$$

where $\hat{V}\left(\hat{\tau}_{HT}\right)$ is the HT estimator of the variance under simple random sampling and $R^2$ is the determination coefficient of the prediction model. With $R^2 = 1$ the variance is 0 and the estimate coincide with the real value. Indeed, the reduction in variance gained using the model-assisted estimator is directly linked to the model performance.

Finally, to assess the efficiency of the model-assisted estimator for both the mean and total value, we compared the estimates against the design-based estimates produced just from the field plots through the relative efficiency coefficient (RE):

$$RE = \frac{\widehat{Var}\left(\hat{E}_{HT}\right)}{\widehat{Var}\left(\hat{E}_{ma}\right)}$$

where $\widehat{Var}\left(\hat{E}_{HT}\right)$ and $\widehat{Var}\left(\hat{E}_{ma}\right)$ are the estimated variance of the design-based and model-assisted estimates, respectively. Values of RE greater than 1 are evidence of greater precision in the model-assisted estimates [22–25]. RE coefficient can be interpreted as the factor by which the original sample size would have to be increased to achieve the same precision as that achieved using the remotely sensed auxiliary data.

## 4 Results

After the variable selection, 21 variables were chosen as the best candidates for prediction. These include three *medoid* and 18 *harmonic* predictors (Fig. 3), confirming the relevance of *harmonic predictors*. The most important variables were the sine of the NIR band, followed by the sine of the red edge 3 bands and the sine of the red edge 2 bands.

The final OOB error in terms of RMSE was 1.74 Mg ha$^{-1}$ or 35% of the mean net equivalent $CO_2$ stock measured in the field. The $R^2$ was 0.69, indicating that S2 data provide meaningful information for predicting $CO_2$. The RF model was used to predict

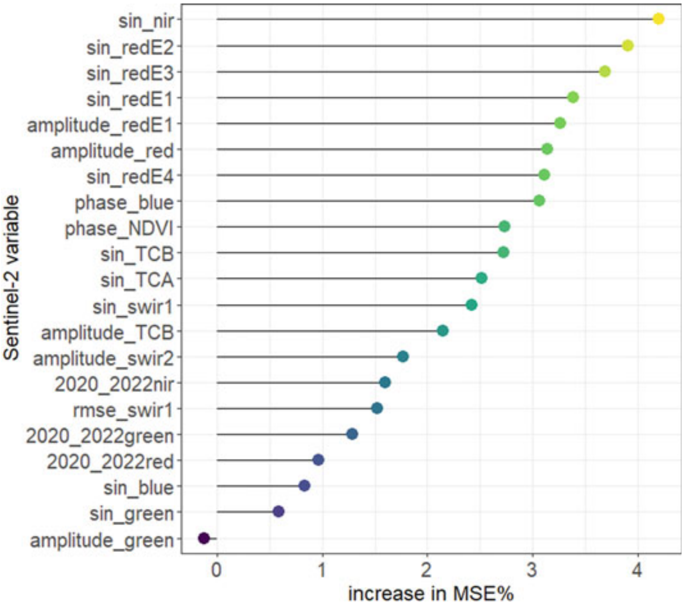


**Fig. 3** Sentinel-2 variables importance


**Fig. 4** Net equivalent $CO_2$ stock map generated with RF model. In blue the study area grid, while red dots represent the ground samples

net equivalent $CO_2$ stock over the study area (Fig. 4). Predictions ranged between 3.13 and 7.84 Mg ha$^{-1}$ with a standard deviation of 0.84 Mg ha$^{-1}$.

Based on the HT estimator, $\hat{\mu}_{HT} = 4.95$ Mg ha$^{-1}$ with a $SE(\hat{\mu}_{HT}) = 0.45$ Mg ha$^{-1}$. By contrast, based on RF predictions for the entire study area, $\hat{\mu}_{ma} = 4.93$ Mg ha$^{-1}$ with a $SE(\hat{\mu}_{ma}) = 0.17$ Mg ha$^{-1}$, which corresponds to an RE coefficient of 7.1, demonstrating more effective results with the model-assisted estimator. Analogous results were obtained for the total carbon stock for which the model-assisted estimator outperformed the HT one ($\hat{\tau}_{HT} = 118.47$ Mg with a $SE(\hat{\tau}_{HT}) = 10.87$ against $\hat{\tau}_{ma} = 125.76$ Mg with $SE(\hat{\tau}_{ma})$ = 8.73), with a RE coefficient of 1.54 (Table 1).

**Table 1** Mean $(\hat{\mu})$ and total $(\hat{\tau})$ values of net equivalent $CO_2$ stock (Mg ha$^{-1}$) with the design-based and model-assisted estimators

| | Deign-based | Model-assisted | RE |
|---|---|---|---|
| $\hat{\mu}$ | 4.95 | 4.93 | / |
| $SE(\hat{\mu})$ | 0.45 | 0.17 | 7.1 |
| $\hat{\tau}$ | 118.47 | 125.76 | / |
| $SE(\hat{\tau})$ | 10.87 | 8.73 | 1.54 |

## 5 Discussions and Conclusion

In this study, we demonstrated the advantage of exploiting S2 data for mapping and estimating net equivalent $CO_2$ stock in a tree plantation of 20 ha, in Guatemala. Using exclusively the ground data, we estimated the net equivalent $CO_2$ stocked on average in each 10-m cell over the plantation as 4.95 Mg ha$^{-1}$ ± 0.9 Mg ha$^{-1}$, with a confidence interval of 95%. Exploiting S2 predictors, random forests, and the model-assisted estimator, the estimate was much more precise, i.e., 4.93 Mg ha$^{-1}$ ± 0.29 Mg ha$^{-1}$. Indeed, the ratio between the variances of the design-based and the model-assisted estimates (RE, see Sect. 3.4) was 7.1. This means that, by using remote sensing data, it is possible to reduce the ground sample size by a factor of 7.1 while obtaining estimates with the same precision of those do not exploiting remote sensing data. This is a crucial advantage to reduce costs associated with ground data acquisition. Among the 21 predictors selected by the random forests model, 18 were *harmonic predictors* and just 3 were *medoid predictors*. This confirms the advantage of using time series analysis instead of single images. Accordingly, using *harmonic predictors* the model reached large accuracy with $R^2$ equal to 0.69 and RMSE up to 35%.

Last but not least, the procedure herein presented exploits open access S2 data and is scalable and replicable globally across other tree plantations. The procedure we presented allows obtaining reliable estimates and 10-m resolution maps informing on the amount of per pixel biomass. This also informs on the tree status, supports the management of the tree plantation, and helps the remote monitoring over time.

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4. FORWARDS

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# Rooftop Solar Photovoltaic Systems for Building of Industrial

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**Abstract.** Rooftop Solar Photovoltaic systems may be crucial in the current energy scenario generating electricity on-site where buildings which are used for other purposes and have unused rooftop or other areas, such as, among other things, manufacturing processes, parking lots and residential building because these unused areas may be used to install Photovoltaic system. Moreover, the sizing of this type of systems is easily adjustable due to its modularity and its cost competitiveness when comparing other kinds of power generation sources. Currently, in Spain the potential to cover the electricity demand through Rooftop Solar Photovoltaic system may be between 20 and 30%. The industrial sector, which has a great unused rooftop and consume large amounts of energy, may play a major role in the energy transition. Electrical parameters of four Rooftop Solar Photovoltaic systems installed in Industrial Cooling and refrigeration industries have been monitored for one year in order to provide the input parameters to estimate the indices. The array power rating varies from 52.8 to 400 kW. Load matching metrics based on on-site measurements have been presented using recording intervals of 5 min. High self-consumption indices are achieved, close to 100%, while the self-sufficiency indices vary between 3.75 and 17.66%. Moreover, the sunshine self-sufficiency index ranges between 6.63 and 30.94%.

**Keywords:** Rooftop solar photovoltaic systems · Industrial cold · Energy efficiency

## 1 Introduction and Objectives

Renewable energies may be crucial in the current energy scenario because they could reduce the effects of Fossil energies on the environment. They could help to reach a


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higher level of reducing greenhouse gas emissions and have great potential to reduce the cost of electricity generation. The electrical energy generation through renewable energies grew 8% in 2021, where solar photovoltaic and wind energies represented two-thirds of that growth [1]. Photovoltaic solar energy do not only correspond to large photovoltaic plants but also to medium-small photovoltaic self-consumption systems, also called Rooftop Solar Photovoltaic systems; as they are modular systems, require low maintenance and the solar resource is distributed. Rooftop Solar Photovoltaic systems have a great potential to generate electricity onsite: roofs, parking lots or any kind of available areas due to the abundance of solar resource and the low cost of photovoltaic technology.

It is estimated that Rooftop Solar Photovoltaic systems (Rooftop PV) in Spain may cover the electricity demand between 20 and 30% while 18% of the installed capacity of photovoltaics in Europe corresponds to commercial Rooftop PV systems [2]. The analysis has assumed that the Rooftop PV area was 40% of the building area. Modules were crystalline silicon technology; they were installed south facing and the tilt angle was 20°. Meanwhile, PV energy yield was estimated using the Photovoltaic Geographical Information System (PVGIS) and a uniform value of 14% of systems losses and losses due to ageing were considered.

In this context, analysing the matching of electricity consumption in industries and photovoltaic electricity generation profiles could make it easier for the industrial sector to play a major role in the energy transition. In addition, this type of generation is aligned with the objectives and plans in terms of energy of Spain (*Plan Nacional Integrado de Energía y clima 2021–2030*), and the European Union (REPo-werEU Plan), as well as the objectives of the Sustainable development goals (SDG) [3–5].

On the other hand, it should be mentioned that electricity meets an average 30% of final energy demand across all sectors [6]. One-fifth of this percentage rate was estimated that was be consumed in the refrigeration sector where air conditioning was also taken into account. The refrigeration sector not only plays an essential role for the food sector as it guarantees its optimal conservation, but it is also vital for the chemical, plastic, building industries and other advanced industries, such as electronic-data processing or biotechnologies [7]. Therefore, those industries that require refrigeration cycles may match with solar energy, both thermal, solar photovoltaic and hybrid, and may increase the coefficient of Performance (COP) [8]. The assessment of this matching from an energy point of view, especially when considering electrical energy, may be very useful not only when sizing but when optimizing photovoltaic installations. Analysis of the matching between demand and photovoltaic generation is further analyzed in the residential sector, commercial buildings and urban areas, there are several reviews where it can be possibly to find more details [9–12]. In agro-food sector, the potential of the Rooftop PV systems in oil mills, for different PV array orientations and inclinations, was evaluated through self-sufficiency and self-consumption indices [13, 14]. However, the industrial sector is still short of details, it should be taken into account that manufacturing the sector had the largest share (30%) of final energy demand in the world in 2019 [15]. Economic criteria for evaluating the investment of a satisfactory industrial and commercial rooftop distributed photovoltaic may be found in [16]. Moreover, new parameters have been introduced, such as the self-sufficiency index for sunshine hours, which allows the evaluation of the system in its operating hours and therefore allows the photovoltaic systems to be optimized in order to obtain higher COPs [17]. Although, these studies show valuable information to assess potential of Rooftop PV systems, nevertheless, there is a gap of the on the set of indices that can analyse the real load matching metrics based on-site measurements and design Rooftop PV systems of the industrial sector. In this way, the main objective of this manuscript is to analyse the indices and parameters, which can provide the matching between the electricity consumption and electricity generation of four Rooftop Solar Photovoltaic systems installed in Industries Cooling and Refrigeration industries. It is intended to provide parameters which may assist in the evaluation of the potential of photovoltaic distributed systems in this industrial sector from an energy criterion using the self-consumption and self-sufficiency indices, both taking into account the full day and only the sunshine hours.

## 2 Data and Methods

Four industries of the cold sector with Rooftop PV, have been monitored for a year. Active power corresponding to the electrical generation ($P_{\mathrm{PV,gen},\tau_k}^{min,day}$) and the electrical consumption ($P_{\mathrm{L},\tau_k}^{min,day}$) have been measured. The recording interval considered was five minutes, which may be appropriate as the consumption profile of this kind of the industries show little variability. Input data have been processed in order to avoid missing and invalid data according the recommendations of International Electrotechnical Commission (IEC) standards 61,724-1 [18], IEC 61,724-2 [19] and IEC 61,724-3[20]. Missing data have been filled by data processing. A linear interpolation was used; moreover, a filter with a minimum and maximum value of the active power was also checked. Matlab® was used to estimate the calculated parameters and indices.

Measured power data, both electrical consumption and generation, their data distribution was shown in the box diagrams, Figs. 1 and 2. This graphic representation contains a series of numerical data through its quartiles, representing in a box the values between the first quartile (25%) and the third quartile (75%). In this way, the 25th, 50th and 56th percentiles have been calculated. In these figures, the outliers are also plotted using the '+' symbol.

Energy parameters are calculated through the measured power parameters, which are considered constant throughout the recording interval. The electrical consumed energy during the year ($E_{\mathrm{L,annual}}$), electrical energy which is demanded from the electrical network ($E_{\mathrm{FG,annual}}$), electrical energy generated through photovoltaic systems ($E_{\mathrm{PV,gen,annual}}$), self-consumed electrical energy ($E_{\mathrm{PV,CON,annual}}$) and the electrical energy generated which is exported to the electrical network ($E_{\mathrm{TG,\ annual}}$), may be estimated according to Eq. 1:

$$E_{annual} = \sum_{\min=1}^{59} \sum_{day=1}^{365} P_{\tau_k}^{\min,day} \times \tau_k \tag{1}$$

where $\tau_k$ is the duration of the recording interval, $P_{\tau_k}^{min,day}$ corresponds to the considered power. In this sense, it may correspond to $P_{\mathrm{PV,gen},\tau_k}^{min,day}$ $P_{\mathrm{L},\tau_k}^{min,day}$, $P_{\mathrm{FG},\tau_k}^{min,day}$ (power from grid),

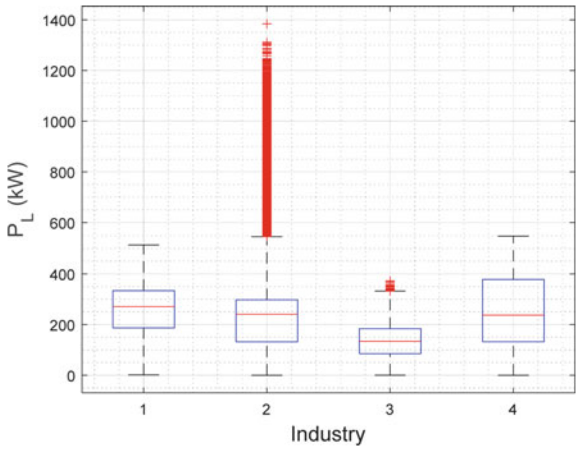


**Fig. 1** Boxplot of the electrical consumed power of the different analysed industries

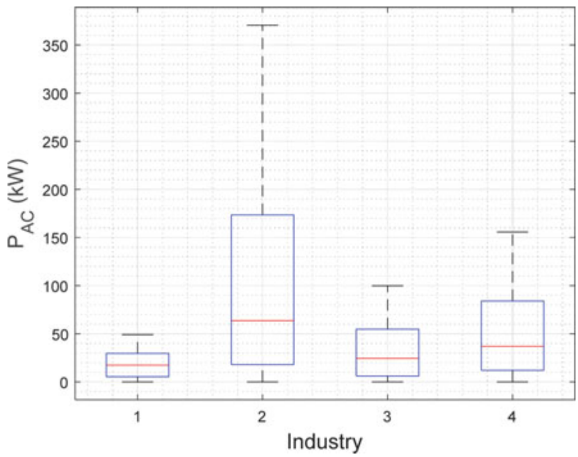


**Fig. 2** Boxplot of the electrical generation power from Rooftop Solar Photovoltaic systems, which are installed in the analysed industries

$P_{\mathrm{TG},\tau_k}^{min,day}$ (power to grid) or $P_{\mathrm{PV,con},\tau_k}^{min,day}$ (photovoltaic self-consumed power) depending on the calculated parameter.

Regarding the power from grid, it may be estimated as Eq. 2:

$$P_{\mathrm{FG},\tau_k}^{min,day} = \begin{cases} 0 & if\, P_{\mathrm{PV,gen},\tau_k}^{min,day} \geq P_{\mathrm{L},\tau_k}^{min,day} \\ P_{\mathrm{L},\tau_k}^{min,day} - P_{\mathrm{PV,gen},\tau_k}^{min,day} & if\, P_{\mathrm{PV,gen},\tau_k}^{min,day} < P_{\mathrm{L},\tau_k}^{min,day} \end{cases} \quad (2)$$

Power to grid could be estimated as Eq. 3:

$$P_{\mathrm{TG},\tau_k}^{min,day} = \begin{cases} P_{\mathrm{PV,gen},\tau_k}^{min,day} - P_{\mathrm{L},\tau_k}^{min,day} & if\, P_{\mathrm{PV,gen},\tau_k}^{min,day} \geq P_{\mathrm{L},\tau_k}^{min,day} \\ 0 & if\, P_{\mathrm{PV,gen},\tau_k}^{min,day} < P_{\mathrm{L},\tau_k}^{min,day} \end{cases} \quad (3)$$

Photovoltaic self-consumed power, $P_{\text{PV,con},\tau_k}^{min,day}$, could be obtained from the following Eq. 4 [21–23]:

$$P_{\text{PV,con},\tau_k}^{min,day} = \begin{cases} P_{\text{PV,gen},\tau_k}^{min,day} & if\, P_{\text{PV,gen},\tau_k}^{min,day} < P_{\text{L},\tau_k}^{min,day} \\ P_{\text{L},\tau_k}^{min,day} & if\, P_{\text{PV,gen},\tau_k}^{min,day} \geq P_{\text{L},\tau_k}^{min,day} \end{cases} \tag{4}$$

Moreover, electrical consumed energy during solar hours is also calculated, ($E_{\text{L,HS,annual}}$). Sunshine and night hours can be estimated by means of an astronomical model that determines when sunrise and sunset occur [24]. This parameter shows only the electrical consumed energy when the Rooftop PV systems can provide energy. Nevertheless, when estimating sunshine hours all the days are considered as clear days. Once solar hours are estimated for each day, the electrical consumed power in solar hours could be estimated with the following expression, Eq. 5:

$$P_{\text{L,SH},\tau_k}^{min,day} = \begin{cases} \text{NaN} & ifmin \text{ is at night hours} \\ P_{\text{L},\tau_k}^{min,day} & if\, min \text{ is at Sunshine hour} \end{cases} \tag{5}$$

On the other hand, the self-consumption and self-sufficiency indices are estimated, taking into account both the full hours and the solar hours. The self-consumption index ($\varphi_{sc}$), which can be defined as the ratio of self-consumed photovoltaic energy ($E_{\text{PV,con}}$) and generated photovoltaic energy ($E_{\text{PV,gen}}$), Eq. 6, indicates the level of use of self-consumed photovoltaic energy with respect to the generated photovoltaic energy. On the other hand, the self-sufficiency index ($\varphi_{ss}$) provides the percentage of the energy consumption ($E_{\text{L}}$) that is covered from the generated photovoltaic energy, [9, 23] Eq. 7

$$\varphi_{sc,annual} = \frac{E_{\text{PV,con},annual}}{E_{\text{PV,gen},annual}} \tag{6}$$

$$\varphi_{ss,annual} = \frac{E_{\text{PV,con},annual}}{E_{\text{L},annual}} \tag{7}$$

The self-sufficiency index in solar hours is estimated as the quotient between self-consumed electrical energy divided by the consumed energy in solar hours [17], Eq. 8.

$$\varphi_{ss,SH,annual} = \frac{E_{\text{PV,con},annual}}{E_{\text{L,SH},annual}} \tag{8}$$

The self-sufficiency index in solar hours indicates the level of coverage of this technology, limited exclusively to the consumption in the period of time in which this energy source is active. Therefore, it can allow a better characterization of photovoltaic self-consumption systems in the industrial sector because this index only focuses on the performance during solar hours: this type of systems only provides energy if there is enough irradiance. It must be highlighted that when considering consumption profiles in the industrial sectors, the casuistry is very wide and some consumption profiles have nocturnal variability or a large amount of energy consumption compared to solar hours. In this situation, the self-sufficiency index may be influenced and the self-sufficiency in solar hours may estimate better the real matching between electrical demand energy and electrical generation energy.

## 3 Results and Discussion

Figure 1 shows the distribution of the consumed power in solar hours during a year for four cold industries through a box diagram. In addition, Table 1 shows the 25th, 50th and 75th percentiles for each industry.

**Table 1** 25th, 50th and 75th percentiles of the electrical consumed power of the different analysed industries

| | Industry #01 | Industry #02 | Industry #03 | Industry #04 |
|---|---|---|---|---|
| $P_{L,Q1}$ (kW) | 187.22 | 131.84 | 85.34 | 132.31 |
| $P_{L,Q2}$ (kW) | 270.65 | 240.80 | 134.51 | 237.25 |
| $P_{L,Q3}$ (kW) | 333.71 | 297.92 | 184.18 | 377.82 |

Industry #01 is the one with the highest first quartile and median, 187.22 kW and 270.65 kW, respectively. While the lowest values correspond to industry #03, 85.34 kW and 134.51 kW, respectively. Industry #03 also has the lowest 75th percentile, whose value is 184.18 kW. These lowest power values could be expected as it is the industry which has the lowest consumed energy, as it can be seen in Table 3. On the other hand, industry #04 is the one with the highest 75th percentile with a value of 377.82 kW.

Regarding photovoltaic generation, the distribution can be seen both in Fig. 2 and Table 2. The lowest array power rating ($P_0$), corresponds to industry #01, which 75% of the generated powers are greater than 5.45 kW and only 25% stay above 29.59 kW. While for industry #02, the one with the highest $P_0$, the 25th percentile is 18.01 kW and the 75th percentile is 173.45 kW.

**Table 2** Values of the 25th, 50th and 75th percentiles of boxplot of the electrical generation power from Rooftop Solar Photovoltaic systems, which are installed in the analysed industries

| | Industry #01 | Industry #02 | Industry #03 | Industry #04 |
|---|---|---|---|---|
| $P_0$ (W) | 52.800 | 400.080 | 110.200 | 180.255 |
| $P_{AC,Q1}$ (kW) | 5.4480 | 18.0060 | 6.0480 | 12.1560 |
| $P_{AC,Q2}$ (kW) | 17.5080 | 63.6360 | 24.5160 | 36.9720 |
| $P_{AC,Q3}$ (kW) | 29.5920 | 173.4480 | 54.7920 | 84.0720 |

Table 3 shows annual estimated parameters: electrical consumed energy ($E_{L,annual}$); electrical consumed energy only during solar hours ($E_{L,HS,annual}$), electrical generated energy at through photovoltaic system ($E_{PV,gen,annual}$), self-consumed electrical energy ($E_{PV,CON,annual}$), electrical generated energy that is exported to the electrical grid ($E_{TG,annual}$) and the electrical demanded energy from the electrical network ($E_{FG,annual}$).

The annual electricity demand of industries #01, #02 and #04 are quite similar; however, the electricity demand of industry #03 is half of the previous values. In the four

**Table 3** Energy estimated parameters of the different analysed industries

| | Industry #01 | Industry #02 | Industry #03 | Industry #04 |
|---|---|---|---|---|
| $E_{L,annual}$ (Wh) | 2,047,659,744 | 2,115,858,927 | 1,025,212,256 | 1,744,916,584 |
| $E_{L,HS,annual}$ (Wh) | 1,159,342,646 | 1,207,044,116 | 603,810,959 | 1,108,096,352 |
| $\frac{E_{L,HS,annual}}{E_{L,annual}}$ | 0.5662 | 0.5705 | 0.5890 | 0.6350 |
| $E_{PV,gen,annual}$ (Wh) | 76,819,444 | 396,331,280 | 128,250,114 | 221,048,592 |
| $E_{PV,con,annual}$ (Wh) | 76,819,173 | 373,728,031 | 128,167,580 | 220,671,042 |
| $E_{TG,annual}$ (Wh) | 271 | 22,603,249 | 82,534 | 377,550 |
| $E_{FG,annual}$ (Wh) | 1,970,840,572 | 1,742,130,896 | 897,044,675 | 1,524,245,542 |

industries, electrical consumed energy is slightly higher in solar hours, in these hours the percentage of electrical consumed energy with respect to the full demand varies between 56.5 and 63.5%. Regarding generation, the array power rating varies from 52.8 kW in industry #01 to 400 kW in industry #02. For this reason, industry #02 is the one with the highest generation of electricity from photovoltaic sources, while industry #01 is the one with the lowest generation.

The self-consumption indices, as shown in Table 4, are close to 100%, therefore, almost all the electricity generated with photovoltaic systems is self-consumed in the analysed industries. However, self-sufficiency indices are relatively low between 3.75% for industry #01 and 17.66% for industry #03. On the other hand, the sunshine self-sufficiency index, which evaluates the self-consumed energy compared to the consumed energy that takes place during solar hours, thus, only when the photovoltaic system can provide energy, varies between 6.63 and 30.94%. With these data, perhaps it may be said that photovoltaic generators are quite small with respect to the electrical consumed power by these industries. Therefore, Rooftop PV systems could be higher the one installed, in this way, they will provide greater electricity coverage, thus, higher self-sufficiency index.

**Table 4** Values of the self-consumption, self-sufficiency and sunshine hourly self-sufficiency indices of the analysed industries

| | Industry #01 | Industry #02 | Industry #03 | Industry #04 |
|---|---|---|---|---|
| $\varphi_{SC}$ (%) | ~ 100.00 | 94.30 | 99.94 | 99.83 |
| $\varphi_{SS}$ (%) | 3.75 | 17.66 | 12.5 | 12.65 |
| $\varphi_{SS,HS}$ (%) | 6.63 | 30.94 | 21.23 | 19.91 |

## 4 Conclusion

Four Rooftop Solar Photovoltaic systems installed in industries of the cold sector have been monitored for a year. The recording interval of the measured parameters was five minutes. Electrical measured parameters can be very useful in order to evaluate the performance of r Rooftop PV systems installed in industrial buildings and they may be used for optimizing PV system design. Different load metrics are shown which may be very useful for the analysis of Rooftop PV systems, such as self-consumption and self-sufficiency indices, both taking into account the 24-h period and solar hours. In addition, graphs of the power consumed and the photovoltaic generation corresponding to the aforementioned industries with their corresponding self-consumption system are also shown.

The self-sufficiency index for solar hours has been estimated, it allows a better characterization of Rooftop PV systems in the industrial sector because this index only focuses on the performance during solar hours and it can avoid the nocturnal variability of electricity consumption.

The self-consumption indices of the four industries are close to 100%, while the self-sufficiency indices vary between 3.75 and 17.66%. It can be said that almost all the generation is self-consumed by the industries and these Rooftop PV systems are relatively small compared with the consumed energy of the industries.

For future works, which is currently under progress, it is proposed to analyse more parameters and provide a set of parameter and performance metrics through measured parameters, which could analyse the industrial sector with Rooftop PV, as well as how indices may vary if other parameters of the photovoltaic system are modified.

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# Sustainable Alternative to Antimicrobial Uses: New Probiotics

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**Abstract.** Indiscriminate use of antimicrobials is linked to a hazardous increase in antimicrobial resistances (AMR). Global concern in AMR has restricted antimicrobial use through new tight legislation and research on new sustainable alternatives is needed. Probiotics with their ability to positively regulate the growth of beneficial bacteria of the intestinal microbiota are proposed as a solution to this problem. The aim of this study was to isolate and characterise the probiotic potential of 44 lactic acid bacteria (LAB) obtained from sow's colostrum and milk. Two candidates were selected after determining the AMR profile in this collection for further in vitro assays: a *Lactiplantibacillus plantarum* (LA-34 M) and a *Loigolactobacillus coryniformis* (LA-10). Their antibacterial activity was demonstrated against three different enteric pathogens (*Escherichia coli*, *Salmonella* spp., and *Clostridium perfringens*). Adherence test were performed using the epithelial cell line IPI-21, where La-10 and La-34 showed highly adherence to cell culture (64% and 68% respectively). Furthermore, an invasion assay against *Salmonella* Typhimurium demonstrated that booth strains were able to reduce significantly ($p < 0.05$) *S.* Typhimurium invasion after 1 and 2 h of incubation. These results show once more the interest of LAB in pathogen control. Further in vitro and in vivo assays will allow to determine the commercial potential of these two isolates.

**Keywords:** Antimicrobial resistance · Probiotic · Lactic Acid Bacteria · Sustainable alternative · Food-animal production

## 1 Introduction

Antimicrobial resistance (AMR) is one of the threats to global health, food security, and animal health nowadays [1]. The European Union/European Economic Area (EU/EEA) shows each year more than 670.000 infections and more than 33.000 dies caused by bacteria resistant to antibiotics (2020/2022 data) [2]. The overuse and misuse of antibiotics both in human medicine and in veterinary medicine is linked to a rise in antimicrobial resistance. AMR can be spread from animals to humans, particularly from livestock to humans by animal products, water, and the manure used as fertilizer [3].

The European Union increased the regulation over the antibiotic use by regulating their use in sub-therapeutic doses as growth promoters and their prophylactic use [4, 5].


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The critical actual situation and the necessity of new future alternatives focus in a quick reduction and replacement in the use of antibiotics are all integrated on the objective number 12 of the 2030 sustainable development goals entitled "responsible consumption and production" [6]. New alternatives for the use antimicrobials would affect food-animal industry helping them to progress towards a more sustainable production system.

New researches situate probiotics as the most promising alternative. Probiotics are described as "live microorganisms that when are administrated in adequate amounts confer a health benefit to the host" [7]. Probiotics exert their action include bactericidal effects by bacteriocins release, production of metabolites [short chain fatty acids] which create a hostile environment for pathogens, competition for nutrients, host support in non-digestible nutrients or activation of the immune response [7, 8]. When developing probiotics, the first requirement, beyond the demonstrated probiotic activity, it is required to demonstrate the lack of any transmissible antimicrobial resistance [9]. Subsequent in vitro assays should be focus in test adhesion capacity. Adhesion is an quality indicator due to the immunomodulation role these bacteria exert on the mucosa cells and the competitive exclusion against pathogens [10, 11]. Several genus of beneficial bacteria has been used like probiotics and within all these genera the most commonly used were those belonging to the group of lactic acid bacteria (LAB) a group characterized by the production of lactic acid as a product of their glucose fermentation [12].

The aim of this study was to isolate and characterize a new possible candidate probiotic that could be used in swine. For this purpose, sow milk and colostrum samples were plated to find LAB candidates. Bacteria were isolate and identified and last an antimicrobial profile test was performed. After this, in-vitro assays were performed for evaluate further probiotic properties in selected strains. Antimicrobial activity against selected pathogens, adhesion assay with an epithelial cell line and *Salmonella* invasion test were the probiotic-evaluation assays developed.

The present study is sectioned in five differentiated actions. A first introduction where is commented the background and the theoretic context. Material and methods describes the methodology protocol used and the changes introduced on the assays developed: isolation and identification assay, determination of the antimicrobial resistances, antimicrobial activity, cell adhesion ability and invasion assay. The results obtained are depicted in results and discussion section. The conclusion finally extracts the main idea from the study performed and points out new goals in subsequent studies.

## 2 Material and Methods

### 2.1 Isolation and Identification of Potential LAB

Potential LAB were isolated from sow milk samples, collected on the research farm of the Universidad de León. Samples were directly planted on Man, Rogosa and Shape (MRS) agar (Oxoid). Culture and isolation were performed as it was described previously [13]. The identification of LAB isolates was carried out using MALDI-TOF as described previously [14].

### 2.2 Determination of Antimicrobial Resistances

Antibiotic resistance profiling of each LAB candidate was done using two different commercial VetMIC plates (Statens Veterinärmedicinska Anstalt) as previously described [15]. LAB isolated were tested against 14 different antibiotics following EFSA guidelines. Plates were incubated 48 h at 37 °C in anaerobic conditions. EFSA guidelines were followed to determine antibiotic resistance or sensitivity from the minimum inhibitory concentration (MIC) purposed [9]. For antibiotics not referenced by EFSA, breakpoints proposed in previous studies were used [16–18].

### 2.3 Antimicrobial Activity

The potential antimicrobial activity of candidates was further evaluated against two isolates of *Salmonella enterica* subsp., *enterica* serovar Typhimurium (SP11, S28), *E. coli* (EC21, EC60) and, *Clostridium perfringens* (CP84A CP89A), using a spot test as described previously by other authors [19, 20]. The antimicrobial activity was measured by the halo generated. Inhibition was considered positive if the inhibition halo was 0.5 mm or higher. Six replicates were used per isolate.

### 2.4 Cell Adhesion Assay

IPI-21 cell line, an epithelioid cell line derived from the ileum of a male boar, was used in cell culture assays. Cells were grown in Dulbecco's modified Eagle medium (DMEM, Gibco) supplemented with 10% heat inactivated fetal bovine serum (FBS, Gibco). Cells were incubated at 37 °C and 5% $CO_2$ as previous described [21, 22]. BAL isolates capability of adhering to IPI-21 cells was determined following a protocol previously described by other authors [23, 24]. Three independent replicates were made for each tested strain.

### 2.5 Invasion Assay

The protocol used had been previously described by other authors [25, 26] with minor modifications. IPI-21 cell culture was supplemented with a LAB inoculum. After incubation for one hour, *S.* Typhimurium was added in DMEM. A positive control (well with *S.* Typhimurium and no LAB) and a negative control (LAB isolates without *S.* Typhimurium) were included. The assays were performed at 1 and 2 h of co-culture. After incubation, viable bacteria were recovered and plated. For each isolate and incubation time, three replicates were used.

## 3 Results

### 3.1 Isolation and Antibiotic-Resistance Profile

A total of 44 LAB isolated were recovered in pure culture. The identification was carried out using the modifications included in the classification of the family Lactobacillaceae in 2020, based on their genome phylogeny, amino-acid identity and criteria about their physiology and ecology [27]. Species identified were: *Limosilactobacillus reuterii* (27), *Lactobacillus johnsonii* (7), *Limosilactobacillus vaginalis* (2), *Loigolactobacillus coryniformis* (2), *Lactiplantilactibacillus plantarum* (2), *Limosilactobacillus mucosae* (1), *Latilactobacillus curvatus* (1), *Levilactobacillus brevis* (1), *Lactobacillus amylovorus* (1).

Minimum inhibitory concentration [MIC] revealed that more than the 95% of the LAB isolated had more than one antibiotic resistance. Susceptibility percentages (Fig. 1) shows 5 antibiotics with less than 50% of susceptibility percentage for analyzed strains: chloramphenicol, vancomycin, ampicillin, trimethoprim and tetracycline. From the 44 LAB isolates analyzed only two isolates showed resistance to two antibiotics or less. LA-34M isolate identified as *Lactiplantibacillus plantarum* with a trimethoprim resistance and LA-10 isolate identified as *Loigolactobacillus coryniformis* with a tetracycline resistance. This two isolates (LA-10 and LA-34M) were selected for further studies because they were the only isolates the showed less than two antibiotic resistances in concordance with safety guidelines [9].

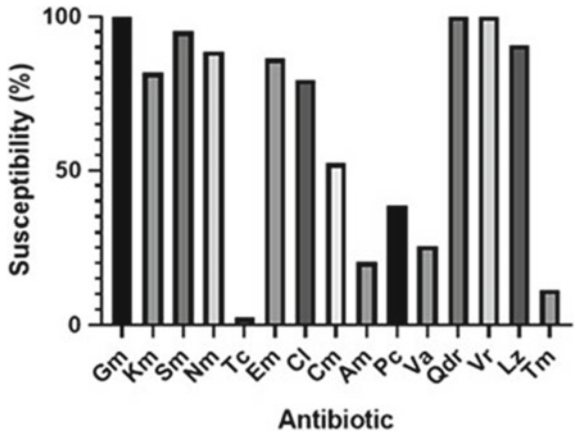


**Fig. 1** Percentage of LAB isolates classified as susceptible to each of the tested antibiotics: Gm (Gentamicin); Km (Kanamycin); Sm (Streptomycin); Nm (Neomycin); TC (Tetracyclin); Em (Erithromycin); Cl (Clindamycin); Cm (Chloramphenicol); Am (Ampicillin); Pc (Penicillin); Qda (Quinupristin-dalfopristin), Vr (Virginamycin); Lz (Lizenolid); Tm (Trimethoprim)

### 3.2 Antimicrobial Activity

Both selected LAB isolates showed good results against *S.* Typhimurium (SP11 and SP28), *E. coli* (EC21 and EC60) and *C. perfringens* (CP34A and CP89A) isolates after 48 hours of exposition. Results are showed on Fig. 3 aggregated by pathogen strain. LA-34M isolate performed slightly better with an average inhibition halo diameter of $25.9 \pm 1.8$ mm. LA-10 meanwhile got an average inhibition halo diameter $19.7 \pm 0.9$ mm.

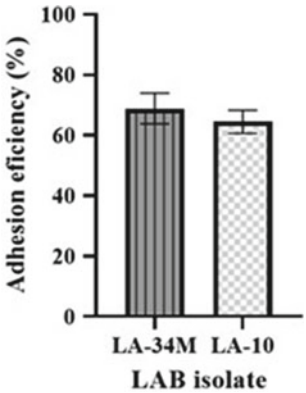


**Fig. 2** Adhesion efficiency of LA-10 (*L. coryniformis*) and LA-34 M (*L. plantarum*) isolates after 2 h of incubation with IPI-21 cells. Results are expressed as the mean of the percentage of the bacteria adhered after two-hour incubation with respect to the initial inoculated concentration with standard deviation bars

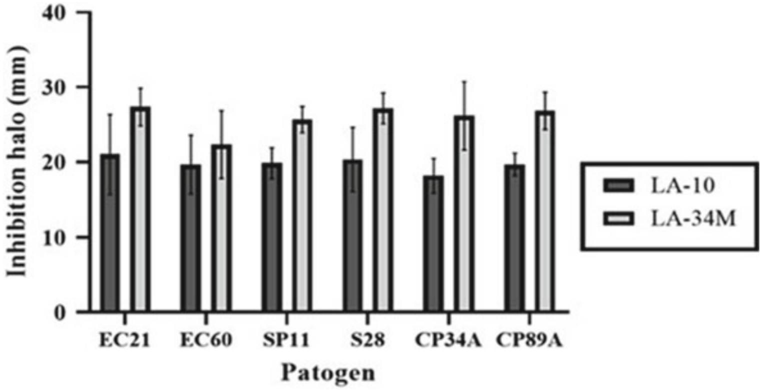


**Fig. 3** Antimicrobial activity of LA-10 (*L. coryniformis*) and LA-34 M (*L. plantarum*) isolates against two isolates of *E. coli* (EC21, EC60), two isolates of *S.* Typhimurium (SPP11, S28) and two isolates of *C. perfringens* (CP34A, CP89A). Antimicrobial activity is expressed in mm of the inhibition halo (mean and standard deviation bars)

### 3.3 Adhesion Assay

Through adhesion to the intestinal epithelium, probiotic microorganisms interfere with the adhesion of other pathogenic bacteria and get involved in host immunomodulation [1, 28]. Results of this assay showed a high adherence capacity for both LAB isolates tested, with an adherence of 64% for LA-10 and 68% for LA-34M (Fig. 2).

### 3.4 Invasion Assay

Probiotics have been shown to be effective in reducing gastrointestinal diseases [25]. Their ability to adhere to intestinal cells by the so-called barrier effect, prevent the invasion and adhesion of enteropathogens to host cells in a process of competitive exclusion [11]. A gentamicin protection assay was carried out to evaluate the effect of LAB isolates in the invasion of IPI-21 intestinal cells by *S*. Typhimurium. After a pre-incubation of IPI-21 cells with LAB isolates (1 h), *S*. Typhimurium was inoculated, and invasion results were measured after 1 and 2 h of co-incubation time. After one hour incubation with *S*. Typhimurium, a significant reduction ($p < 0.05$) was observed for both LAB isolates [reductions of 58.4% and 67.11% for LA-10 and LA-34M, respectively] as compared with the control (Fig. 4a). *Salmonella* invasion was most affected after two hours of incubation with a significant reduction ($p < 0.05$) for both isolates. LA-10 was able to limit the invasion in a 78.5% and LA-34M reduced *S*. Typhimurium invasion in 86.1% compared to control (Fig. 4b).

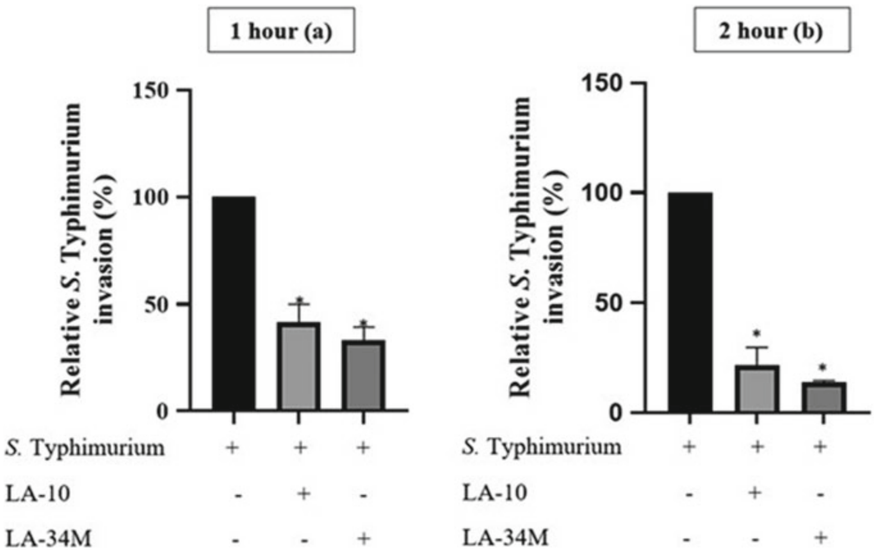


**Fig. 4** Invasion of *S*. Typhimurium on IPI-21 cells in the presence (+) or absence (−) of LA-10 (*L. coryniformis*) and LA-34 M (*L. plantarum*) isolates. *S*. Typhimurium invasion was determined at one (**a**) and two hours (**b**). Values are expressed as the mean with standard deviation bars of the percentage of invasion with respect to the invasion in the positive control, where only *S*. Typhimurium is present. Values significantly different from control ($p < 0.05$) are indicated by an asterisk

## 4 Discussion

Antimicrobial resistance test is the first step to evaluate probiotic potential and the most important one to evaluate probiotic security [1]. Resistance genes are usually shared through horizontal transference and an analysis of the provenance of antibiotic resistance is needed. Many research locates trimethoprim resistance in *Lactobacillus* genera as a usual intrinsic one [17, 29] what does not preclude its potential use. By contrast we could find potential limitations with tetracycline resistance. This has been described as an intrinsic resistance or as a horizontal-gene transfer resistance so further analysis must be carried out to determinate the provenance [26, 30]. Anyway, booth isolates LA-10 and LA-34M were proposed for further analysis due to their low antibiotic resistances and following other similar research previously done where is characterized their probiotics benefits. *Lactiplantibacillus plantarum* before named *Lactobacillus plantarum* has been specially described and tested by many authors as a functional probiotic showing successful results in the in-vitro assays. *Loigolactobacillus coryniformis* has been more rarely characterized as probiotic but suppose due to its characteristics a hopeful project.

Antimicrobial activity obtained on these assays has been described also in many probiotic characterizations with LAB isolates previously performed. This group are able to produce several metabolites that confer antimicrobial activity such as organic acids, sugar polymers or bacteriocins [29]. Specifically, it has been described the mechanism by which organic acids exert antimicrobial activity through their undissociated form, which is able to penetrates into the cytoplasm causing a reduction in intracellular pH [31]. Production of antimicrobial compound by probiotic bacteria is an excellent feature for modulation of intestinal microbiota [32]. Good antimicrobial activity on this group are usually connected with lactic acid production and furthers metabolite and molecular studies should be done to analyze the possible existence of any other antimicrobial substance.

IPI-21 adherence assay confers critical information over how is going to be the communication and the interaction between bacteria and host cells. Obtained results exceeded the percentages observed in similar studies [24]. Good adherence capacity of different LAB strains, especially *L. plantarum* (LA-34M) has been previously described previously. Generally it has been proposed that there is a great interspecific and intraspecific variability in the adherence ability, highlighting the need of evaluating each individual isolate [30, 33]. Both the ability for adhesion and the persistence and survival in the intestinal tract in this species is related to various proteins, hydrolase enzymes and transglycans, which provide the ability to adhere to elements of the intestinal tract of the host [33, 34].

Invasion assay confirm that both LAB isolates were strongly able to decrease *S.* Typhimurium invasion in IPI-21 cells. Similar assays have also showed the ability of BAL isolates, particularly *L. plantarum* isolates, to prevent bacterial invasion, probably as a consequence of the aforementioned ability to produce antimicrobial compounds such as lactic acid that inhibit the colonization of pathogenic microorganisms [35, 36]. However, further studies are required to determine the effectiveness of our LAB isolates in the intestine since results obtained using in vitro assays may be different from in vivo experiments [37].

Assays performed should be completed in concordance with guidelines stablished by previous studies performed. Proposed assays would continue with a bile-salts and pH resistance test to determinate the survival and viability over intestinal conditions. An immunomodulatory assay would be suitable on this study to check the effect of LAB isolates over pro-inflammatory cytokines in IPI-21 cells. Latest in-vivo assays should be performed to confirm in-vitro obtained results.

## 5 Conclusion

The results of the present study demonstrate the potential usefulness of LAB isolated from milk and colostrum in the control of enteric pathogens as a sustainable alternative for antimicrobial use. Our results join and enlarge previous studies and provide two new potential strains *Lactiplantibacillus plantarum* LA-34M and *Loigolactobacillus reuterii* LA-10 for probiotic development. Further studies in-vivo and in-vitro are needed to evaluate their commercial potential.

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# Circular Economy Policies in the Concrete Production

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**Abstract.** In the present scenario, the concept of circular economy is overwhelming in every sector and it also receives attention to overcome the continuous growth and increasing natural resource utilization. One of the major policies in concrete production is to reduce the cost of concrete without compromising the quality of concrete itself. Researchers are looking to derive a solution for resource scarcity, the usage of wastes from industries without properly polluting the environment, and nowadays it becomes more significant than ever before. This article discusses the circular economy policies that can be implemented for concrete production. One of the best options available to reduce the negative impact generated by the concrete sector is the circular economy concept. This article discusses the lenient views of political, social, and legal features and is vital to integrating the solid issues of technical, environmental, and economic features.

**Keywords:** Circular economy · Concrete sector · Environment

## 1 Introduction

One of the major policy item and testing challenges in the concrete sector is the circular economy (CE) concept. CE aims to be an effective utilization of resources and waste minimization. Hence, CE is related to a financial system and it is different from the traditional approach in which the product is a 'take, make, disposal' model. Whereas in CE concept in concrete production leads to natural resources perseveration, waste minimization, less pollution, and effective product utilization and this leads to slowing, closing, and minimizing loops in material utilization, energy leakage, and cost outflow. The argument is those CE models, allow us to keep enjoying similar products and services without compromising the quality. The areas like resource utilization, materials handling, design thinking, product life extension, and recycling products help to achieve CE models that are environmental and economically sustainable.

One of the most consumable materials is concrete with annual production estimated to be greater than 20 GT/year and it is still rising [1]. To reduce or maintain the global


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temperature rise below 2 °C greenhouse gas emissions below 24% as reported by IEA., 2016 [2] as reported by the Paris agreement. Implementation of CE concept is existing on technical, eco-friendly, and financial aspects of few significant policies. When the CE concept is explained and evaluated, social dimensions have been abandoned. CE policies for the concrete/cement sector from the view of decarbonatization emphasized the intentional and unintentional significance of the adoption of strategies as reported by Miller et al. [3]. The CE concept in concrete production is referred to in the terms of economic, social, technical, and environmental aspects in a different way as shown in Fig. 1 [4] for more examination purposes. CE economy policies associated wither directly or indirectly with respect to concrete production. Direct CE polices are associated with material savings, natural prevention, energy reduction, pollution less, cost reduction and without compromising the concrete properties. Whereas indirect polices includes reduction energy consumption and environmental pollution. But polices associated with both are influenced based on application. This study aims to introduce the circular economy policies in concrete production and their feasibility options.

## 2 Concept of Circular Economy

Products from various industrial wastes are used to produce blended concrete without compromising its quality and satisfying CE concepts. Nowadays the concrete available in the environment exists on an analogous scale to biomass stocks [5]. Four types of actions on resources flows are used to define CE principles and policies:

- Narrowing = volume of materials reduction
- Slowing = manufacturing and end-of-use time extension
- Closing = end of use and production time limitation
- Effectively reintegrating = usage of materials.

Waste is significant to describe the flows of resources throughout life cycles assessment but versatile period with dissimilar clarifications contingent as reported by Blomsma [6]. Globally, 70% of cement produced is consumed for concrete production and the balance of 30% of cement is consumed for the mortar [1]. Major particles present in the concrete as bulk, 5.2% of particles are less than 10 μm and in particular, 6.4% of particles are less than 2.5 μm [7].

## 3 Application of Circular Economy Policies for Concrete

Application of CE policies for concrete can be understood, if the PESTEL concept is explained. PESTEL (Political, Economic, Social, Technological, Environmental, and Legal) context is a known polices to analyze, and navigate the features affecting requests and the possible collaborations and struggles to rise from amalgamation [8]. The topics which are conquered around cement/concrete are financial, environmental, and technical policies.

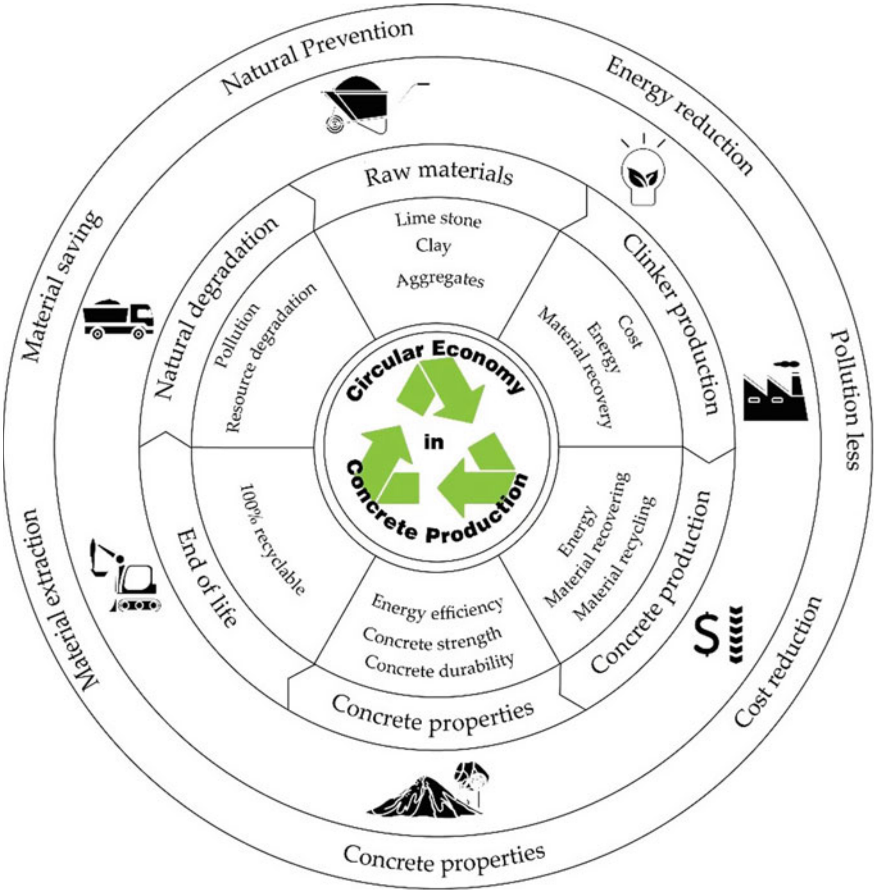


Fig. 1 Circular economy concept in concrete production [4]

### 3.1 Political

In CE, consumption and production schemes remain the same, with greater importance on the efficiency of resources mainly through recycling. To avert, neglect of social and financial significance, and confirm the interferences are operative transversely to the entire supply chain of concrete [3]. CE depends entirely on the recovery of resources and it is demonstrated by the concrete/cement industry. In the context of mix design in the current scenario, the new concrete is produced with mineral admixture and recycled materials resulting in energy cost reduction in concrete production. Wide-scale the ingredient flow and stocks of concrete in the economy, resource loops closing to recycling ingredients is likely to request input energy. Waste prevention and material regaining are developing, recycling is doubtful to consider 100% material recovery [9].

### 3.2 Economic

Three models are followed in the concrete industry as reported by Tukker, Viz. [10], 'pure product' models, 'pure service' models and some follow both models. There are two different value propositions for concrete and hence it leads to different business models, Viz., 'product lease' and 'product related' as reported by Iacovidou and Purnell [11]. CE policies classical aspect a wide variety of benefits returned over a longer time scale, linear economy business cases [12].

### 3.3 Social

Concrete sector is normally a traditional, for comprehensible motives finances are frequently wide, it is expensive errors and consuming more time. Diminishing risk is consequently a robust, experts are improbable to conflict of risk over advanced technical explanations whose security and achievement cannot be guaranteed [13]. Risks raised from technical view is overviewed by industrial sectors, whose present models proposed by business requirement force be confronted [14]. Effect of CE policy, an extensive range of CE indicators are being developed. Repetitive employment of such holistic valuations would advantage from practitioners across cement/concrete sector having higher CE literacy.

### 3.4 Technical

Concrete structures are recognized as one of the most suitable materials and the 'design to reduce' policy is applied. These policies are exploited in a much better way to enhance the CE. Geometrical standardization and optimization are two often technical feasibility recommended. The 'Push' of innovative materials is isolated from the 'pull' of the manufacturing process [15]. Design for durability will play a key role in the implementation of these strategies, as they will not be attainable if the concrete properties are compromised. The crucial observation here is that the choices made at design stage then open and close doors to other strategies further down the lifecycle. The flow of information will be key to determining the extent to which downstream opportunities can be fulfilled.

### 3.5 Environmental

Several methods available in the literature have yielded many effective ways to calculate the embodied carbon in concrete-related products. Understanding and admittance to the data, enhance the holistic environment and impact of concrete in diverse contexts [16]. Even though different contexts exit, there are several instances problematic choices have to be made about which several strategies to implement the trade-offs exist [16]. In the areas of low environmental value, there may be interactions with reintegrating resource flows into the environment, but there may be trade-offs with the safety associated with environment.

### 3.6 Legal

The cement/concrete sector comprises movements of data, materials, and carbon. While analyzing the life cycle stage, specialists require the tools to evaluate different design opportunities for enhancing CE. Enhancing the data organization necessitates managing the flow of resources available globally [12]. The resilience of CE strategies going round the lifecycle thus depends on maintaining the requisite flow of information between practitioners. This is not trivial, as practitioners change within and between life cycle stages in construction. Adequate information, data systems and processes are hence a significant part of the infrastructure to strengthen a CE polices in construction industry.

## 4 Conclusion

CE for the concrete sector would seem to have a bright feature: the potential advantages are recognized worldwide and most policies have been accepted. More research is required to assess, whether the policies can excite, CE most effectively. Creating a financial environment and legal context that conduce to business associated with CE models. One of the best recommendations is given for concrete's role in CE is value assessment. Value systems associated with political and social, support the financial and legal environments in which the concrete sector business models are applied. Political and social features thus cannot be divided from environmental and technical features. All these economic polices are interrelated to attain the CE for concrete production. More research is needed to evaluate how policies can stimulate Circular Economy practices in the most effective way, with particular attention to creating economic environments and legal frameworks that are conducive to Circular Economy business models. Some recommendations associated with the CE strategies are

1. CE polices are not fully material oriented
2. Social and political aspects thus cannot be partitioned from technical and environmental aspects.
3. Circular Economy strategies cannot be viewed solely from the perspective of products or materials.

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# Plastic Pollution and the Need for Responsible Plastic Consumption and Waste Management

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**Abstract.** Plastic pollution is a global anthropogenic threat to all environmental compartments. The current plastic waste management practices include recycling, composting, and incineration for energy recovery or deposition in landfills, resulting in leaks into the natural environment at each stage. Interdisciplinary research and innovation perspectives in policymaking connecting the different actors in the plastic value chain would ensure the closure of material loops, safeguard human health, reduce climate change impacts, and promote biodiversity. This short paper provides an overview of the pervasive nature of plastic waste and microplastics in the natural environment, outlining a harmonious, systematic, and collaborative approach to tackling the plastics value chain while offering a potential circularity of material flows aligned with the principles of a circular plastic economy. Finally, a case is made to incorporate sustainable, restorative, and regenerative plastics production, use, and after-use as one of the unique indicators of Sustainable Development Goal 12. Ensuring sustainable consumption and production patterns in the plastics landscape will demand the development of product standards and a holistic assessment methodology to guide the design of circular products, services, and business models.

**Keywords:** Policy · Soil · Circular plastic economy · Biodiversity

## 1 Introduction

The United Nations (UN) Sustainable Development Goals (SDGs) were launched in 2015, comprising 17 SDGs, within which 169 targets were outlined to be quantifiable against 247 unique indicators [1]. Goal 12 aims to ensure sustainable consumption and production patterns, and governments and corporations have widely adopted it to improve sustainability. However, with the 17 SDGs being clearly outlined and detailed, the lack of clear indicators for the pervasive global atmospheric, aquatic, and terrestrial plastic pollution could undermine the implementation and achievement of the goals [2].


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Plastics and, specifically, marine plastic pollution are mentioned under Goal 14, “Conserve and sustainably use the oceans, sea, and marine resources for sustainable development”, indicator 14.1.1b [1].

As outlined in Goal 12, unsustainable consumption and production patterns lead to climate change, biodiversity loss, and pollution [1]. The unsustainable accumulation of plastic waste throughout its life cycle from energy and material input, production, distribution, use, disposal, and reuse or recycling has often been described as one of the most pressing current environmental challenges [3].

The current plastic landscape presents a linear plastic economy that leads to persistent plastic pollution with detrimental effects on the economy and the environment. Since the beginning of its mass production in the 1950s, about 8300 million tonnes of plastics have been produced. Despite the immense societal benefits, it is estimated that approximately 5800 million tonnes of plastics, representing 70% of the total amount, have become waste, of which 84% or 4900 million tonnes have been disposed of in landfills or the natural environment [3]. Of this, almost 50% is destined for single-use, particularly food packaging [4], leading to unsustainable plastic waste generation.

As shown in Fig. 1, global plastic production was 367 million tonnes in 2020, a slight decrease from 368 million tonnes in 2019, possibly due to increasing bio-based, greenhouse gas-based, and use of recycled feedstock to produce biodegradable plastics [5]. Nevertheless, global production from virgin fossil-based feedstock is expected to double in the next 20 years [6]. Thus, it has become a growing concern and discourse among policymakers, biologists, conservationists, environmentalists, and the general public.

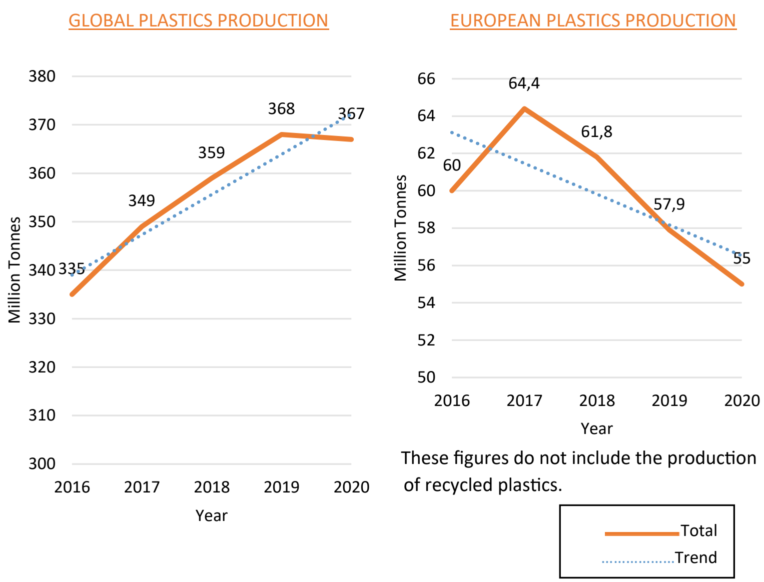


**Fig. 1** An evolution of global and European plastics production from virgin fossil-based feedstock adapted from plastics—the facts 2021 [5]

Responsible plastic production, use, reuse, or recycling leads to a sustainable circular economy. The European Circular Economy Action Plan of 2015, in which a circular economy for plastics is detailed [7], calls for policy-supported structural cooperation of multiple stakeholders, e.g., product designers, manufacturers, end users, and recyclers, to ensure the reduction of plastic pollution. A thriving European bioeconomy will help mitigate climate change, biodiversity loss, and pollution while strengthening European competitiveness [8]. This, coupled with Goal 12, would foster holistic monitoring, reporting, and implementation of a circular plastic economy.

The main aims of this short paper are to (1) state how extensive plastic pollution is; (2) outline the ecological effects on biodiversity due to microplastics in soil; (3) identify potential factors that promote a more sustainable circular plastic economy; and (4) bring a particular focus to the need to center plastics and microplastics while implementing the sustainable strategies and action plans.

## 2 Plastic Pollution

The current plastic value chain requires a foundational change in how innovation and research are conducted to address the opportunities and challenges of plastic pollution. Plastic pollution is intrinsically linked to climate change in its production from virgin fossil-based feedstock, distribution, and the inevitable culmination of its waste in different environmental compartments [9]. Plastic waste is recognized as ubiquitous, relatively non-biodegradable, and almost omnipresent in the earth's ecosystems. As a result, it is considered one of the significant factors in the global decline of biodiversity, posing a major threat to human health [10]. Large numbers of plastics enter the natural environment and are subsequently fragmented, forming small microplastic particles through physical, chemical, and biological processes [10]. Microplastics are plastic particles smaller than 5 mm [11].

It is challenging to quantify and forecast plastic pollution, terrestrial-based to a greater extent than aquatic-based plastic pollution. Ocean plastics can be quantified as floating debris through visual surveys, satellite, and drone imagery [12–14], beach litter through time-consuming manual counting [15], and total plastics through numerical particle tracking and linear mass-balance models [16, 17]. The impediment lies in ascertaining microplastics that result from UV radiation, chemical degradation, and deepsea bottom currents, that ultimately sink to the seafloor [18].

Qi et al. [19] examined the publications on microplastics, entailing 1331 publications published between 2004 and February 2019, and found 71% centered on marine environments, freshwater lakes, rivers, and other aquatic ecosystems, 24% on sediments (from aquatic environments, beaches, and sludge), while only 5% centered on terrestrial ecosystems. There is increased attention on the potential dangers of microplastics in terrestrial ecosystems; however, it still lags. It is estimated that plastic released annually to the terrestrial environment is 4–23 times greater than that released to the marine environment making soil a larger sink for microplastics than marine environments [10]. It is important to note that most plastic wastes in water bodies were initially produced, used, and indiscriminately discarded on land [19]. Therefore, plastic pollution in terrestrial systems should appear in at least one of the 247 unique indicators of the 169 targets outlined in the 17 SDGs placing research and innovation center on the plastic system as currently, the knowledge of microplastics in soils is very limited [20]. Exploring the contamination characteristics and ecological risk assessment of microplastics in soils remains a significant challenge [21].

### 2.1 Microplastics in Soil

Agricultural soils are considered the most vulnerable to microplastic contamination due to exposure to human activities and the threat to food security, health, and the environment [10]. In agricultural practices, the utilisation of sewage sludge and slurry for crop fertilization [22, 23], as well as plastic mulching [24], directly contribute to the accumulation of microplastics on the soil surface. The concentration of microplastics in the soil is expected to increase as the application of biosolids as fertilizer, plastic mulching, and irrigation with environmental water continues [22, 25]. In agroecosystems, the effects of microplastics in soil may impact the production and quality of crop plants by directly affecting plant development and altering the soil environment in which they are grown [26]. The physicochemical properties of soil can be changed by alterations in moisture and nutrient mobility as microplastics reduce water infiltration [27], exorbitant N mineralization reduces soil pH [28, 29], increases soil temperature [28, 30], and changes in aggregate stability [28, 31].

Microplastics can accumulate in the tissues of plants, posing potential implications for human health and plant performance [24, 28]. Soil organisms like mites, collembola, and burrowing mammals have been shown to ingest microplastics smaller than 1 mm and their additives, leading to increased bioaccumulation of toxic chemicals [32, 33]. Moreover, microplastics can act as carriers of other common soil contaminants such as heavy metals, human pathogens, and organic pollutants.

## 3 Circular Plastic Economy

The current plastic life cycle is essentially a linear economy based on three principles governed by their design, i.e., extensive waste and pollution, single-use products and materials, and biodiversity loss as plastics enter and disrupt the natural environment [34]. Since the popular recycling symbols and labels ranging from 1 to 7 of the main plastic polymers were launched over 40 years ago, only 14% of plastic packaging is collected for recycling, of which 4% accounts for process losses, 8% for cascaded recycling into other lower value applications and 2% for plastics recycled into same or similar quality applications [35]. Proper management of the after-use pathways for plastics will determine how sustainable their use and production is. The three main types of plastic waste recycling are mechanical, which produces lower quality than virgin-grade polymers; chemical recycling, e.g., solvent-based purification and depolymerisation using chemical agents that can produce virgin-grade polymers and can be complementary to mechanical recycling; and organic recycling and biodegradation [36].

In Europe in 2020, 23.4% of after-use plastics were sent to landfills, 42% were used in energy recovery operations through incineration, and 34.6% ended up in recycling facilities either inside or outside Europe, of which 0.2% were chemically recycled [5].

The evolution trend from 24.5 million tonnes of waste collected in 2006 to 29.5 million tonnes in 2020 of post-consumer plastic waste in Europe was observed, during which a 117.7% increase in recycling, 77.1% increase in plastic incineration, and a 46.4% decrease in the plastic waste sent to landfills prevailed [5].

To accelerate the transition towards a more sustainable circular plastic economy, regulations are required to control how much plastic waste is produced by compelling companies to be responsible for waste treatment or recycling. After-use pathways such as collecting, sorting, and recycling plastics need to be efficient and cost-effective, with the burden falling equally on the manual sorting from the individual and the proper collection and reprocessing by recycling companies promoting economic and environmental benefits [37]. Policymakers are well-positioned to break this impasse by systemically ensuring shared responsibility and accountability throughout the value chain by strict product requirements, extending the producer's responsibility to its product, and taxation [38]. This would urge regulating plastics at different stages in the lifecycle rather than focusing on one stage, which is usually the waste management stage.

Policy tailored toward a circular business model in the plastics industry would require policymakers and the industry to collaboratively share information while protecting intellectual property, guaranteeing information transparency, and maintaining fair competitiveness, to ensure the resultant plastic products, taking into consideration consumer behaviours as a crucial stakeholder in closing the loop is the end user [38, 39].

## 4 Conclusion and Outlook

Successful implementation of the wider UN SDGs demands systematic solutions. There is an urgent need to develop and implement sound legislation and regulations regarding plastic materials and, subsequently, microplastics in the natural environment. Efforts at standardizing recycling methods and technologies, identifying distribution and waste management gaps, and easing recycling, aid in alleviating the destructive effects of plastic pollution. There is a need to remove the recycling burden from the consumer to the producer while encouraging responsible and sustainable production.

Societal trends, global trade, and new business models cause the plastic landscape to exhibit continuously evolving responses to plastic pollution. Therefore, promoting interdisciplinary research and collaboration, combining insights from environmental, engineering, and behavioural sciences and policymaking will significantly advance the ability to solve the problem effectively. Education, funding for research, and financial incentives for systemic innovation would harmonise towards the explicit goal of a circular plastic economy fostering holistic methodologies that appraise the economic, environmental, and social impacts of different after-use plastic pathways.

Scientific uncertainty of plastic pollution forms a highly complex problem that challenges identifying specific cause-and-effect patterns that inform policy. Therefore, the lack of comprehensive understanding of the sources, fate, and impact of plastic pollution and, inevitably, microplastics on society and the environment should not prevent action from developing and implementing the practical and systematic solution of Goal 12. Supported by research, policymakers should acknowledge the importance of amending Goal 12 to include plastics as climate change, biodiversity loss, and pollution are a consequence of plastics in the natural environment. Ensuring sustainable consumption and production patterns in the plastics landscape demands the development of product standards coupled with a holistic assessment methodology to provide a guideline for the design of circular products, services, and business models.

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# Scale Model Showcase to Drive Policy Making via IoT Composite Indices and Low-Resource Equipment at the Edge of the Computing Continuum

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**Abstract.** This paper summarizes a demonstration of innovative IoT assumptions about: (a) usage of composite indices to drive sustainable environmental policy making in maritime port-city domains, (b) implementation of a full-fledged IoT architecture focused on the optimization of the edge computing through efficiently distributing its components the across the edge-to-cloud computing continuum and (c) easy, quick deployment of low-cost equipment to realize the two previous points. The demonstrator uses scale-models and data on the environmental field simulating a maritime port. The demo consists of running in real time various sensors completely leveraging low-resource equipment at the edge of the edge-to-cloud computing continuum. The resulting composite index could be very useful for the authorities to perform proper actions with the purpose of reducing the environmental impact of these nodes and for the city population in terms of transparency, since a composite index provides clearer information than a huge amount of raw data.

**Keywords:** Internet of Things · Edge computing · Edge-to-cloud computing continuum · Scale-model · Environmental data · Sensors · Real-time · Low-cost equipment · Low-resource equipment · Composite indices

## 1 Introduction

According to some studies [1], atmospheric emissions are the most worrying environmental factor for the sector of ports and cities, being the top priority for policy making in this area in the upcoming years. Realizing that maritime ports are essential logistic hubs upon which large part of the economy lies, this is a crucial aspect to be tackled. The goal is to drive policies in a way that the environmental impact will be reduced while keeping dynamicity and efficiency for the supply chain system as a whole.

In that regard, policies cannot be made on something that is not properly monitored and analysed. Environmental impacts are complex phenomena, sometimes difficult to interpret upfront [2]. Usually, dispersed and heterogeneous environmental information lead to complicated interpretations and may mislead decisions that might not be taken all factors into account [3].


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Composite indices are good tools to represent such real-life phenomena [4]. The objective of those composite indicators is to simplify the information of a complex real phenomenon modelled using a single number between 0 and 1, putting together the usability (simplicity, representation, usefulness) and the technology (data gathering, calculation of the index, data visualization) to come up with a useful solution. The usage of composite indicators has some tradition in different sectors, especially in comparing cities or countries on specific dimensions. The examples are varied; however, those are either based on qualitative measurements or highly relying on static, past (often ancient) data, sometimes even both. However, there is not a single reference of a formal deployment of an IoT system to realize automated composite indicators. The demonstrator of the paper aims at paving the way for such a reference in the context of maritime ports.

To round up the mix, the automation of composite indices is a trending topic (initiatives like PEI [5] or the Composite Indicators week by the European Commission [6] are just two relevant examples), addressed as well peripherally in this work.

Paper aims at demonstrating a use case of the premises above, by using low-cost equipment, providing a scalable on-premises test that can be extrapolated to large-scale scenarios in real maritime ports. The tool to be tested is designed to allow multiple actor (stakeholders) intervening in real phenomena (e.g., pollution associated to traffic in the port-city interface) to agree on smart sustainable indicators and to monitor them.

To achieve so, a scale demonstrator is built. First, low-cost sensors for measuring $CO_2$, $CH_4$, CO, $NO_x$, $PM_{2.5}$, illuminance and noise levels will be used. All of them have required a work of calibration and interpretation of results to be properly integrated. Second, embedded microcontroller units (Arduino UNO) are used to gather some of those sensors (grouped in sets of 2 or 3) used to acquire the measurements, pre-process them (format and curation-wise), prepare their values and to forward them to the platform. The upward communication is performed using Wi-Fi to reach other local devices under an IP-based communication. In particular, the data are sent using the MQTT protocol, equipping each Arduino Board with MQTT clients (a library validated for such device). At this point, a relevant demonstration is also performed to avoid sending data in plain text (preventing security-related issues). Third, the IoT hub (gateway) is deployed in another low-resource computing equipment (Raspberry Pi). At that point, all data acquired (received as entities' updates), is processed on-premises at the gateway (far-edge of the IoT-edge-cloud continuum) being adapted to a common data model and frequency structure (following consolidated references). Fourth, data are sent (in that structured way) under a publish-subscribe schema to a FIWARE Orion acting as an IoT context broker [7]. This broker lives within an advanced gateway that is part of the edge tier of the IoT solution which means that the data is processed near its source. This is one of the main principles of the edge-to-cloud continuum paradigm which is covered in the developed IoT platform in the EU H2020 project ASSIST-IoT [8]. Then, a composite index is calculated in a more (computationally) powerful element using the data previously gathered. The particular composite index used in the prototype demonstrator is a reduced version of the so-called PEI (Port Environmental Index) defined by the H2020 PIXEL project: "a global quantitative environmental index fed on a variety of data types (including real-time), allowing ports to access the progress of their own environmental performance" [5]. Finally, the rest of the components of the complete IoT solution are also used to provide the user with a real-time, single and combined visualizations of the measured data and the resulting composite index.

This paper is organized as follows: Sect. 2 exposes the innovation under this work and its theorical background, including the architecture of the solution. Section 3 justifies the relevance of the proposed demonstrator prototype to the audience of the EURECA-PRO conference. Section 4 embraces the description of the demo proposal, first setting the objectives as well as the contents, then enumerating and detailing the technological concepts underlying this demonstration. Finally, the closing section exposes the conclusions obtained from the work and proposes a feasible future work line.

## 2 Innovation

Maritime ports are clearly shifting towards digitalization [9]. Main works conducted till now have been focused on logistics, operations and administrative functionalities, that are normally executed by the so-called Port Community Systems [10]. However, there is an increasing trend to apply digital innovation for addressing environmental aspects in the ports and their surroundings [11]. There are a few factors that are still preventing maritime ports to fully adopt such approach: (i) first, there is not a clear baseline for the parameters to be looked for and how to decouple those to represent only port's actual impact [12]; (ii) second, regulations are quite heterogeneous and hugely dependent on each country/region [13]; (iii) third, there is not a consolidated standard or technology to use nor which to benchmark with; (iv) finally, evidences in the state of the art [14] mention specific advanced environmental monitoring systems that require considerable investments from the port authorities, due to the complexity of the equipment used and the vendor lock-in that is usually associated to such solutions relying on cloud Software as a Service (SaaS) [15].

From another perspective, the IoT (as technology and as market field) is experiencing a giant step forward during the last few years. It is estimated that 24.1 billion "smart" devices will be sending data over the network by 2030 [16]. In addition, these data are getting richer and easier to be managed at diverse locations thanks to the miniaturization and the increased computing capacity on ever-smaller equipment. The evolution of this equipment allows to move part of the workloads from the classical cloud centralized environments to new ones which are closer as possible to the source of the data, distributing them in a more efficient way. Here is where comes to relevance the edge computing paradigm, whose benefits are the optimization of the bandwidth, the inherent support of low latency applications and an increased security and privacy of the data [17].

The architecture developed in the ASSIST-IoT project focuses precisely on enhancing edge computing in distributed, modern, next generation IoT deployments. Drawing from cloud-native concepts, bringing them closer to the edge of the network, the architecture achieves a complete implementation of the edge-to-cloud continuum. All the elements of this architecture are integrated independently of its physical location. The developed Smart Orchestrator [18] oversees the distribution of the enablers (software and hardware pieces representation and packaging in ASSIST-IoT) and workloads across the continuum following appropriate AI policies. Furthermore, this orchestrator uses Kubernetes (K8s) which has become a de facto standard in the last few years for the cloud -native workload orchestration [19].

Whenever proposing the architecture to realize the prototype of this paper, authors relied on ASSIST-IoT design principles while adopting a practical view based on previous experiences in calculating composite indices for maritime ports [20]. This is where the novelty of the demonstration proposed comes into play. Leveraging IoT equipment and techniques to solve complex and expensive problems such as real-time monitoring of the environmental impact of a port is a clear innovation that has been actively pursued lately [21]. In particular, the main innovations behind this demo are: (a) The usage of low-cost, low-resource, domain-agnostic devices and sensor equipment to produce successful environmental monitoring results, (b) the adoption of cloud-native techniques (smart orchestration deployment using K8s) at the edge leveraging open-source, public-funded results and (c) the low difficulty level to deploy such system (physical and logical) and its integration into a relevant IoT decentralised platform in use while keeping security of data. It is also an innovative aim to demonstrate that all procedures to be performed conducting the demo are easily transferrable and replicable in a real port.

Here, it is worth mentioning that this demonstrator prototype is not aimed to generate actionable data results *per se*. Collecting data from real sensors (see Sect. 4.2) falls within the scope of validating the acquisition, processing and forwarding capacities of the proposed system. However, the actual values of the data and the results of the composite indicator in this prototype are not relevant to take decisions in lab-demo conditions. Some aspects like noise and vessel and terminal machinery processing (e.g., loading a container) are simulated using scale prototypes together with synthetic phenomena generation (buzzes as ship horns, etc.), therefore this paper does not present statistics or data of results generated. Authors wish to highlight that the goal is the demonstration of a hypothesis, using low-resource equipment and certain software architecture and tools.

Therefore, software-wise, a modular architecture (as illustrated in Fig. 1) was designed composed of:

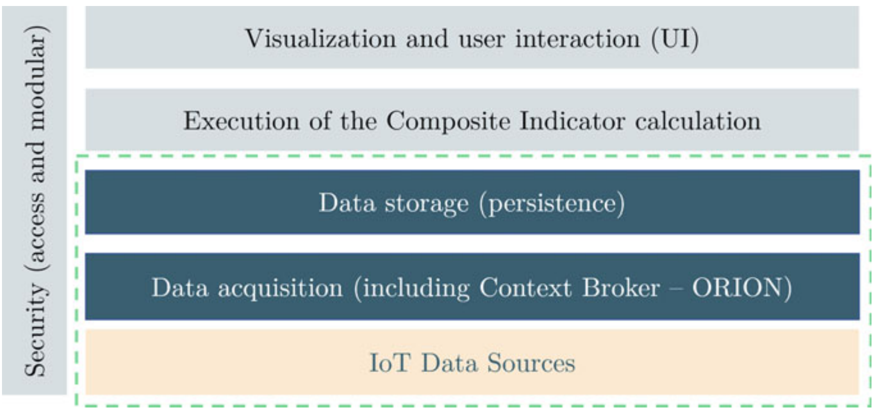


**Fig. 1** Architecture used for deploying the demonstrator

- In the edge component: data acquisition, based on the gathering, pre-processing (curation, format change, adaptation) of data inflows preparing them to be stored and to feed the calculation of the composite index. This module also includes the aforementioned Context Broker (FIWARE Orion), that constitutes the core element of knowledge distribution. Here, the last value of each harvested data source is kept, available for querying and with notification capacity to all interested subscribers (data storage element, in this case).
- Same as above, a data storage element, with No-SQL lightweight selected databases to allow a simple configuration, insert and query while residing at the edge of the network.
- In the centric (more powerful) equipment, the modules of Composite Index calculation execution (a sophisticated mathematical calculation based on the results of the project PIXEL [22]), security (based on FIWARE enablers KeyRock and Wilma with ad-hoc custom additions) and a visualization component (relying on Vue.js framework behind a web server) are located.

## 3 Relevance of the Prototype

The relevance of this demonstration to EURECA-PRO conference can be framed under four viewpoints. Primarily, Internet of Things mechanisms (e.g., publish/subscribe to a context broker) and data-gathering devices are used in a prototype environment. Second, due to the connection (inherent, by design) with a full-fledged and mainly focused on the Edge IoT system (the demonstrator includes one analytical model—the composite index calculation—through which the monitoring of the environmental measures has clear added value). Third, the proposed demonstrator allows to observe in real time a composite index (value between 0 and 1) that is easily interpretable and that condenses enough information to drive sustainable policies in the adopting entity (in this case, oriented to maritime ports). While using this kind of tool, it can be monitored how a specific policy (for instance, shifting to liquified natural gas propelled equipment instead of fuel) improves the impact on the environment. In addition, it can be used to synthetically generated inputs to predict how the index would behave in advance when foreseeing new policies to be applied. To the eyes of the authors, the previous contributes directly to the topic "*Policy making for energy efficiency, carbon footprint reduction*". Last, the most relevant point for EURECA-PRO conference audience might be the usage of low-cost, low-resource equipment to conduct a full experiment simulating a maritime port scenario. One of the main worries in the current network/edge-cloud landscape is the initial cost to kick off innovative proofs of concept. With the system proposed, a real, valuable evaluation will be able to take place using widely available, cheap, reasonably accurate equipment valid for large-scale tests. Nonetheless, the demonstrated IoT platform is ready to be deployed in real infrastructures as servers in the public cloud or industrial gateways near the port machinery.

Here, authors state that the global cost of an IoT-based system deployment (like the one proposed in this paper) in an Industrial, operational, large-scale scenario would be far more complex than the prototype devised in this article. In such cases, costs like staff involvement, proper certifications (e.g., electromagnetic compatibility, dust protection, encapsulation, etc.) and testing would be needed. However, those costs should be understood as fixed investments that would be required in any deployment, therefore the focus of the outlined technology should be put on the equipment acquisition and scalability side of analysis.

# 4 Demo Proposal

## 4.1 Objectives and Contents of the Demo

The basic objective of the demo is the observation in real time of an environmental composite index fed by on-field collected environmental data in a single platform. Advanced goals of the demo are: (i) applying a real-time composite index model calculation over gathered data that can provide value to drive policy making, (ii) showing how to easily deploy (plug-and-play fashion) an IoT system over collected sensors. In addition, the demo will allow the user (attendee of the event) to use an IoT system (touch, play) and move the scale-model (ship, crane, containers) to check how environmental values in a "simulated" port scenario change over the time and depending on the position/flow of the different elements. In that sense, other actions can be performed such as reproducing a sound acting as a ship horn, producing $CO_2$ emissions breathing, changing light values simulating night/day or modifying the position and flow of a crane's container.

## 4.2 Technological Components and Configuration Schema

As introduced at the beginning of the paper, the demonstration has needed various physical and logical elements to be running, schematically laid out as indicated in the sketch of Fig. 3:

- A "port" scale model, composed by a 1:150 Ship-to-Shore (STS) crane and a 1:980 container vessel. Both elements are mounted over a plain-land space simulating a port terminal yard.
- Three "Smart IoT boxes": physical envelopes containing 2 or 3 sensors each and one Arduino UNO to capture data and an ESP module to connect via Wi-Fi to the gateway. The boards perform real-time data collection from the sensors that are connected to them, and then publish these data into an IoT gateway. Models of the equipment used are (from left to right, in order, in Fig. 2):

**Fig. 2** Sensors and boards used in the prototype demonstrator (original construction partially extracted from sources: roboticafacil.es, naylampmechatronics.com, prometec.net and Wikipedia.org)

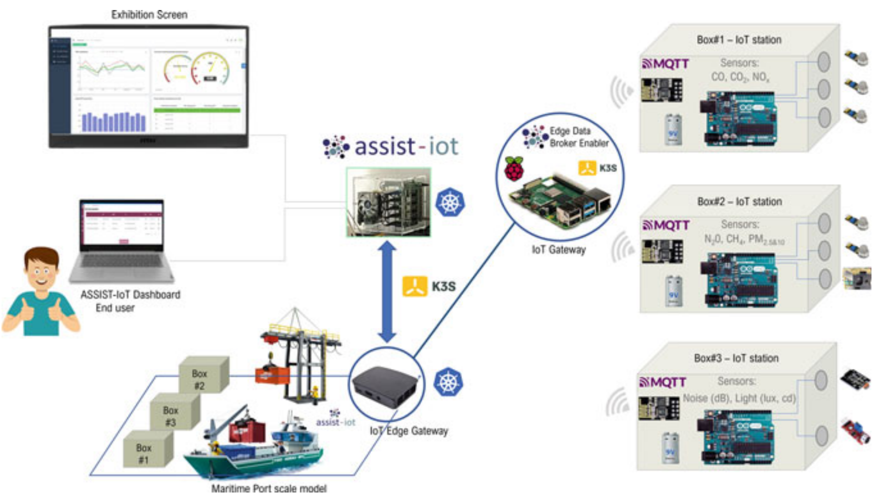


**Fig. 3** Prototype of the demo

- Light sensor: photoresist device, model KY-018.
- CO2 (and other gases) sensor: device designed to change its resistance against certain concentration of alcohol, benzene and other gases—MQ135.
- Noise sensor: KY-038.
- ESP-01 board to allow the Arduino UNO to connect via Wi-Fi with the edge element of the deployment (the IoT Gateway).
- Arduino UNO R3: microprocessor board with pinned connection to act as I/O with sensors, applying certain processing and logic over the captured data.

- An IoT Gateway Station: a small single-board computer (SBC)—the Raspberry Pi 4 Model B—using a Raspbian Linux OS and running a light K8s distribution (K3s) [23] where proper software components will be running to act as a fully integrated gateway with the platform. Here, the ASSIST-IoT's Edge Data Broker Enabler boosted by FIWARE Orion allows the reception of Smart IoT data from the boxes under a publish-subscribe fashion. In addition, this gateway is in charge of moving these data to the upper tier of the architecture.
- The upper tier of the edge-to-cloud continuum adoption for the proposed demo: a more powerful equipment is needed to perform the composite index calculation using the data collected at the edge tier. Acting as the master node of the K3s cluster, this element also hosts the visualization panel (a developed web platform) and the project's dashboard in a web server. For the demonstrator, a cluster of Raspberry Pi Model B (as show in Fig. 4) can be used instead of a classical server.
- Front-end elements: a laptop to allow visitor to interact with the system and a screen (monitor) to show the detailed results of the composite index.
- A Wi-Fi router to provide communication among all components. The connection will be established via MQTT (boxes-gateway) and HTTP over TCP/IP using the Kubernetes networking (gateway-cluster).

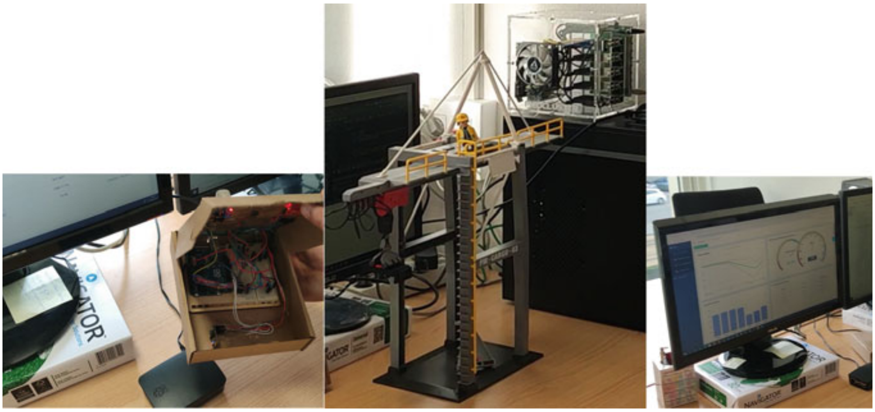

**Fig. 4** Deployment of edge node (left), showcase scale demonstrator with centric on-premise cluster (middle) and composite index observation (right)

In summary, all components used in the demo share the same main principles: low-cost and easy to plug-in devices. Once again, the procedures above should serve to realize the ease of deployment of such a system (physical and logical) and its integration into a relevant decentralized IoT platform in large-scale scenarios like real maritime ports and Smart port-cities.

## 5 Conclusions and Future Work

With the indicated demonstration the authors have achieved to validate the premises of the hypothesis. A low-budget equipment (several widely available sensors prized less than two euros each, a cluster of Raspberry Pis and a RPi acting as an edge node, together with an enclosure, an Arduino UNO, and a motherboard for pin connections) has been enough to set up a full-fledged system that materializes the end-to-end expected functionality. While it must be considered a scale prototype, the fact of using open-source software (the actual core of the demonstrated platform) coming from European research projects result in an affordable deployment even scaling up towards a real-life scenario (in a maritime port).

Therefore, combining relevant information ($CO_2$ sensors, noise, data from ships, etc.) in real time into a single interpretable value (following clear instructions) sets the foundations for (a) taking decisions after a quick glance to the value of the index, (b) analyzing the impact of adopted measures and (c) designing hypothetical scenarios to simulate the evolution of the environmental impact in port-city contexts.

Finally, the authors can see clearly that a possible and feasible future work could be to deploy the described prototype in a real scenario (preferably a real port). The IoT boxes should be installed near the port activity scenarios (container terminals, vessels, …), with a good connection with the IoT gateways installed on the ground of the job, which will preprocess the data and send it to a central server to calculate the PEI and show its visualization to the port authorities, satisfying the principles of the edge-to-cloud continuum. Then, the number of sensors and equipment could be increased, as well as using more professional and more powerful equipment, but keeping the same architecture (ASSIST-IoT approach), in order to compare the results of the different deployments.

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# Contrasting Compositional and Abundance Patterns in Zooplankton Communities Between Mountain and Lowland Ponds

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**Abstract.** Understanding the patterns and mechanisms underlying community structure and composition along altitudinal gradients is key for modern ecology and biogeography; indeed, this research agenda can provide a useful toolbox to forecast the consequences of climate change on present-day ecosystems. However, spatial variation of zooplankton communities at different elevations has rarely been addressed, and most available research on aquatic systems has focused on species richness only. Here, we aim to study the effect of elevation on zooplankton communities, both in terms of species composition and abundance. NMDS analysis was performed to examine community-level patterns in the ordination space between plateau and mountain ponds. In addition, we used SIMPER to assess whether these ponds differed in the composition of zooplankton communities and identify species groups that contributed to biotic dissimilarities between mountain and lowland regions. Mann–Whitney's tests were run to verify the existence of statistical differences in the total abundance and relative abundances of constant, rare and accessory species between plateau and mountain ponds. Our findings illustrate a clear patterning in zooplankton community composition and abundance between mountain and lowland ponds in a geographically extensive area of the Iberian Peninsula. These contrasting patterns were correlated with a set of environmental features that vary concomitantly along altitudinal gradients (e.g., mean annual temperature, ionic content, nutrient concentration and the development of dense aquatic plant stands). Accessory species contributed most to total abundance at increasingly lower elevations, although small-sized rotifers were the dominant component of zooplankton communities in both pond types. These results should bring certainty to predictions about the effects of future climate on freshwaters, especially in the context of the potential consequences of altitudinal migrations on the spatial variation of community composition and abundance of these small planktonic animals.

**Keywords:** Elevation · Ponds · Zooplankton

## 1 Introduction

It has long been recognized that altitudinal gradients can provide insightful information on how species are constrained by environmental features [1]. Recent studies suggest


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that community-level responses to these gradients may be used to understand the long-term consequences of climate change on present-day biotas [2], providing the basis for the design of spatially-explicit management and conservation schemes [3, 4].

Most studies assessing the role of elevation on biodiversity have focused on species diversity metrics *s.s.* [5–7], especially in the terrestrial realm [8–10]. Almost no studies yet exist on species abundance patterns or dissimilarities in community composition of aquatic biotas [11–13].

Zooplankton occupy a fundamental position in aquatic food webs, contributing significantly to nutrient recycling [14]. At the ecoregional level, local environmental factors, such as lake morphology, water chemistry and watershed characteristics, as well as anthropogenic factors, act together to influence zooplankton community composition and structure (e.g. [15–17]). However, to our knowledge, variation in taxonomic composition of zooplankton communities along altitudinal gradients has rarely been addressed in limnological literature, and most available research has focused on species richness metrics only [6, 18].

The aim of this study was to evaluate the effect of elevation on the composition and structure of zooplankton communities. Elevation relates to the diversity of organisms and puts these into a spatial-explicit context by linking responses of small-scale and large-scale patterns of biodiversity to their surrounding environment, particularly for high-altitude species. This has the potential to advance the field of freshwater biogeography into a more predictive science as we deal with one of the biggest challenges of our times: climate change. We hypothesized that altitudinal gradients influence zooplankton community composition and abundance through concomitant effects on rare (i.e., species occurring in less than 20% of study sites), accessory (i.e., species occupancy is restricted to less than 50% of the ponds) and constant species (i.e., those occurring in more than half of the sites). We also expected that species abundances will decrease at increasing elevations in mountainous 'pondscapes'.

## 2 Study Area

The 78 ponds considered in our study are located in Castilla y León, an extensive region (94,233 km$^2$) in the Iberian Peninsula, which is drained mainly by the Duero River and its tributaries (see Fig. 1). The altitudinal range in the region is very wide, with an extensive central plateau where elevation ranges between 700 and 1000 m a.s.l., surrounded by a set of mountain ranges, with an altitude of up to 2600 m a.s.l. In the central plateau the climate is Mediterranean, with considerable seasonal variation in temperature and precipitation. Summers are hot and dry, and winters are cold and wet. Average annual precipitation ranges between 400 and 600 mm. In the mountain systems, winters are cold and long and summers are warm and short. The average annual precipitation varies between 800 and 1500 mm, being in the form of snow in winter.

In terms of land use, agricultural activity is dominant in the central plateau, although there are pine plantations, forests and shrublands. In contrast, most of the area in the mountains surrounding the plateau is occupied by grasslands, shrublands and forests, the latter being less common.

Of the 78 selected ponds, 50 are plateau ponds (700–1220 m.a.s.l.) and 28 are mountain ponds (1360–2100 m.a.s.l.). The hydrological regime is different in the two types

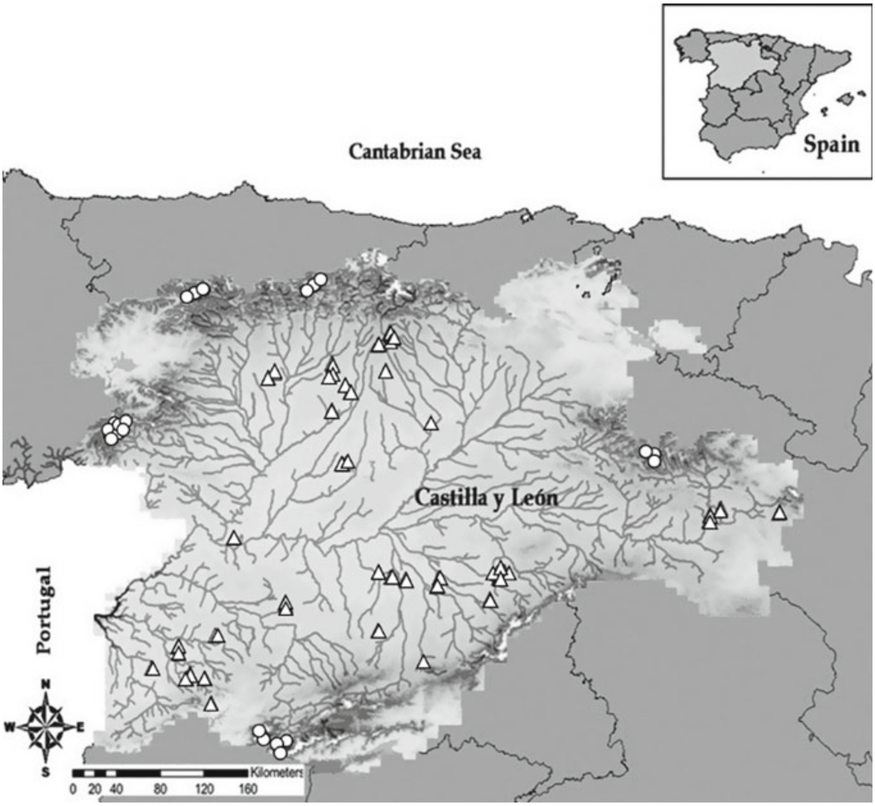


**Fig. 1** Inset map of Spain and map of Castilla y León showing the location of plateau (triangles) and mountain (circles) ponds

of ponds. In most of the plateau ponds, water originates from aquifers and precipitation, and these systems experience a strong reduction in water volume during the summer. On the other hand, in mountain ponds, water comes from surface runoff and precipitation in the form of rain or snow. All mountain ponds have a glacial origin. Most of the ponds are small and shallow and show considerable variability in their environmental conditions [11].

## 3 Methods

### 3.1 Field Sampling and Analysis of Environmental and Biotic Variables

The plateau ponds were sampled once in July 2004 and 2005 and the mountain ponds in July 2007 and 2008. For the collection of zooplankton samples, a transect was established from the shore to the centre of each pond, where a variable number of sampling points were placed depending on the surface of the pond ($<1$ ha $= 5$ points; 1–5 ha $= 7$ points; $> 5$ ha $= 10$ points). At each point, 3 l of water were collected using a 6-cm diameter, 1-m long methacrylate tube. All samples were combined to constitute an integrated sample.

In lentic systems deeper than 5 m, additional samples were collected in the deepest areas using a Niskin-type hydrographic bottle. Three points were placed in the centre of the pond and a volume of 2.5 l of water was collected at different depths (ca., 4 and 8 m depth). The collected water was used to form an integrated sample. The samples were filtered in situ through 25-μm filters, which were introduced into Falcon tubes containing 15 ml of pond water. After fixation of the samples with 4% formalin, the individuals were identified and counted using an inverted microscope.

Identification was performed to the species level, if possible. Rotifers were identified following the keys of [19] and [20]; for crustaceans, references included [21] and [22].

In each pond, several water samples were collected at the same points used to collect zooplankton samples and all samples were integrated into a single composite sample. Conductivity, pH, temperature and dissolved oxygen were measured directly in the integrated sample using different field probes. Concentrations of total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate and chlorophyll *a* were determined in the laboratory. All samples were stored at 4ºC until analyses, which followed standard methods [23].

The total surface area of each pond was measured using SIGPAC images [24] (Geographic Information System for Agricultural Plots, http://www.sigpac.jcyl.es/visor/), whereas mean depth values were determined at each sampling point (see above). The abundance of hydrophytes (i.e., submerged and floating-leaved aquatic plant life forms) was estimated by the percentage of the pond surface that was occupied by these plants. For fish, three functional categories were identified, representing an increasing gradient of predation pressure on the zooplankton guild (see [25]). Data on the diet of different fish species were obtained from the available literature [26–29].

## 4 Statistical Analysis

### 4.1 Environmental Features

Mann–Whitney's tests were used to explore differences in the environmental features between plateau and mountain ponds. Relationships of environmental variables with elevation were also tested by means of the Spearman's rank correlation coefficient ($r_{sp}$).

### 4.2 Zooplankton Community Composition and Structure

We performed a multidimensional non-metric scaling (NMDS) analysis using the Bray–Curtis distance matrix to examine community-level patterns in the ordination space between plateau and mountain ponds. Taxa in less than 5% of the ponds were previously removed and data were log-transformed before analysis. We used the stress value to determine the best possible configuration in a three-dimensional NMDS plot. The scores of the ponds for the first two axes of the NMDS analysis were also correlated with altitude and local environmental features using the Spearman's rank correlation coefficient.

The ANalysis Of SIMilarity (ANOSIM) with 999 random permutations was applied in order to test for statistically significant differences in community composition between mountain and lowland ponds. In addition, we used the SIMilarity of PERcentage Analysis (SIMPER) to assess whether these ponds differed in the composition of zooplankton communities and identify species groups that contributed to biotic dissimilarities between mountain and lowland regions.

The structure of zooplankton communities was described by calculating the total abundance of (1) all constituting species and (2) for species divided into higher taxonomic ranks (here, cladocerans, copepods and rotifers). To evaluate the effect of elevation on the spatial frequency of zooplankton species, these were categorised as rare, accessory or constant species based on their occupancy patterns (see [17] for details). Mann–Whitney's tests were used to verify the existence of statistical differences in the total abundance and relative abundances of constant, rare and accessory species between plateau and mountain ponds.

Statistical routines were run using PRIMER7 [30] and STATISTICA v.8.

## 5 Results

### 5.1 Elevation and Local Environmental Features in 'Pondscapes'

Conductivity, pH, chlorophyll *a* and nutrient concentrations were significantly higher in plateau than in mountain ponds (Mann-Whiney test, $p < 0.001$). Likewise, plateau ponds had significantly ($p < 0.01$) higher hydrophyte cover and were also less deep ($p < 0.001$) than mountain ponds. Most environmental features decreased significantly at increasing elevations, especially conductivity ($r_{sp}$ = –0.808, $p < 0.001$) and total phosphorus concentration ($r_{sp}$ = –0.651, $p < 0.001$).

### 5.2 Zooplankton Community Composition and Structure

The NMDS analysis revealed a clear partitioning between mountain and lowland ponds (see Fig. 2). The highest correlations ($p < 0.001$) between NMDS scores and environmental variables were found for conductivity ($r_{sp} = 0.528$), total phosphorus ($r_{sp}$ = 0. 577), temperature ($r_{sp} = 0.501$), total nitrogen ($r_{sp} = 0.487$), altitude ($r_{sp} = -0.425$), mean depth ($r_{sp} = 0.442$), nitrate concentration ($r_{sp} = 0.442$) and fish predation pressure ($r_{sp} = -0.383$). However, this axis was also significantly and positively correlated with hydrophyte cover ($r_{sp} = 0.273$, $p < 0.05$) and chlorophyll *a* ($r_{sp} = 0.332$, $p < 0.01$). For the second axis, the highest correlations were observed with conductivity ($r_{sp}$ = –0.450) and altitude ($r_{sp}$ = 0. 335).

Mountain and lowland ponds differed significantly in terms of species composition and community structure (ANOSIM, $R = 0.399$, $p < 0.001$). In this regard, SIMPER analysis revealed strong differences (88.73%) in zooplankton communities between these pond types. The species that contributed most to these differences were the rotifers *Keratella cochlearis*, *Keratella quadrata*, *Anuraeopsis fissa* and *Polyartra vulgaris* (Table 1). With the exception of *K. cochlearis*, these rotifer species were far more frequent and abundant in plateau systems, which included a total of 40 exclusive species. The most frequent and abundant species in mountain ponds were *K. cochlearis* and *K. quadrata*, and 43 species were recorded only in these systems.

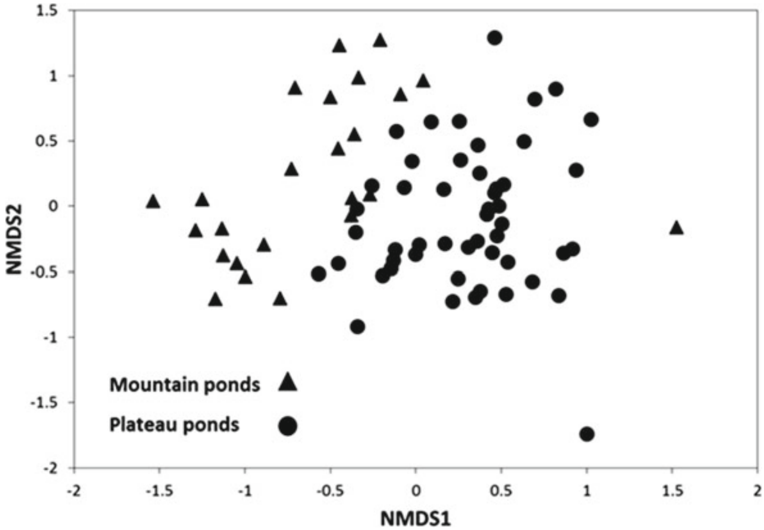


**Fig. 2** Non-metric multidimensional scaling (NMDS) biplot of zooplankton communities in mountain (triangles) and plateau (circles) ponds

**Table 1** SIMPER analysis showing species ranked according to their contribution to the biotic dissimilarity between plateau and mountain ponds (only up to 70% cumulative contribution is shown)

| Taxa | Mean abundance | | Cumulative contribution % |
|---|---|---|---|
| | Mountain | Plateau | |
| *Keratella cochlearis* | 70.90 | 72.72 | 14.05 |
| *Keratella quadrata* | 10.62 | 103.21 | 24.28 |
| *Anuaraeopsis fissa* | 2.97 | 249.77 | 33.76 |
| *Polyarthra vulgaris* | 0.82 | 113.53 | 42.84 |
| *Lepadella patella* | 0.65 | 77.09 | 46.59 |
| *Brachionus calyciflorus* | 0 | 72.89 | 50.19 |
| *Hexarthra* mira | 0.10 | 55.84 | 53.74 |
| *Polyarthra dolichoptera* | 6.25 | 39.98 | 57.04 |
| *Termocyclops* sp. | 0 | 18.62 | 60.21 |
| *Lecane bulla* | 0.08 | 30.71 | 62.51 |
| *Brachionus angularis* | 0.11 | 39.45 | 64.75 |
| *Lecane closterocerca* | 0.39 | 41.98 | 66.93 |
| *Bosmina longirostris* | 5.57 | 8.83 | 69.04 |

Mann–Whitney's tests suggested significant differences in total abundance (both in terms of all constituting species and for species divided into cladocerans, copepods and rotifers) between mountain and lowland ponds ($p < 0.001$). Abundances always decreased significantly with elevation (Table 2). However, the small-sized rotifers dominated zooplankton communities along the altitudinal gradient, representing (on average) 76% and 83% of the total number of individuals in both lowland and mountain ponds, respectively. The relative abundance of accessory species (those species than occur in less than 50% of the ponds) was significantly ($p < 0.001$) higher in lowland ponds; however, no differences in the contribution of common and rare species to community composition were found between the two pond types.

**Table 2** Descriptive statistics (mean, minimum and maximum) for zooplankton community structure and results of Mann–Whitney's tests for the two groups of ponds

| | Plateau ponds | Mountain ponds | Mann–Whitney |
|---|---|---|---|
| Total abundance | 1190 (24–8641) | 204 (0.45–1409) | < 0.001 |
| Rotifera abundance | 1093 (3–8185) | 186 (0.4–1404) | < 0.001 |
| Cladocera abundance | 57 (0–381) | 17 (0–161) | < 0.001 |
| Copepoda abundance | 40 (0–429) | 4 (0–44) | < 0.001 |
| % Abundance constant species | 35.5 (0–94.8) | 42.9 (0–96.2) | n.s |
| % Abundance accesory species | 43.4 (3.8–99.9) | 19.3 (0.7–80.6) | < 0.001 |
| % Abundance rare species | 20.4 (0.07–90.3) | 23.0 (0.1–87.1) | n.s |

# 6 Discussion

## 6.1 Elevation and Local Environmental Features in 'Pondscapes'

We originally selected a set of ponds covering a relatively wide altitudinal gradient (see above). Local environmental features clearly differentiated between the two groups of lentic systems. Differences were mostly based on the ionic content and trophic state of the ponds, being lower in and around mountainous ranges, which can be explained in terms of the intense water-level reductions and anthropogenic impacts facing lowland areas. This is a legitimate hypothesis, not least because most of these lowland ponds suffer from intense agricultural activity in their surrounding basins. Agriculture leads to higher conductivity values in freshwater lentic systems [31, 32], as well increases the concentration of nutrients and chlorophyll *a* by boosting the amount of nutrient loading from the catchment. This higher nutrient availability in lowland ponds, together with a higher degree of mineralization and substrate characteristics, are responsible for the higher growth of aquatic vegetation in these waterbodies compared to mountain systems [33, 34], as detected in our study.

### 6.2 Zooplankton Community Composition

Our study evidenced the existence of important differences in the composition of zooplankton communities between mountain and plateau ponds. Half of the regional species pool was, indeed, almost exclusive for each pond type. Compositional differences were captured by the first axis of the NMDS ordination, an axis that was strongly correlated with elevation and a set of environmental features that vary concomitantly with altitude, such as mean annual temperature, conductivity, trophic state and hydrophyte cover. Hence, variation in climatic constraints and local environmental conditions along altitudinal gradients are strong mechanisms underlying the assembly of zooplankton communities. Interestingly, a similar finding was already documented for aquatic plants in the same geographical setting [11]. In plateau ponds, for example, zooplankton communities were dominated by small-sized rotifers, including several *Lecane* species (e.g., *Lecane quadridentata, Lecane bulla, Lecane closterocerca, Lecane lunaris*), *Chydorus sphaericus*, *Lepadella patella*, Bdelloidea, *Mytilina ventralis* and *Testudinella patina*, most of which are associated to complex aquatic plant stands of marginal littoral areas [35, 36] and more eutrophic conditions [37, 38]. Also raptorial copepods, such as *Megacyclops viridis*, were relatively abundant in lowland 'pondscapes'. By contrast, in ponds at higher altitudes, with lower ionic and nutrient content and higher predation levels by zooplanktivorous fish, *Kellicottia longispina*, *P. vulgaris*, *Asplanchna* sp or *Ascomorpha* sp were frequent.

### 6.3 Zooplankton Community Structure: Variation in Abundance Patterns Between Mountain and Lowland Ponds

Zooplankton community structure was affected by elevation, with clear differences in the total abundance of species: higher altitudes were associated with lower zooplankton abundance. Elevation can control the assembly of planktonic communities, particularly their abundance patterns. For instance, establishment success relies on species-specific abilities to cope with extreme climatic conditions in mountainous regions. Similarly, concomitant effects of elevation on other local abiotic and biotic features, such as productivity and aquatic plant growth [39], can constraint colonization, food availability, somatic development and refugia against predation [40, 41], thereby controlling population size and density at the local level.

Zooplankton communities in both pond types showed a similar dominance pattern, with rotifers having the highest number of individuals. This pattern was particularly remarkable in ponds at higher altitudes and was likely the result of the higher abundance of pelagic species (e.g., *K. cochlearis*, *K. quadrata*, *Brachionus angularis* and *Brachionus calyciflorus*). This prevalence of rotifers over crustaceans is not a new finding though [42–45]: their reproductive mode, short generation times and rapid ability to respond to bottom-up processes are some of the empirical explanations for this pattern [42]. However, the dominance of rotifers in waterbodies located in mountain ranges contradicts more classical models describing the functioning of shallow lakes and ponds, most of which associate the numbers of this group to increasing nutrient levels (e.g., [46–48]).

Our results also suggest that accessory species contributed more to total abundance in plateau than in mountain ponds. Previous studies emphasised that total surface area is a strong determinant underlying the abundance of these species in zooplankton communities [17]. Although our results showed no significant differences in the total surface area between both pond groups, smaller ponds (<1 ha) were far more numerous in and around the plateau. Hence, we speculate that the higher contribution of accessory species in these small ponds could somehow reflect the dominance of species adapted to the smaller number of niches that small ponds can offer compared to their larger counterparts [17].

In summary, our findings illustrate a clear patterning in zooplankton community composition and abundance between mountain and lowland 'pondscapes'. The altitudinal gradient shaped the local abiotic and biotic environmental features of these waterbodies, including the ionic content, nutrient concentrations and the development of dense aquatic plant stands. Community composition and abundance showed contrasting patterns with elevation and their variation was correlated with a set of environmental features that vary concomitantly along the altitudinal gradient. For instance, accessory species contributed most to total abundance at increasingly lower elevations. However, small-sized rotifers were the dominant component of zooplankton communities in both pond types, which is consistent with their opportunistic lifestyle, high reproductive rates and short life cycles. Hopefully, these results will bring certainty to predictions about future climate in freshwaters, especially in the context of the potential effects that altitudinal migrations might have on compositional variation and abundance patterns of these small planktonic animals.

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# Teachers' Perceptions of Fisheries Ecolabels and Game-Based Learning Activities in the Framework of Education for Sustainable Consumption

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**Abstract.** Socio-environmental sustainability in oceans implies that marine fisheries should be sustainable, and the Education for Sustainable Consumption could promote sustainable artisanal fishing. Our survey on elementary school teachers' perceptions on fish ecolabels, including environmental and social values of sustainable fisheries, showed positives opinions. However, most of them do not read the labels information of products in fishmongers and supermarkets before making their purchases. With the aim to provide teacher resources on sustainable fisheries, an educative experience linking Environmental Education, Education for Sustainable Consumption, and knowledge about small-scale fishing is proposed. This didactic sequence includes explanatory activities, reflection and debate on responsible consumption, sustainable fisheries and ecolabels, as well as game-based learning activities. This intervention will promote students to be aware of de concept of sustainable fisheries concept, training them towards responsible consumption through critical and supportive attitudes related to Sustainable Global Goals 12 (ensure sustainable consumption and production patterns) and 14 (conserve and sustainably use the oceans, seas and marine resources).

**Keywords:** Education for sustainable consumption · Sustainable fisheries · Environmental education

## 1 Introduction

Increased interest in oceans socio-environmental problems and opportunities can promote support to obtain environmental sustainability and human well-being [1]. This way, many efforts are being made to mitigate negative effects on marine ecosystems and achieve sustainable fishing, although fisheries have rarely been sustainable [2]. Economic development, social objectives and environmental protection are key areas in this fishing sustainability; combining them properly is a necessary and possible challenge


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in fisheries management [3]. Fisheries management needs to be addressed towards the achievement of the sustainable development goals (SDGs) [4], and the protection of marine areas, with resources extraction and pollution limited, are essential for the conservation of marine biodiversity and ecosystems [5]. On these paths are the artisanal fisheries (small-scale fisheries), defined based both on the characteristics of the fishing fleets [6] and on the own culture forged around artisanal fishermen [7].

Ocean literacy can contribute to improving sea conservation, mainly incorporating questions about environmental problems, from pollution to biodiversity loss and natural resource depletion [8–10]. Game-based learning activities have shown to be suitable approaches to understanding these environmental problems, allowing to relate causes and effects in their sustainable management [11–14].

Most of these educational approaches are oriented towards the management and knowledge of biodiversity (included as marine natural resources), therefore from the perspective of the SDG14 on conserving and sustainably using the oceans, seas, and marine resources for sustainable development. This represents dealing directly or indirectly with several of its targets, mainly reducing marine pollution (target 14.1), protecting and restoring marine ecosystems (14.2), sustainable fishing (14.4), and conserving coastal and marine areas (14.5). This suitable perspective could be complemented with educational actions that reinforce empowerment as citizens through awareness as responsible consumers. That is, carrying out educational actions aimed at SDG12 to ensure sustainable consumption and production patterns.

The Education for Responsible Consumption educates to achieve environmental sustainability [15], being one of the actions from the educational field required for the involvement of citizens in the urgent global transition to fairer and more sustainable societies [16]. With the Education for Sustainable Consumption, students obtain tools for their active participation in the economic, cultural, political, and social context of their nearest environment, their community, and their country. Precisely for this reason, education for consumption is so important, because educating for consumption is preparing students to access products competently and effectively and, in turn, to become aware of the positive and negative implications of their acts of consumption, understanding that, when consumed excessively, the destruction of resources is also exorbitant [17].

In the case of marine natural resources and fisheries, not only the resources consumed are important, but also how these resources have been obtained, so as to minimize wasted resources and the effects of their extraction on marine ecosystems, while maximizing the positive socio-environmental impacts. That is, carry out educational actions oriented towards the targets 12.2 Sustainable management and use of natural resources, 12.7 Promote sustainable public procurement practices, and 12.8 Promote universal understanding of sustainable lifestyles, while promoting the target 14.9 to support small-scale artisanal fishers' access to markets.

The Education for Sustainable Consumption can help in the consecution of this goal, facilitating that the consumers understand the labels of the fish and can choose between the different options, those coming from sustainable fisheries.

Here, we explore teachers and preservice teachers' perceptions about fish (eco)labels and propose game-based learning activities on marine fisheries for primary education in the framework of the Education for Sustainable Consumption.

## 2 Teachers' Perceptions and Attitudes on Fish Ecolabels

### 2.1 Context and Methodology

This study was developed in the framework of the Ecos(i)Food project, on Scientific, Educational and Management tools for the sustainability of traditional fisheries in the Principality of Asturias (North of Spain). This project is funded by the State Programme of R + D + i oriented to the Challenges of Society (code MCI-20-PID2019-108481RB-I00/AEI/10.13039/501100011033). In Asturias, with more than 335 km of shoreline along the Bay of Biscay artisanal fisheries constitute a cultural and traditional identity factor, and a source of employment and income for coastal communities [18].

The assessment of teachers' attitudes and perceptions about fish ecolabels importance and use was evaluated through the Ecosifood's questionnaire. This questionnaire, implemented in *Google Forms,* was voluntarily and anonymously filled out by the students (pre- and in-service teachers) of a postgraduate teacher training course on research and innovation in early childhood and primary education at the University of Oviedo. The questionnaire was answered by 21 teachers (76.2% women, 23.8% men; 25 years old average age), 55% of the students enrolled in the postgraduate programme. A descriptive data analysis was performed with the statistical software PSPP v.1.4 (https://www.gnu.org/software/pspp/).

### 2.2 Results and Learning Needs

Postgraduate teachers' perceptions of fish ecolabels, including environmental and social values of sustainable fisheries, are positives. They buy fish mainly in supermarkets (61.9%) and, to a lesser extent, in fishmongers (28.6%), choosing fresh fish most of the times (38.1%) or always (33.3%). Almost everyone (90%) is aware of seeing labels with the fish displayed for sale. The issues that they say to consider when buying fresh fish are in Table 1. Price, fish in season, and their perception of the fish are the main factors to choose the fish to buy, being the geographic origin the fourth variable. Fishing gear types and label information are less considered in the choice, and one quarter (23.8%) never take into account the fishing gear. This attitude may be due to not knowing the impact that the different types of gear can have on the sustainability of fisheries and the conservation of marine biodiversity.

Their recognized attitudes are different from their own perceptions about what they consider to be important to make a purchase decision. Most consider that an ecolabel should be mandatory (71.4%) or necessary (28.6%), but do not read (76.2%) the labels' information in supermarkets and fishmongers before making their purchases.

These results, obtained from those who educate the next generations, show the need to design teaching materials that can be used in their teaching–learning experiences. This way, their students not only will not only consider the existence of ecolabels important, but also use them in their fish purchasing decisions.

## 3 Game-Based Learning Activities Design

With the aim to provide teacher resources on sustainable fisheries for these primary education teachers, an educative experience linking Environmental Education, Education

**Table 1** Issues that teachers and preservice teachers say to consider in their fish consumer' choices (percentages showed, n = 21)

| Items | Always | Most of times | Sometimes | Never |
|---|---|---|---|---|
| Geographic origin | 28.6 | 47.6 | 23.8 | 0.0 |
| Fishing Gear types | 19.0 | 23.8 | 33.3 | 23.8 |
| Fresh fish (and seafood) seasonality | 33.3 | 52.4 | 9.5 | 4.8 |
| Price | 33.3 | 57.1 | 9.5 | 0.0 |
| Labels' information | 23.8 | 38.1 | 9.5 | 28.6 |
| Own perception | 33.3 | 53.4 | 14.3 | 0 |

for Sustainable Consumption, and knowledge about small-scale fisheries (in the regional context of Asturias, N. Spain) is proposed (see Table 2 to learning objectives).

**Table 2** Learning objectives of the didactic intervention proposal for primary education

| Learning objectives |
|---|
| Conceptualize sustainable development, sustainable fisheries and responsible consumption |
| Differentiate between types of fishing and the fishing gear used in the Bay of Biscay |
| Recognize the most representative fish species of the Cantabrian Sea |
| Identify attitudes and behaviors that favor care and respect for the marine environment |
| Develop attitudes and values that promote sustainability and responsible consumption |
| Compare sustainable fishing with destructive fishing<br>Discern between the concepts of consumption and consumerism |
| Analyze how fish eco-labels are related to responsible consumption |

Therefore, a didactic sequence with five types of activities has been designed (Table 3). This didactic sequence includes explanatory activities, reflection and debate on responsible consumption, sustainable fisheries and eco-labels, as well as game-based learning activities. Fishing for hits is proposed including several independent tasks designed as learning games (alphabet games, getting the concept, question games). These learning games were aimed at learning different characteristics of marine biodiversity, marine natural resources collected in small-scale fisheries, the chain of consumption that goes from fishing boats to the purchase of fish by the consumer, and the possible content of ecolabels. An example of a virtual alphabet game is this Ecosifood Rosco Pesquero (in Spanish: https://bit.ly/Roscopesquero), made with the *Genially* application for interactive slideshows, in which students must choose the correct word related to fisheries and responsible consumption to advance through each letter of the alphabet.

**Table 3** Learning activities for the education for sustainable consumption on fisheries resources didactic proposal

| Learning activities | Brief description |
|---|---|
| 1. Sustainable fisheries versus destructive fishing | Explanation related concepts about:<br>1 Sustainable development<br>2. Sustainable fishing and destructive fishing<br>2.1. Environmental and social effects<br>2.1. Artisanal fishing in Asturias<br>3. Fish and seafood<br>3.1. Cantabrian Sea representative fish species<br>3.2. Protected marine species<br>4. Ecolabels<br>Summary by students |
| 2. Consumption versus consumerism | Learning video<br>Socio-environmental impacts consumerism<br>Responsible consumption<br>Relationship among ecolabels, sustainable fisheries and responsible consumption |
| 3. Game-based learning | 1. Escape room The Kraken<br>2. Fishing for hits<br>2.1. Alphabet games<br>2.2. Getting the concept<br>2.3. Question games |
| 4. Designing eco-labels! | What should an ecolabel include?<br>Collaborative design by students |
| 5. Educational field trips | Optional, depending on the school's possibilities and locality:<br>1. Fish market<br>2. Fishmongers |

Most the environmental education approaches to ocean literacy [see [8–10]] are mainly related to knowledge and management of marine biodiversity and their environmental problems (the SGG 14). Instead, this educational proposal, while working on some of the SDG14 goals, is aimed at changing consumption behaviors, making students aware of what represents responsible consumption (SDG12), in order to promote sustainable fisheries. The designed didactic sequence uses various types of activities, from exposure to reflection, highlighting those with a game-based learning focus. In this sense, it is methodologically close to other formal and non-formal educational approaches that use games to learn about the oceans, marine natural resources, and their conservation [11–14], in which concepts are learned, and environmental problems are analyzed and debated, from various educational games specially designed for each case.

From the perspective of Education for Responsible Consumption, not only is the role of different actors (external to the students) in marine environmental problems considered [11], but a holistic approach to the whole of society is sought, just as it is desirable against other marine environmental problems (e.g., marine litter: [19]). In our case, the aim is that students become aware that they can be, using their environmental knowledge, leading actors in solving environmental problems [20], with possible effects on the rest of society. Specifically, becoming empowered citizens through their conscious consumption decisions [21], which can have positive impacts on promoting sustainable fisheries.

This way, this educative intervention will promote students to be aware of the concept of sustainable fisheries concept, training them towards responsible consumption through critical and supportive attitudes. In this sense, that students knowing whether the fish they are going to consume comes from sustainable fisheries, could make them aware of the economic and socio-environmental process of fisheries, and introduce them to sustainable development and environmental care, developing social skills and positive values, such as solidarity and empathy.

## 4 Conclusions

- Elementary (pre- and in-service) schoolteachers shown positives perceptions about fish ecolabels, including features based on environmental and social values of sustainable fisheries.
- However, most of them do not read the labels information in fishmongers and supermarkets before making their purchases.
- Results show the need to design teaching materials which can be used in their teaching–learning experiences to promote sustainable fisheries through citizen empowerment in the Education for Sustainable Consumption framework.
- A didactic sequence including explanatory activities, reflection and debate on responsible consumption, sustainable fisheries and eco-labels, as well as game-based learning activities, is proposed.
- This intervention will promote students to be aware of sustainable fisheries concept, training them towards responsible consumption through critical and supportive attitudes related with Sustainable Global Goals 12 and 14.

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# Health, Habits and Responsible and Sustainable Consumption

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**Abstract.** Natural resources are essential for human well-being, quality of life and health. Current consumption of these resources is disproportionate, with a markedly commercial character. The need arises to change the current paradigm of consumption towards a responsible and sustainable consumption in line with Sustainable Development Goal (SDG) 12. Thus, from the Ponferrada campus (Universidad de León), under the Eureca Pro project, a series of initiatives based on sustainable education through learning based on practice have been developed. The main objective was to raise awareness and sensitise the general population about those behaviours that allow us to achieve the goals set out in SDG 12 in relation to healthy lifestyles, making known sustainable alternatives that benefit our quality of life. Three workshops and a community activity addressed responsible consumption in relation to healthy nutritional habits and the use of clothing and accessories. From the point of view of the university as a healthy environment, a promoter of health, through the revitalisation of the local environment and its economy, the focus was on education, awareness and empowerment, key elements for a more sustainable development of societies and economies. It is necessary to carry out more programmes aimed at the acquisition of knowledge and the development of attitudes and skills that allow people to decide about their future in a conscious and responsible way, as well as the execution of these decisions based on responsible, sustainable and healthy consumption.

**Keywords:** Responsible consumption · Sustainable Development Habits · Feeding Behavior · Healthy lifestyle

## 1 Introduction

In the last decades of the twentieth century, mainly under the influence of marketing, there have been important changes in Western consumption patterns [1, 2]. Thus, in an attempt to be "up-to-date", motivated by "trends", consumers engage in excessive consumption with a transcendental impact on the environment and its natural resources. They enter into a disproportionate dynamic of acquisition-disposal of products and services, without


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satisfying a real need [3]. In this context, it is worth highlighting the importance of natural resources and the environment in the well-being and health of human beings, as well as their direct relationship with quality of life [4]. This shows the influence of consumption, not only on the environment, but also on people's health and quality of life. The need therefore arises to change the current consumption paradigm, with a markedly commercial and consumerist character determined by market needs, with the aim of evolving towards responsible and sustainable consumption, based on real needs, in which people are aware of the acquisition of available resources and services, and of the repercussions this entails for people and the environment at all levels [5].

In this respect, sustainable education is effective in the process of raising consumer awareness while facilitating knowledge and the acquisition of values and attitudes, which is fundamental in the development of decision-making skills. It substantially facilitates, through its use, the understanding of the social and environmental impact resulting from their lifestyles and choices [6]. It is a fundamental tool for changing the current consumer profile. From a participatory approach, the aim is not only to acquire knowledge about responsible consumption and its impact, but also to empower people. Thus, achieving informed, aware and empowered consumers [4, 7].

In this context, in addition to the development of sustainable lifestyle habits, the environment takes on special relevance as an essential conditioning factor. In this line, the university as a healthy environment that promotes health [8–10], is a suitable environment where, in addition to generating knowledge, it promotes human development and the improvement of the quality of life of the general and university population. At the same time, they produce assets, promoters of behaviour at the family, work and/or social level [11].

In this way, based on the above, a series of initiatives based on sustainable education have been designed and implemented on the Ponferrada campus (Universidad de León) under the Sustainable Development Goals (SDGs) in terms of responsible production and consumption (no. 12), health and wellbeing (no. 3) and quality education (no. 4). Thus, in line with the philosophy of healthy habits and responsible consumption of the campus and EURECA PRO, the aim was to address values related to responsible and sustainable production and consumption in relation to the achievement of lifestyle habits that are beneficial to health and quality of life.

Based on the above, the main aim of this initiative was to raise awareness and sensitise the general population about those behaviours that allow us to achieve the targets set out in the SDG 12 in relation to healthy lifestyles, making known sustainable alternatives that benefit our quality of life. In addition, the secondary aims were to promote critical thinking, as well as different sustainable perspectives related to responsible consumption.

## 2 Methods

Three workshops and a community activity have been carried out in which sustainable education has been used as a tool for the empowerment of participants, as well as the acquisition of knowledge, values and attitudes necessary for conscious and responsible decision-making. On the other hand, it has been combined with learning based on practice, focusing the contents on practice and linking them to theory. In this way, in addition to generating knowledge, awareness and involvement is sought, while at the same time generating responsibility for the decisions taken.

Through this methodology, we addressed responsible consumption in relation to healthy nutritional habits and the use of clothing and accessories.

With regard to food, two workshops focused on the university community and the general population, both with the same methodology based on reuse cooking and waste reduction, as well as the impact of sustainable nutritional habits and responsible consumption on health, all using locally sourced or zero-kilometre products [12].

Firstly, during the month of March, "Healthy, sustainable and responsible consumption cuisine with a taste of Bierzo" was held, followed by "Sustainable, healthy and responsible consumption cuisine with a taste of Bierzo, from the vegetable garden of Bierzo for Europe" in May, each lasting 2 h. Both workshops had the same objectives, however, the second one, apart from being aimed at the general population and local university students who wished to participate, was broadcast in streaming for all the members of the Eureca Pro community, with an international scope. The objectives were the following.

- To correctly execute the activities of pre-preparation, preparation, preservation, finishing and service of healthy, sustainable and responsible consumption culinary preparations.
- To understand the importance of healthy, sustainable and responsible food consumption on health and the environment.
- Knowing the sustainable raw materials of the Bierzo region, as well as their preparation and preservation, according to quality protocols and hygiene standards, risk prevention and environmental protection.
- Execute healthy and nutritionally balanced culinary preparations.
- Performing sustainable and responsible conservation of raw materials and culinary preparations according to quality protocols and hygiene standards, prevention of occupational hazards and environmental protection.
- Maintain a spirit of innovation, responsible, healthy and sustainable consumption.

In order to achieve the objectives specified above, it was intended to achieve them in accordance with the following contents.

1. Importance of a healthy and sustainable diet, as well as responsible consumption on health and the environment.
2. Presentation of products from the region of El Bierzo.
3. Preparation of the work space.
4. Sustainable and responsible use of raw materials and material resources.
5. Handling of raw materials according to criteria of sustainability and responsible consumption.
6. Creation of sustainable and responsibly consumed culinary preparations by making use of the raw materials.
7. Packaging and/or preservation for each genre or culinary preparation.
8. Sustainable and responsible waste management.

The fundamentally practical nature of this type of workshop meant that a different menu was proposed for each one, to be prepared by the participants and subsequently consumed by them (Table 1). In the second edition, due to its international nature, local alternatives were sought in the regions or countries from which they were attending in order to achieve the maximum possible adaptation to the environment, given that, as mentioned above, it is a fundamental determinant in the acquisition of lifestyle habits.

**Table 1** Menus of the different healthy, sustainable and responsible consumption cooking workshops

| | | |
|---|---|---|
| *"Healthy, sustainable and responsible consumption cuisine with Bierzo flavour"* | | |
| Menu | *First course* | Salad with goat's roll, fruit vinaigrette of El Bierzo and walnuts |
| | *Second course* | Crepe stuffed with octopus, vegetables, mushrooms, creamy potato and gratin of cheese |
| | *Dessert* | Chestnut mousse, honey and pistachios |
| *"Sustainable, healthy and responsible consumption cuisine with Bierzo flavour, from the Bierzo market garden for Europe"* | | |
| **Menu** | *First course* | Lamb's lettuce salad, duck ham, fruit vinaigrette of El Bierzo, roasted tomatoes and walnuts |
| | *Second course* | Scrambled eggs with sautéed vegetables, chestnuts, boletus, cecina and scallops |
| | *Dessert* | Torrija cake, biscuit summit and fruit compote from El Bierzo |

The learning outcomes were achieved when the participants were able to correctly execute the activities of pre-preparation, preparation, conservation, finishing and service of healthy, sustainable and responsible consumption culinary preparations, in the scope of a kitchen, according to quality protocols and hygiene standards, risk prevention and environmental protection. As well as understanding the importance of healthy and sustainable food on health and the environment, based on responsible consumption of local raw materials (in this case, the Bierzo region). And the evaluation criterion consisted of attendance and participation in at least 80% of the sessions. In this respect, it is worth mentioning that each and every one of the participants attended 100% of the sessions.

On the other hand, in terms of responsible consumption of clothes and accessories, we organised two types of initiatives, a sewing workshop and a community activity, a clothes and accessories exchange market in line with SDG 12.

Thus, through "Conscious Sewing", the aim was to introduce participants to the world of sewing by analysing its terminology, tools and basic materials (thread, needles, scissors...). A brief description of the different sewing techniques was also given, with the aim of making a pair of shorts and a cloth bag, all from the reuse of a pair of long jeans. In this way, a new use was given to an unused item of clothing, which undoubtedly has a positive impact on the environment, quality of life and, ultimately, on health. The benefit obtained is twofold, since waste is avoided or significantly reduced, as other necessary objects (blouse and bag) are generated; and on the other hand, pollution and the costs associated with the destruction of textile waste are avoided. In this line, the objectives to be achieved with this proposal were, to acquire the necessary practical knowledge that allows us to remodel our garments to give them a second life, contributing in this way, to acquire an awareness of the impact that fashion has on our planet and how our habits can contribute to the development of a more sustainable slow fashion model. On the other hand, to know and handle the basic sewing material: measuring tape, pins, needles, scissors, thimbles and threads. Also, to learn the procedure for assembling a garment. Finally, to make basic stitches by hand. The contents contemplated for the achievement of the objectives set were the following.

1. Introduction to basic sewing.
2. Handling of tools and materials.
3. Basic knowledge of sewing.
4. Sewing pattern.
5. Cutting the trousers and making the bag.

Thus, the learning outcomes would be based on the acquisition of general knowledge by the participants of the textile, clothing and leather materials used in the course; they will learn basic pattern making and sewing and finishing techniques necessary to make fabric accessories.

Finally, the evaluation criteria consisted of attendance and participation in 80% of the sessions. However, it is worth mentioning once again that, as in the workshops described above, attendance and participation was 100% of the sessions.

The clothes and accessories exchange market, in line with SDG 12 and the responsible consumption line of the Eureca Pro project, was held in December for the entire university community and allowed for the exchange of clothes and accessories. The aim of this initiative consisted of active and effective participation in textile sustainability, giving a second life to garments in good condition. In this way reducing the excessive consumption and the impact on the environment derived from the manufacture and marketing of these garments by the textile industry.

In this way, participants handed in the garments they wished to donate and received a voucher for the same number of items they had donated; this voucher could be exchanged at the street market. The surplus clothes were donated to the Gente Solidaria Association. Attendance and participation were a success.

## 3 Conclusion

Achieving a more balanced, sustainable and healthy world in order to achieve a better quality of life in the present and for future generations is one of the great challenges of our time. Sustainable development must be understood as a long-term commitment to the future, given that the resources we use every day are essential for our well-being and quality of life, and therefore our health. The prevailing consumerist profile marked by the needs of the market and not by a real need, does not contribute to improving our health or our environment. Thus, there is a need for a change in the consumption paradigm in line with the objective of development 12, responsible production and consumption. In this social transformation towards a more sustainable society, the acquisition of knowledge and the development of attitudes and skills that allow people to decide about their future in a conscious and responsible way, as well as the execution of these decisions, are fundamental. Thus, education and awareness-raising are unavoidable and necessary aspects to achieve this goal. It is not only necessary that they are aware of this reality, but also that they are aware of it and internalise it, being able to make decisions and use the tools at their disposal to make a positive contribution, obtaining benefits for the environment and their health in the short and long term. For this reason, from the Ponferrada Campus (Universidad de León), aligned with the Sustainable Development Goal (SDG) no. 12, responsible production and consumption in combination with SDGs 3 and 4 related to health and well-being and quality education respectively, and within the Eureca Pro philosophy on healthy habits and responsible consumption, we have carried out a series of initiatives on responsible and healthy consumption. Thus, from the university as a healthy environment promoting health, we have sought to transform the learning and training environments in order to transfer knowledge to society and thereby raise awareness, empower and mobilise about the need to consume in a responsible and healthy way. The dynamization of the local environment and its economy has been one of our maxims, as applicability, accessibility and low cost are key factors to achieve adherence.

Education and awareness-raising are key to a more sustainable development of societies and economies, and more interventions and programmes are needed in this area. These should encourage more sustainable social and environmental consumption, promoting rational use of available resources and minimising waste. Likewise, it is also essential that they encourage reuse and recycling, without forgetting healthy, sustainable and safe food that also favours respect for the producers of the food necessary for it.

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# Comparative Exergy Analysis of Heat Pumps for Heat Recovery Applications

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**Abstract.** Heat pumps have a multitude of applications and therefore there are many types of heat pumps. In one peculiar application heat pumps proved to be very effective, for low grade waste heat recovery. Several criteria can be considered for choosing a heat pump, such as application scope, coefficient of performance, etc. Sometimes these criteria are not enough, and some more must be found. The paper suggests the use of comparative exergy analysis in order to choose the heat pump that best suits the application for which is intended. Exergy analysis is a powerful tool that allows us to analyze in detail the processes that are taking place in a heat pump, enabling us to choose knowingly between different types of heat pumps the one that best suits our application. Two new criteria for choosing a heat pump are suggested: cycle compression work and environmental impact of the refrigerant. Exergy analysis shows that the choice of the vapour compression heat pump, purely from COP point of view is legitimate, but the choice of the gas pump can be rightful due to smaller cycle compression work and refrigerant used, which in case of gas compression heat pump is air, neutral in terms of environmental impact.

**Keywords:** Heat pump · Exergy efficiency · Coefficient of performance · Gas compression heat pump · Vapour compression heat pump

## 1 Introduction

As many of the European countries struggle to find a secure energy supply, energy efficiency became a major concern. More than that EU aims at becoming the first climate-neutral continent by 2050.

The Commission has therefore revised the Energy Efficiency Directive, together with other energy and climate rules, to ensure that the new 2030 target of reducing greenhouse gas emission by at least 55% (compared to 1990) can be met [1].

An important part of increasing energy efficiency can be considering heat recovery from low temperature waste heat.

Other countries like U.S. are interested in climate neutrality, too. As a result, U.S. Department of Energy disseminate ways of saving energy using heat pumps in households [2]. The US Department of energy developed a web page to showcase ways to save energy. Among the ways of saving energy, an important place is occupied by heat


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pumps, which can be used both for air conditioning and for the production of domestic hot water. Various possibilities for the production of domestic hot water are suggested, presenting pros and cons and also presenting possible solutions to solve disadvantages.

US Department of Energy also developed a guide for using heat pumps in industry [3] for steam and fuel savings presenting features favourable for heat-pump installations, examples of heat-pump applications and types, and also guidelines for selecting heat-pump type.

Heat pump applications in industrial manufacturing activities, suggests in most cases, the usage of mechanical vapour compression type heat pumps for low temperature heat recovery, in accordance with literature [4].

Heat pump technology has returned in actuality along with the new global energy issues, but it isn't a new technology. A great variety of heat pump designs were developed and their construction became increasingly complex [5], they have increased efficiency but also a higher price.

Therefore, many criteria must be taken into account when choosing a heat pump, such as COP, the ability to provide simultaneous cooling and heating, purpose of use, source of heat (air-source, geothermal/ground-source or water-source) heat pumps, absorption heat pump (AHP), also called a gas-fired heat pump. For example, in the case of households, even if they are much more efficient than other heating solutions, they still consume electricity, therefore in addition to the price, the low need for electricity can be a selection criterion.

In addition to various criteria listed above, exergy analysis is well suited for furthering this goal, for it enables to point the location, type and true magnitude of losses, providing helpful information both quantitatively and qualitatively.

To exemplify how the exergy analysis can be helpful when selecting a heat pump, a comparative exergy analysis between a vapour compression and a gas compression heat pump will be performed.

## 2 Gas Compression Heat Pump

The basic design of the gas compression heat pump is similar to the vapour compression heat pump as seen in Fig. 1.

From a thermodynamic point of view, the heat pump with vapour compression operates after a Carnot cycle, modified to be applied in practice. The isentropic expansion in the detentor is replaced with an isenthalpic process in the expansion valve, while in the compressor there is an isentropic compression, resulting temperatures higher than $T_c$, the condensing temperature (Fig. 2) [4, 6–12].

In Fig. 1, $q_0$ is heat transferred in evaporator, $q_c$ is heat transferred in condenser and $l_c$ is work needed for compression.

In Fig. 2, $q_a$ is heat transferred in evaporator (denoted by $q_0$ hereafter), $q_i$ is heat transferred in condenser (denoted by $q_c$ hereafter). The theoretical cycle for the steady state flow gas compression heat pump (Fig. 2) is a Joule cycle [4, 7, 8, 10, 11] in which the expansion and the compression is achieved employing turbomachinery.

While the functioning of vapour compression heat pump has been widely presented in many works as they are widely used, the gas compression heat pump is not so used and therefore literature concerning them are rare.

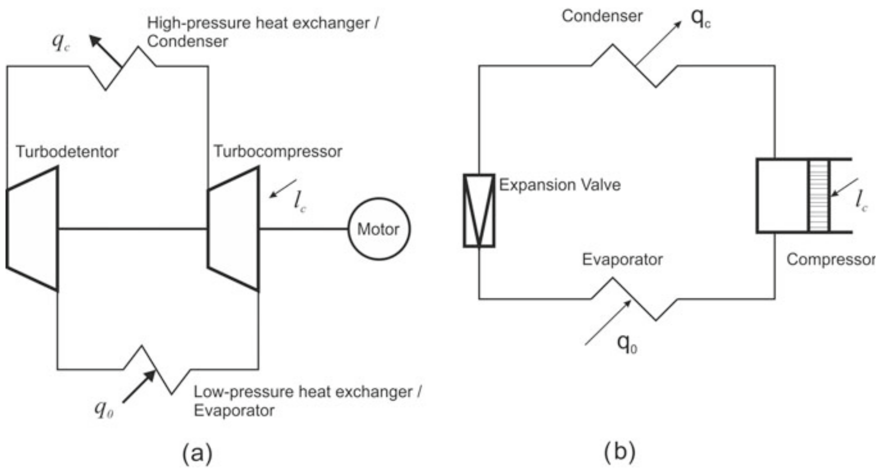


**Fig. 1** Schematics of a gas (**a**) versus vapour (**b**) compression heat pump

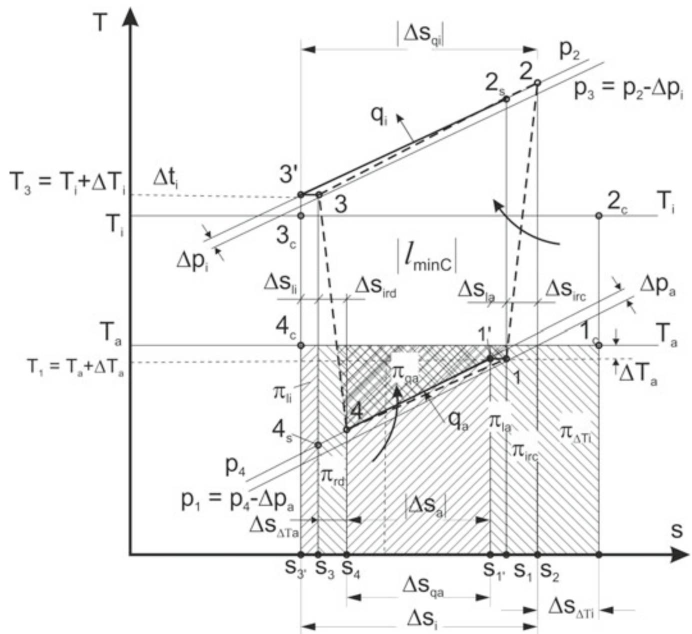

**Fig. 2** The actual cycle of a gas compression heat pump [8]

A basic characteristic of the gas compression heat pump is the compression ratio $\beta_c$ [6, 7, 12]:

$$\beta_c = \frac{p_2}{p_1} \tag{1}$$

where: $p_2$ is the outlet pressure, $p_1$ is the inlet pressure of the turbocompressor, in bar.

A characteristic parameter of heat pumps is the COP (Coefficient Of Performance), denoted with $\mu$. The theoretical COP $\mu_t$, can be expressed for gas compression heat pump with the following formula [6, 7, 12]:

$$\mu_t = \frac{1}{1 - \beta_c^{\frac{1-k}{k}}} \tag{2}$$

where: k is the adiabatic coefficient and $\beta_c$ the compression ratio.

The theoretical COP $\mu_t$ for vapour compression heat pump is [6, 7, 12]:

$$\mu_t = \frac{|q_c|}{|l_t|} \tag{3}$$

where: $q_c$ is the heat transferred in condenser in kJ·kg$^{-1}$, and $l_t$ is the theoretical work of the cycle in kJ·kg$^{-1}$.

Another parameter based on which heat pumps can be compared is the exergy efficiency $\eta_E$, that can be calculated using equation [6, 7, 12]:

$$\eta_E = \frac{|l_{\min C}|}{|l|} \tag{4}$$

where: $l_{minC}$ is the specific minimum work of the ideal Carnot cycle kJ·kg$^{-1}$, while $l$ is the specific work of the actual cycle in kJ·kg$^{-1}$.

Based on the actual cycle of the gas compression heat pump (Fig. 2) [6, 7, 12] calculations can be performed in order to highlight characteristic parameters which can be compared with the corresponding characteristics of the vapour compression heat pump.

## 3 Results

One of the most important applications of the heat pumps are waste heat recovery from low temperature sources. They are commonly used for household heating and providing domestic hot water in order to use the recovered heat. When there are no waste heat sources, ground source heat pumps with coils buried underground are used.

First assumption is that they are going to be used for household heating and providing hot water, delivering heat at a temperature of 55 °C.

Equations required for calculus of the vapour compression heat pump is presented in [4, 8, 9] and the algorithm was tested for a single stage vapor compression heat pump [13] while the algorithm for the gas compression heat pump is presented in [8].

Assumptions made in order to perform the calculus:

- the refrigerant used is vapour compression heat pump is ammonia (R717) while in gas compression heat pump is air;
- heat source temperatures considered are 5, 10 and 15 °C, resulting temperature lifts of 50, 45 and 40 °C. The selected three points are enough to illustrate the trends, as literature shows [4, 6–8, 12], that when the temperature of the source increases, the ideal Carnot COP $\mu_C$, the theoretical COP $\mu_t$ and the practical COP $\mu_e$ are increasing too.

Data for calculation are: $T_i = 55$ °C—temperature of delivered heat, $T_a = 5$, 10, 15 °C—ambient temperature, $\Delta T_c = 5$ °C—temperature difference required for heat transfer in condenser (heat delivery), $\Delta T_0 = 5$ °C—temperature difference required for heat transfer in evaporator, $\Delta T_{sr} = 5$ °C—temperature difference for sub-cooling (for vapour compression heat pump). The mechanical efficiency of the compressor is calculated for vapour compression cycle so in case of the gas compression heat pump the same values will be used in calculus for better comparison.

Results are presented in Tables 1, 2, 3 and Figs. 3, 4, 5, where VCHP stands for Vapour Compression Heat Pump while GCHP for Gas Compression Heat Pump.

**Table 1** Characteristics of vapour and gas compression heat pump for 50 °C temperature lift

| Nom | Vapour compression | Gas compression |
|---|---|---|
| Cycle compression work $\boldsymbol{l}$ (kJ kg$^{-1}$) | 337.480 | 74.966 |
| Evaporator heat transferred $\mathbf{q_0}$ (kJ kg$^{-1}$) | 998.075 | 27.293 |
| Condenser heat transferred $\mathbf{q_c}$ (kJ kg$^{-1}$) | 1335.556 | 102.259 |
| Ideal Carnot COP $\boldsymbol{\mu_C}$ | 6.563 | 6.560 |
| Theoretical COP $\boldsymbol{\mu}$ | 3.957 | 1.364 |
| Practical COP $\boldsymbol{\mu_e}$ | 3.561 | 1.310 |
| *Losses due to irreversibility of* | | |
| Compression $\boldsymbol{\pi_{irc}}$ (%) | 11.816 | 19.361 |
| Expansion $\boldsymbol{\pi_{irl}}$ (%) | 7.144 | 30.186 |
| Heat transfer in evaporator $\boldsymbol{\pi_{q0}}$ (%) | 5.413 | 2.644 |
| Heat transfer in condenser $\boldsymbol{\pi_{\Delta Tc}}$ (%) | 15.422 | 16.250 |
| Pressure drops in heat exchangers $\boldsymbol{\pi_l}$ (%) | – | 4.30 |
| Work of ideal Carnot cycle $\boldsymbol{l_{minC}}$ (kJ kg$^{-1}$) | 203.498 | 14.16 |
| Exergy efficiency $\boldsymbol{\eta_E}$ (%) | **60.30** | **20.79** |

The letters are bold because it was intended to highlight the variables that will be represented in the following figures

While exergy efficiency of vapour compression heat pump is relatively constant, in case of gas compression COP is increasing with temperature lift (Fig. 3), meaning that is decreasing with the ambient temperature $T_a$.

COP of the gas compression heat pump is very small, practical COP ranging from 1.31 to 1.438 for temperature lift of 50–40 °C. In both analysed cases, COP is increasing as ambient temperature $T_a$ is increasing (as temperature lift is decreasing), Fig. 3.

Analyzing tables above and data represented in Fig. 4, can be seen that exergy efficiency of the gas compression heat pump is very small approximately three times smaller than the efficiency of vapour compression heat pump 60.65% compared to 18.27% for 40 °C temperature lift (Fig. 4).

**Table 2** Characteristics of vapour and gas compression heat pump for 45 °C temperature lift

| Nom | Vapour compression | Gas compression |
|---|---|---|
| Cycle compression work $\boldsymbol{l}$ (kJ kg$^{-1}$) | 293.072 | 74.969 |
| Evaporator heat transferred $\mathbf{q_0}$ (kJ kg$^{-1}$) | 1003.521 | 32.315 |
| Condenser heat transferred $\mathbf{q_c}$ (kJ kg$^{-1}$) | 1296.593 | 107.285 |
| Ideal Carnot COP $\boldsymbol{\mu_C}$ | 7.292 | 7.289 |
| Theoretical COP $\boldsymbol{\mu}$ | 4.424 | 1.431 |
| Practical COP $\boldsymbol{\mu_e}$ | 3.981 | 1.374 |
| *Losses due to irreversibility of* | | |
| Compression $\boldsymbol{\pi_{irc}}$ (%) | 11.239 | 23.746 |
| Expansion $\boldsymbol{\pi_{irl}}$ (%) | 6.788 | 30.727 |
| Heat transfer in evaporator $\boldsymbol{\pi_{q0}}$ (%) | 6.155 | 3.529 |
| Heat transfer in condenser $\boldsymbol{\pi_{\Delta Tc}}$ (%) | 15.304 | 17.987 |
| Pressure drops in heat exchangers $\boldsymbol{\pi_l}$ (%) | – | 4.378 |
| Work of Ideal Carnot cycle $\boldsymbol{l_{minC}}$ (kJ kg$^{-1}$) | 177.805 | 14.719 |
| Exergy efficiency $\boldsymbol{\eta_E}$ (%) | **60.67** | **19.63** |

The letters are bold because it was intended to highlight the variables that will be represented in the following figures

Regarding losses due to irreversibility in case of gas compression heat pumps are proportionally bigger as losses of vapour compression heat pump (Fig. 5).

For example, losses due to irreversibility of compression reach the value of 23.746% for 45 °C temperature lift while for vapour compression the loss is only 11.239% (Tables 1, 2 and 3).

In case of gas compression heat pump losses are slightly decreasing with the increase (Fig. 5) of the temperature lift (decreasing with ambient temperature $T_a$ increase), while for vapour compression losses due to irreversibility of compression $\pi_{irc}$, expansion $\pi_{irl}$ and heat transfer in condenser $\pi_{\Delta Tc}$ are increasing with temperature lift (decreasing with higher ambient temperatures $T_a$).

One important aspect is shown to us by the values of specific heat transferred in evaporator $q_0$ and condenser $q_c$.

Values for heat transferred in evaporator $q_0$ (yielded by the environment) in case of vapour compression are ranging from 998.075 kJ·kg$^{-1}$ for 50 °C temperature lift to 1008.388 kJ·kg$^{-1}$ for 40 °C temperature lift while in case of gas compression 27.293 to 40.541 kJ·kg$^{-1}$.

**Table 3** Characteristics of vapour and gas compression heat pump for 40 °C temperature lift

| Nom | Vapour compression | Gas compression |
|---|---|---|
| Cycle compression work $\boldsymbol{l}$ ($kJ\ kg^{-1}$) | 253.693 | 68.033 |
| Evaporator heat transferred $\mathbf{q_0}$ ($kJ\ kg^{-1}$) | 1008.588 | 40.541 |
| Condenser heat transferred $\mathbf{q_c}$ ($kJ\ kg^{-1}$) | 1262.281 | 108.574 |
| Ideal Carnot COP $\boldsymbol{\mu_C}$ | 8.204 | 8.200 |
| Theoretical COP $\boldsymbol{\mu}$ | 4.976 | 1.498 |
| Practical COP $\boldsymbol{\mu_e}$ | 4.478 | 1.438 |
| *Losses due to irreversibility of* | | |
| Compression $\boldsymbol{\pi_{irc}}$ (%) | 10.780 | 21.651 |
| Expansion $\boldsymbol{\pi_{irl}}$ (%) | 6.346 | 31.269 |
| Heat transfer in evaporator $\boldsymbol{\pi_{q0}}$ (%) | 7.020 | 4.532 |
| Heat transfer in condenser $\boldsymbol{\pi_{\Delta Tc}}$ (%) | 15.441 | 19.825 |
| Pressure drops in heat exchangers $\boldsymbol{\pi_l}$ (%) | – | 4.454 |
| Work of Ideal Carnot cycle $\boldsymbol{l_{minC}}$ ($kJ\bullet kg^{-1}$) | 153.866 | 13.696 |
| Exergy efficiency $\boldsymbol{\eta_E}$ (%) | **60.65** | **18.27** |

The letters are bold because it was intended to highlight the variables that will be represented in the following figures

## 4 Summary

Exergy analysis is a powerful tool that allows us to analyze in detail the processes that are taking place in a heat pump, enabling us to choose knowingly between different types of heat pumps the one that best suits our application.

Data presented in Tables 1, 2 and 3 shows that not only COP can be taken into account when choosing a heat pump.

As a result, two new criteria for choosing a heat pump are suggested:

1. One important aspect, considering the energy crisis, must be the cycle compression work $l$, for which lower values mean smaller electric drive motors.
2. Another aspect that must be taken into account is the environmental impact of the refrigerant.

Exergy analysis shows that the choice of the vapour compression heat pump, purely from COP point of view is legitimate, as data presented above are indicating that COP and exergy efficiency of the vapour compression heat pump is significantly higher than values for gas compression. Also values of specific heat transferred in evaporator $q_0$ and condenser $q_c$, are indicating that at the same thermal load the flow rate of the gas refrigerant must be significantly higher, resulting an increase of the gas compression heat pump size. This is another aspect which is also in favour of choosing vapour compression instead of gas compression.

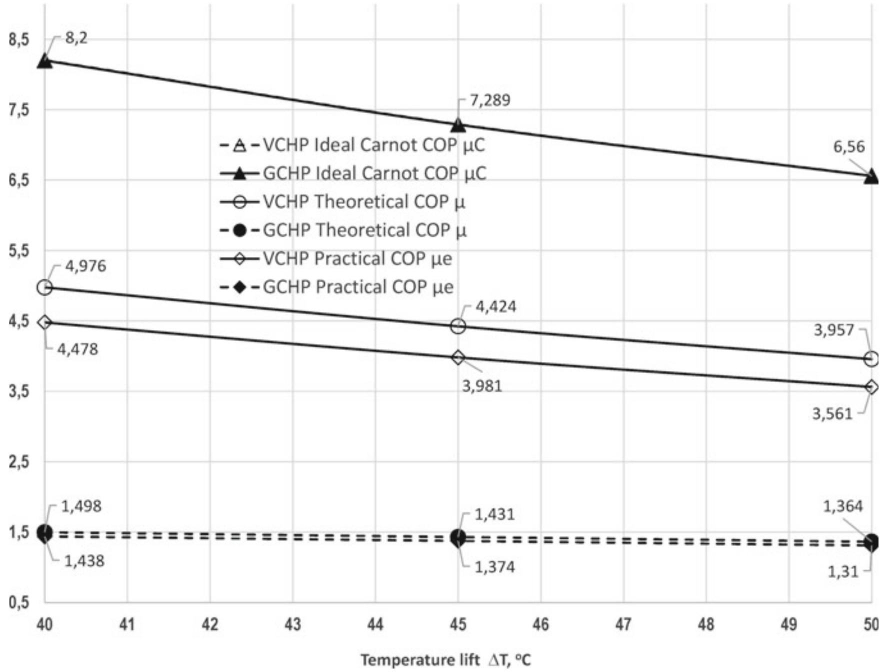


**Fig. 3** The COP for vapour (▬) and gas (—) compression heat pump

Anyway, the use of gas compression heat pump should not be totally disregarded.

Considering the two new criteria suggested above, the choice of the gas pump can be rightful due to smaller cycle compression work *l* and refrigerant used, which in case of gas compression heat pump is air, neutral in terms of environmental impact.

In some areas of activity, such as mining, safety at work prevails over other considerations. In mining or other areas where a faulty heat pump can send in the environment potentially hazardous gases like some refrigerants used in the vapour compression heat pumps, using air as refrigerant can be a decisive criterion in choosing a certain type of heat pump.

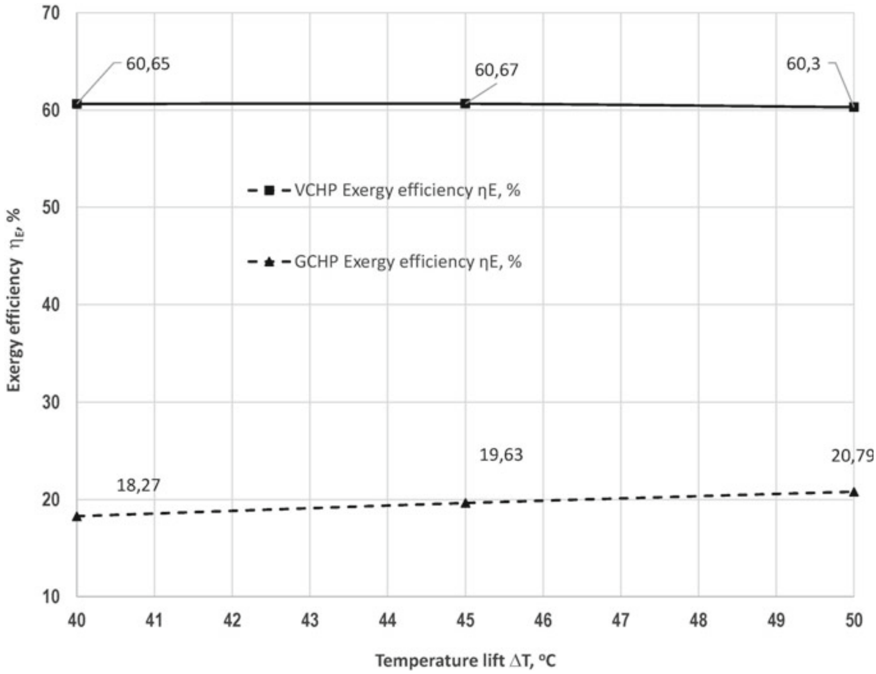


**Fig. 4** Exergy efficiency for vapour (▬) and gas (—) compression heat pump

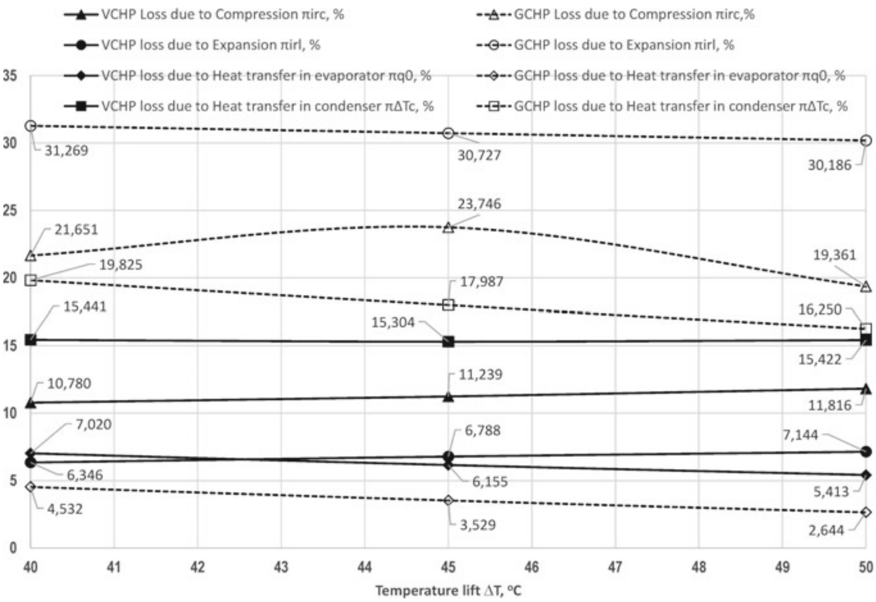


**Fig. 5** Losses in vapour compression (▬) and gas compression heat pump (—)

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# Research on the Valorization of Green Sludge Resulting from the Manufacture of Sodium Dichromate in Romania

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**Abstract.** The Târnăveni Chemical Plant was a inorganic chemical plant in Romania. In the good old days, even 6500 employees worked here. When it was productive, the Chemical Plant produced a lot of inorganic products such as: sodium bichromate, potassium bichromate, barium salts, chromium salts, or zinc oxide. In 2002, the plant was closed and taken over by AVAS. The sodium (potassium) dichromate manufacturing process results in a tailings called green slime. The tailings deposited in the landfill are strongly contaminated with dichromate ion, as a result of the process of manufacturing chromium salts. This ion, according to the statistics, is found in the material in a concentration of 1.73–2.20%. This concentration is enormous, taking into account the existing environmental protection regulations. The present paper presents the initial phase of research regarding the removing of this waste.

**Keywords:** Recovery of industrial waste · Dichromate · Magnesium carbonate

## 1 Existing Situation on Green Sludge Tailings

### 1.1 The Technological Flow for the Manufacturing of the Sodium Dichromate

The technological flow was based on the reaction between the chromium ore, the dolomite and soda lime at 1100–1250 °C in rotary kiln reactors 55 m long and 2.7 m in diameter protected on the inside with checker brick.

After dosing the raw matters and the oxidizing roasting, the wet grinding phase of the sinter in the oven will occur, followed by the settling and the filtering.

The so-called "green muds" settling in pits 2 and 3 and representing 80–90% of the content of pits 2 and 3 resulted from the filtering phase.

After the evaporation (for concentration) the chromate solutions obtained through acidification with concentrated $H_2SO_4$, the passage from chromate to dichromate and the separation by centrifuging of the sodium sulfate still processed as sub-product occurred.

After the concentration of the dichromate solutions in 2 phases with the ongoing separation of the sodium sulfate, the crystallizing of the dichromate solutions, the centrifuging, the drying and the packaging of the sodium dichromate occurred.


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Through their specificity, the sodium dichromate plants generated toxic wastes. The toxicity was rendered by the presence of $Cr^{6+}$

All the wastes resulting both from the filtering phase, the so-called "green sludge" and the ones resulting from cleaning, settling on the machines (crust, dust, settled suspensions etc.) settled with great rigor only on pits 2 and 3. In the Table 1 is presented the chemical composition of green sludge.

**Table 1** Green mud chemical composition in pits 2 and 3 (%)

| Component | Test I | Test II |
|---|---|---|
| $Cr_2O_3$ soluble in water | 2.2 | 1.73 |
| $Cr_2O_3$ soluble in HCl | 2.8 | 3.01 |
| $Cr_2O_3$ total | 9.6 | 11.65 |
| $SiO_2$ | 9.8 | 5.92 |
| $Al_2O_3$ | 5.4 | 6.0 |
| $Fe_2O_3$ | 8.38 | 8.38 |
| MgO | 28.9 | 24.85 |
| CaO | 26.0 | 24.39 |
| P.C | 8.12 | 10.81 |
| $H_2O$ | 40.2 | – |

## 2 Environmental Aspects

The material deposited in the dump site is heavily contaminated with dichromate ion, due to the manufacturing process of chromium salts. This ion, according to statistics provided by S. C. Bicapa S. A. Târnăveni is found in the material in a concentration of 1.73–2.20%. Such concentration is enormous, given the existing environmental regulations [1].

Maximum permissible concentration in soil—20 mg/kg (less susceptible soils intervention threshold).

After performing the leaching tests, a leachate with the following characteristics resulted (Table 1).

The analysis of the percolate resulted in the following characteristics (Table 2).

Since percolation waters reach the surface waters through exfiltration, the concentration values of heavy metal ions were compared to the permissible concentrations for waste water discharge into surface waters, according to NTPA 002/2005 (Table 4).

From all those tests it results that hexavalent chromium concentration is much higher than the permissible one, requiring elimination of this waste.

It is advisable to remove hexavalent chromium before performing any other waste recovery operation to avoid contamination of the obtained products and migration of the ion into the technological waters in excessive concentrations.

**Table 2** Leachate chemical composition (mg/kg)

| Ion | Leachate mg/kg dry substance | Accepted for waste category | | |
|---|---|---|---|---|
| | | Inert | Non-hazardous | Hazardous |
| $Ca^{2+}$ | 1043.76 | | | |
| $Cr^{6+}$ | 230.66 | 0.2 | 4.0 | 25.0 |
| $Fe^{3+}$ | 3.01 | | | |
| $Ni^{2+}$ | 0.71 | 0.2 | 5.0 | 20.0 |
| $Zn^{2+}$ | 1.25 | 2.0 | 25.0 | 90.0 |

**Table 3** Percolate chemical composition (mg/l)

| Ion | Percolate (mg/l) | Accepted for waste category | | |
|---|---|---|---|---|
| | | Inert | Non-hazardous | Hazardous |
| $Ca^{2+}$ | 939.39 | | | |
| $Cr^{6+}$ | 207.60 | 0.1 | 2.5 | 15.0 |
| $Fe^{3+}$ | 2.71 | | | |
| $Ni^{2+}$ | 0.64 | 0.12 | 3.0 | 12 |
| $Zn^{2+}$ | 1.12 | 1.2 | 15 | 60 |

**Table 4** Percolate chemical composition (mg/l) according with NTPA 002/2005

| Ion | Percolate (mg/l) | NTPA 002 |
|---|---|---|
| $Ca^{2+}$ | 939.39 | 300 |
| $Cr^{6+}$ | 207.60 | 0.1 |
| $Fe^{3+}$ | 2.71 | 5.0 |
| $Ni^{2+}$ | 0.64 | 0.5 |
| $Zn^{2+}$ | 1.12 | 0.5 |

We regard this stage as the key point of the entire process of eliminating waste from the sludge tank belonging to S.C. Bicapa S.A.

## 3 Washing Test Water on Green Sludge

The elimination of hexavalent chromium from various environments can be achieved with the help of specific reagents, but in the case of large amounts of material, the application of these procedures is not feasible [2, 3]. Water washing tests were performed using small volumes of water in repeated washings, being acknowledged that washing a material several times with small volumes of water is more efficient than once with a large volume of water.

By applying this way of washing, the concentration of the chromate ion is expected to decrease significantly after each stage.

Obtained experimental data show completely different behaviour of waste when washed with water. Thus, it was found that after a significant number of washings, washing waters maintain a relatively constant concentration (Table 5; Fig. 1).

**Table 5** Green sludge washing test

| Washing | Fixed residue (mg/dm$^3$) | Washing | Fixed residue (mg/dm$^3$) |
|---|---|---|---|
| 1 | 2710.0 | 10 | 1092.5 |
| 2 | 2562.5 | 11 | 980.0 |
| 3 | 2155.0 | 12 | 1025.0 |
| 4 | 1720.0 | 13 | 870.0 |
| 5 | 1547.5 | 14 | 1045.0 |
| 6 | 1345.0 | 15 | 997.5 |
| 7 | 1302.5 | 16 | 907.5 |
| 8 | 1227.5 | 17 | 760.0 |
| 9 | 1152.5 | | |

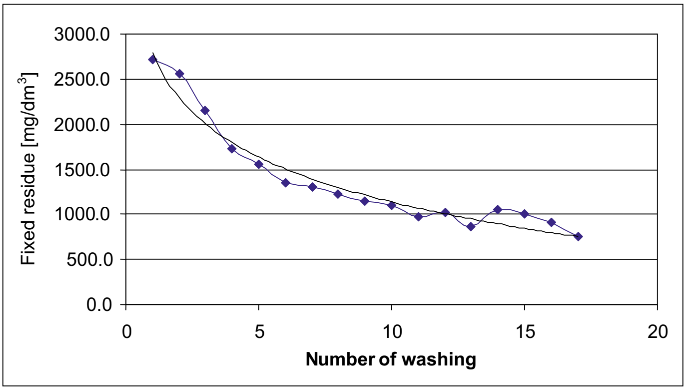


**Fig. 1** Diagram for number of washings

This behaviour is due to the fact that chromate ion is in a slightly soluble form in waste.

Chemical analyses showed that chromate ion is found in waste as calcium chromate, derived from the reaction of calcium ion with sodium chromate.

$$Na_2CrO_4 + Ca^{2+} + CO_2 = CaCrO_4 + 2\,Na^+ \quad (1)$$

This reaction also explains that sodium ion is not associated to chromate ion, as resulted in sinter wet-milling. Furthermore, the lack of sodium in the vast majority of samples shows that it was leached by rainwater in time.

Given the lack of sodium ion, maintenance of chromate ion in waste can be explained by its association with calcium ion in time, forming a precipitate of calcium chromate, sparingly soluble.

The solubility of calcium chromate is given in Table 6.

**Table 6** Calcium chromate solubility

| Temperature (°C) | Solubility $CaCrO_4$ |
|---|---|
| 0 | 4.5 |
| 10 | |
| 20 | 2.25 |
| 30 | 1.83 |
| 40 | 1.49 |
| 50 | |
| 60 | 0.83 |

The solubility of calcium chromate significantly decreases with increasing temperature.

Lack of magnesium in percolation waters is due to high solubility of magnesium chromate (137 g/l at 20 °C) which moves the equilibrium of the double replacement reaction decisively to the left:

$$CaCrO_4 + Mg^{2+} = MgCrO_4 + Ca^{2+} \quad (2)$$

In order to increase the efficiency of the washing process, chromate ion should shift to a more soluble form, such as sodium or magnesium chromate. Since recovery of magnesium is intended, to avoid contamination of the product with chromium, the option is to wash the sodium carbonate waste.

## 4 Magnesium Leaching

The sludge resulted after the washing and the removal of the chromate ion is diluted with water in a ratio of 1/5–1/10.

The resulting pulp which contains magnesium hydroxide and magnesium carbonate in a percentage of 35–40%, calcium hydroxide, calcium carbonate and sterile minerals consisting of iron oxides and chromium and silicon dioxide undergoes leaching with carbon dioxide in a ratio of 0.8 as opposed to the quantity necessary from a stoichiometric point of view. At this stage, the dissolution of the magnesium hydroxide occurs according to the reaction (3) [3–8]:

$$Mg(OH)_2 + CO_2 = Mg(HCO_3)_2 + H_2O \quad (3)$$

At the same time, the non-hydrated magnesium oxide as well as the magnesium carbonate non-decomposed by calcination, will be dissolved according to the reactions (4) and (5):

$$MgO + 2\,CO_2 + H_2O = Mg(HCO_3)_2 \tag{4}$$

$$MgCO_3 + CO_2 + H_2O = Mg(HCO_3)_2 \tag{5}$$

Due to the insufficiency of the carbon dioxide, as a consequence of the solubility differences, the calcium bicarbonate eventually present in the solution will precipitate according to the reaction (6):

$$Ca(HCO_3)_2 = 2CO_2 + H_2O + CaCO_3 \tag{6}$$

After the solubilization in a first stage taking up 20–30 min, the pulp undergoes filtering with depression. After the filtering there results a solution containing magnesium bicarbonate and a filtered product containing 10–12% $Mg(OH)_2$ and $MgCO_3$, $CaCO_3$ and sterile minerals. The filtered product, after being hydrated in a ratio of 1/5…1/10, is introduced in a second solubilization stage with carbon dioxide until the calcium ion appears in the solution. The appearance of the calcium ion in the solution shows the exhaustion of the magnesium oxide with much more reactive. This pulp is filtered again when a solution with a low content of magnesium and calcium bicarbonate results, which is circulated again as well as a sterile material containing mainly calcium carbonate and sterile minerals representing a second sub-product which can be valued as such. The filtered solution is recirculated in the hydrating tank from the main operation supply for solubilization [9, 10].

The filtered solution resulting during the first stage of solubilization is warmed until boiling for the precipitation of magnesium according to the reactions (7) and (8):

$$Mg(HCO_3)_2 = MgCO_3 + H_2O + CO_2 \tag{7}$$

$$Mg(HCO_3)_2 = Mg(OH)_2 + 2CO_2 \tag{8}$$

Boiling the solution at temperatures ranging between 105 and 110 °C for 20–30 min, the magnesium hydroxide and oxide precipitate, this precipitate undergoing hot filtering, at a temperature exceeding 80 °C, obtaining a final magnesium concentrate with a purity exceeding 98% MgO and a filtered water reintroduced in the preheating circuit during the first stage. The carbon dioxide resulting after the discomposure of the magnesium bicarbonate by boiling is captured and circuited again during the solubilization stage. During the second preheating stage, the heat coming from the burning gas from the calcination oven of the magnesium concentrate is recovered.

The water resulting from the first preheating stage is circuited again.

## 5 Experimental Results

The separation tests were conducted on an average, not dry sample, because during the preliminary tests it has been noticed that the material dried in advance is much more refractory to leaching and especially to washing.

The leaching was conducted in three stages, without a $CO_2$ add during the reactions. The magnesium and calcium oxide extractions for these tests were (Table 7).

**Table 7** Magnesium and calcium oxide extractions

| | Oxide | Recovery |
|---|---|---|
| Extraction 1 | CaO | 7.26 |
| | MgO | 34.63 |
| Extraction 2 | CaO | 6.64 |
| | MgO | 23.24 |
| Extraction 3 | CaO | 3.62 |
| | MgO | 9.70 |
| Extraction total | CaO | 17.52 |
| | MgO | 67.57 |

The evolution of the MgO/CaO ratio during the three extraction stages is the following (Fig. 2).

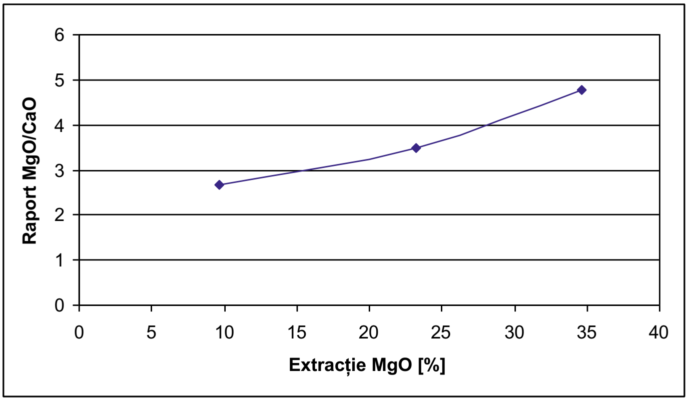


**Fig. 2** The evolution of the MgO/CaO ratio

This diagram confirms the fact that by increasing the magnesium concentration, the calcium concentration drops.

The technological process is powerfully influenced by dilution. Practically, magnesium oxide extraction becomes effective at 8:1–10:1 dilution. The influence of the dilution is determined firstly by the solubility of the magnesium bicarbonate. If in the case of the calcium bicarbonate things are very clear, as previously presented, in the case of magnesium, things are radically different. In the specialty literature there is no clear data indicating the solubility of the magnesium bicarbonate. According to some experimental data, there are clues that the solubility of this bicarbonate can exceed 15 g/l.

This data is also confirmed by the diagram below, presenting the dependence of the magnesium extraction according to dilution.

Stirring the pulp is also very important as far as the reaction speed of the carbon dioxide with the magnesium carbonate/hydroxide is concerned.

Because the process for the dissolution of the magnesium carbonate depends on the concentration of the carbon dioxide, it is obvious that it will also depend on the temperature, given that the solubility of this gas drops at the same time with the temperature drop.

## 6 Conclusions

The green sludge resulting from the manufacture of sodium dichromate is one of the most dangerous industrial wastes, due to the high content of leachable toxic substance.

In the present paper, the authors present preliminary tests aimed at the reduction of hexavalent chromium content and the extraction of magnesium from green slimes.

Water washing of this waste, despite the fact that it leads to a reduction in the concentration of leachable substances, is not an effective process for reducing the content of hexavalent chromium.

Extraction of magnesium from green sludge using carbon dioxide leaching has been found to be one of the most effective methods. The main advantage of using this process is the fact that the green sludge does not need to be calcined beforehand.

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# Thermal Hydrogen Production from Petroleum Reservoirs Using Steam Reforming and In-Situ Catalyst Application: A Technical and Economic Analysis

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**Abstract.** Fluid and solid hydrocarbon reservoirs are one of the most important fossil energy sources in the world. However, due to the high emission of $CO_2$ and other greenhouse gases, the application of fossil energy is not sustainable. Nevertheless, the infrastructure of the existing oil reservoirs should also be part of the ongoing utilization of the resources; petroleum reservoirs can be used to produce green hydrogen through wet combustion. This technique enables the production of hydrogen or hydrogen-containing synthesis gas from depleted petroleum reservoirs. This paper gives a brief review of the existing literature, relevant patents, and experiments on the topic. A new type of catalytic hydrogen production from depleting oil reservoir is introduced. Hydrogen production capability and the economic feasibility are evaluated using data from the literature and the relevant process parameters. Finally, the application limitations of the new process in oil reservoirs are introduced and explained; the physical and chemical parameters which affect the applicability are discussed.

**Keywords:** Hydrogen generation · Depleted oil reservoirs · Enhanced oil recovery · In-situ combustion · Wet combustion · Air injection · Fossil energy

## 1 Introduction

In situ combustion is one of the thermo-chemical enhanced oil recovery methods, which are particularly suitable for heavy oils and oil sands. The method is based on the injection of air or other oxidant, which then leads to heat of reaction in the reservoir through combustion thus enhancing the oil recovery by improving the flow properties [1].

Hydrogen production measurements gave promising results in in-situ combustion tests both at core [2, 3] and field scales [4]. These results prove that hydrogen is produced in thermal processes in principle [5], and in particular in the in-situ combustion [4]. The effect is technically quantified at reservoir scale with a significant extent of up to 30% hydrogen in the gas phase [4]. The numerical evidence of these effects can be found in


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this simulation study [6]. However, it should be admitted that to date, hydrogen formation has only been demonstrated in some cases rather as a byproduct of combustion, which was only measured for safety and tracer reasons.

Thermal hydrogen production is based on the principle of thermally induced reactions of hydrocarbons present in the reservoir. The thermal energy can be generated both as a side effect of steam flooding or in-situ combustion with high-pressure air injection. The methods for the recovery of hydrogen or synthesis gas from petroleum reservoirs are legally protected in the patents [7–10].

In principle, in chemical processes, the equilibrium reaction can be blocked by kinetic inhibition in certain temperature ranges. To eliminate this kinetic inhibition, catalysts can be used. In the case of in-situ combustion, the effectiveness of catalysts has already been proven [11]. The technology presented in this study differs from other methods in that the catalysts are to be introduced into the reservoir not for the combustion process, but for the formation of hydrogen from the decomposition reactions of the coke.

The technology in this paper formally represents a production variant of blue hydrogen. The climate impacts and the relevant emissions from the production of blue hydrogen and the resulting assessment with regard to the similarity with green hydrogen are dealt with in [12–15], among others. The topic is currently being intensively investigated but will not be elaborated further in this paper.

## 2 Investigation Methods

For the thermal process of hydrogen production, several potential well designs are possible. Important is to inject the air or the oxidizing agent from the deepest point and to allow the highest possible absorption of the resulting synthesis gases close to the sealing rock. Decisive factors include the highest possible permeability as well as formations free of faults and fractures. A heterogeneous permeability distribution would lead to unfavorable, uncontrolled fire courses, therefore homogeneous formations are advantageous. To enable the injection of a catalyst, an alternating injection of water and gas (i.e., air) must be carried out. The water is the carrier of the catalyst, which is mixed into the injected water in powdered form. The process thus resembles "wet combustion" due to the co-injection of water and gas.

The main reactions were defined by Murthy et al. for laboratory conditions [16] and by Hajdo et al. for the test field combustion [4]. The most important reaction with an impact on the hydrogen production is the coke gasification under steam conditions above 250 °C [4, 16]:

$$C + CO_2 \leftrightarrow 2CO \tag{1}$$

$$C + H_2O \leftrightarrow CO + H_2 \tag{2}$$

Murthy et al. estimated, that the following reaction leads to a water gas shift reaction inside of the coke zone, this could be observed in the really low amounts of CO produced in in-situ combustion field test [4]:

$$CO + H_2O \leftrightarrow H_2 + CO_2 \tag{3}$$

The methanation processes result in methane ($CH_4$) rather than $H_2$, methane is produced in field trials in similar quantities to hydrogen [4]. It is found that in core flooding experiments the methane production is more likely than the hydrogen production [2]:

$$CO + 3\,H_2 \leftrightarrow CH_4 + H_2O \tag{4}$$

The thermolysis or thermal cracking is the process, in which hydrogen is produced by thermal effects as discussed in Butron et al. [5]. However it should be mentioned that this accounts for maximum 10% of the produced hydrogen in total [4]:

$$C_nH_m + n/2\,O_2 \rightarrow n\,CO + m/2\,H_2 \tag{5}$$

Based on the above discussion and data presented, the requirements for a hydrogen-forming process in oil reservoirs can be formulated as follows:

- First, coke formation from crude oils must take place.
- The coke must react with water vapor without the influence of oxygen at a high-temperature range. This is to be justified by the fact that otherwise a combustion reaction of the coke or the formed hydrogen with the oxygen takes place.
- After the reaction, there must still be enough water vapor to produce a water gas shift reaction.
- The resulting hydrogen should migrate as quickly as possible to the production well(s) of the reservoir and be extracted there.

Figure 1 shows the process in seven steps, how hydrogen could be produced by combustion in petroleum reservoirs. Following steps can be helpful for the design of the process:

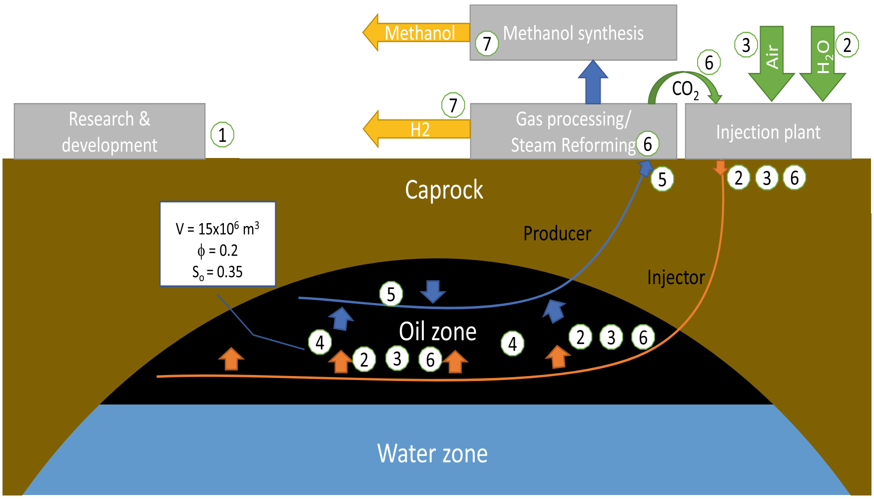


**Fig. 1** Wet combustion illustration process

1. Numerical simulation

In this step, a model of the reservoir can be built based on history matches and existing production data. To calculate an in-situ combustion process, drill core tests as well as fluid sampling are necessary. These samples are aimed at the combustion properties and the lumping of the petroleum compounds to evaluate in-situ combustion reaction schemes using pseudo components. Based on this data, the process of in-situ combustion can be simulated in various thermal simulators such as CMG (Computer Modeling Group) Stars, Eclipse 300 and so on. The simulation is challenging, since in addition to the representative simulation of the four phases (water, oil, gas, and coke), each individual (pseudo) component must be considered in the context of its migration, convection, and an individual consideration of the respective component phase, especially for various gases and lighter oils must be made. Furthermore, the PVT (Pressure-Volume-Temperature) characterization of the frequently occurring mixtures represents a particular challenge.

2. Injection of water with catalyst

Ideally, the injection of hot water or steam is already conducted before the hydrogen production measurements. In this case, the reservoir can be taken over directly preheated. This method would have the advantage that, the injection of a powdered catalyst for the subsequent provision of hydrogen can already be started and mixed with the hot water. This is therefore meaningful because the method can be used in several cycles and the catalyst can reduce the activation energy towards the chemical equilibrium and thereby specifically reducing the kinetic inhibition of several gas phase reactions.

3. Injection of the oxidation agent (normally air)

This is followed by the injection of air or the treated air (this is characterized by a higher oxygen content, but this is also more energy-intensive to generate) or another agent of oxidation. Other oxidizing agents or strong heating agents are only suitable in the case of industrial waste or material and or energy flows that can no longer be used economically. This oxidizing agent is then injected into the reservoir and leads to oxidation of the crude oil and the associated developments of coke, thermal energy, water vapor and other combustion products. The key point here is that air injection itself is **not** the hydrogen-forming process. Rather, the contact with the oxidation component is very unfavorable for the hydrogen since hydrogen will react with the oxidation agent and thus release the desired chemical energy as heat of the combustion reaction.

4. Shut-in time

As part of the next step, hydrogen formation is to be improved by shut-in-time. This is advantageous if the resulting thermal energy as well as the existing components are sufficient for further hydrogen formation in-situ. However, the shut-in time should not last so long that other components such as methane increase, or the water phase condenses out again. This is particularly relevant because a condensed water phase leads to a significantly lower relative permeability and a pressure loss in the transport of the remaining gas phase. Furthermore, the colder water phase is no longer suitable for the surface steam reforming operations.

5. Production phase

In the next step, the gas phase is to be produced. The production of the gas phase can be started after the shut-in time either with only a slight pressure reduction, to avoid too much liquid production or too high-pressure gradients. Furthermore, various publications and patents propose to selectively control hydrogen production through membranes in situ [10], but this is not a sound approach in the context of the high thermal loads of up to 800 °C in the reservoirs and the current costs of membrane technology.

6. Gas operation plant

In the gas operation plant the normal gas treatment is done isothermally. Normally, the gas is dried, but this would be disadvantageous here due to the need for water vapor. This is because of the steam reforming reactor, where the steam can be used for the reactions.

7. Hydrogen generation

After the production of the gas phase, hydrogen can be generated with the scheme shown in Fig. 2. For this purpose, it is also possible to operate steam reforming with conveyed carbon monoxide and other components. This would make it possible to use the extracted methane, which is in about the same desired deficiency as hydrogen, without causing $CO_2$ emissions. The $CO_2$ is then reinjected into the reservoir via a compression station. Obviously for $CO_2$ injection another well in already depleted areas of the field can be used. Also, the $CO_2$ can be reused in the context of a methanol-synthesis.

## 3 Technical Evaluation

The following approximations are based on the data from [3, 4, 6, 9, 10] and simulations and calculations in numerical and generical models. Assuming a reservoir, as in Fig. 1, with a porosity of 20% and a residual oil saturation of 0.35, a formation of approx. 500 $Nm^3$ hydrogen from 1 $m^3$ crude oil can be assumed for the most optimistic case based on the discussion above. For a reservoir with a total volume of approx. $15 \times 10^6$ $m^3$, a crude oil quantity of approx. $1.05 \times 10^6$ $m^3$ can thus be assumed; the quantity of hydrogen formed can reach up to $525 \times 10^6$ $Nm^3$. In the case of the application of in-situ combustion, the extraction efficiency is correspondingly high, since in most cases a pure gas phase with high temperature can be extracted. A hydrogen feed efficiency of approx. 50% should therefore be assumed here, i.e., a feed of approx. $262 \times 10^6$ $Nm^3$ hydrogen would be optimally achievable. For other processes, in particular non-gasifying processes, the transport efficiency is correspondingly lower because of critical gas saturation as well as relative permeability.

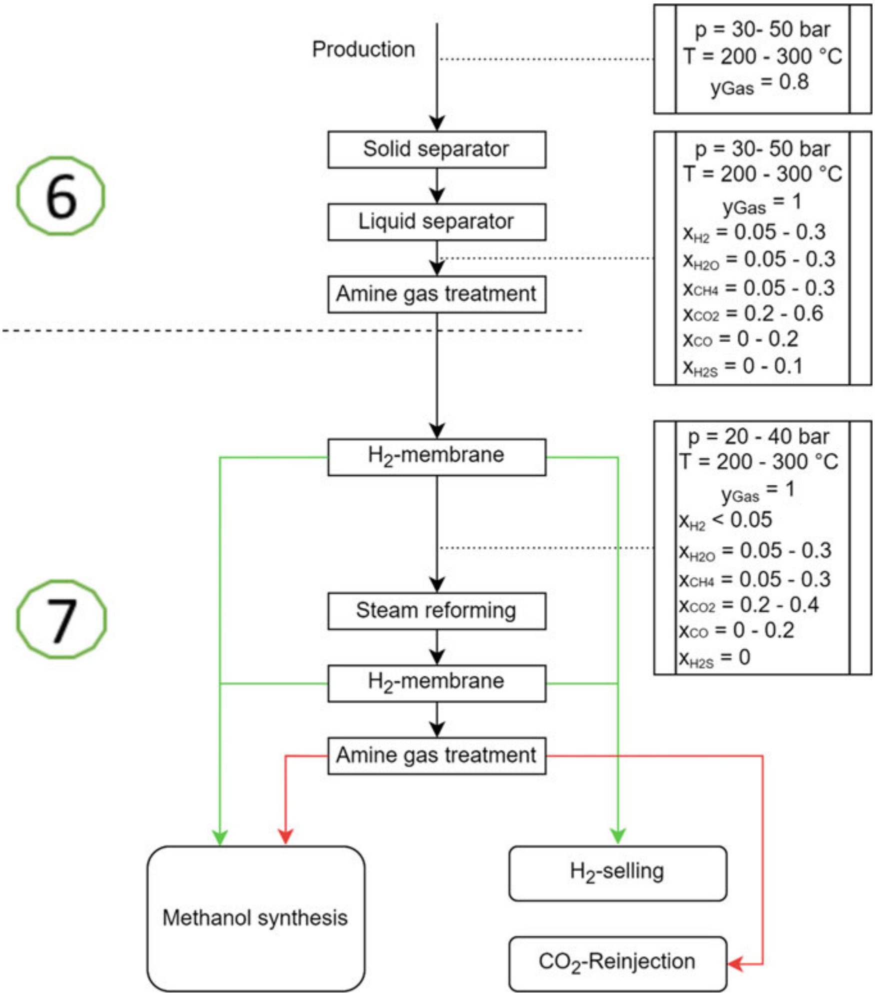


**Fig. 2** Gas operation plant (6) and hydrogen generation (7) processes

Assuming a molar weight of the oil ($m_{m,oil}$) of 200 g/mol and a stock tank density ($\rho_{oil}$) (at norm pressure and norm temperature) of 700 kg/m$^3$ (derived from [17–19]) the molar quantity of the oil stored in the reservoir ($n_{oil}$). can be calculated. This molar quantity of residual oil represents the potentially utilizable chemical energy inside the reservoir.

$$n_{oil} = V_{oil} * \rho_{oil} * 1000/m_{m,oil} \tag{6}$$

$$n_{oil} = 3.68 \times 10^9 \text{ mol} \tag{7}$$

Based on this calculation, the upper and lower necessary amount of oxygen can be determined using reference values such as 30–50 mol oxygen per mol of oil and thus the lower and upper amount of air to be injected. In this way, the total volume of air injection can be calculated as $V_1$, this volume being calculated always at the surface pressure $p_1 = 1$ bar and has the isontropic coefficient $\kappa = 1.4$. The compression necessaraly needs to exceed the reservoir pressure, which is the parameter the injection pressure $p_2$ is derived from. Using this, the necessary work for air compression $W_{V,Iso}$ can be determined on the basis of the necessary compression pressure via isentropic compression [20]:

$$W_{V,Iso} = \frac{p_1 V_1}{\kappa - 1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}} - 1\right] \tag{8}$$

The temperature reached by the compression $T_2(p_2)$ plays a significant role for the cooling capacity or further use of the energy. The temperature of the compressed medium is estimated by the inlet temperature of the compression $T_1$ and the pressure change in the compressor $\mathrm{p}_2$ [20]:

$$T_2(p_2) = T_1 \cdot \left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}} \tag{9}$$

For corrosion protection reasons, cooling must be conducted during compaction depending on the maximum injection temperature. However, this is not significant compared to the required compaction power. Assuming an overall electrical efficiency of 50%, this results in the electrical work per standard cubic meter of hydrogen, the compaction energy is the biggest variable cost factor.

Furthermore, the pumping and treatment of the gases must be conducted as part of the process, but this can be done with an addition of 100% on the expected energy quantity. In principle, gas compression is the most energy-intensive process; this is why the energy analysis is conducted on this basis.

## 4 Economic Evaluation

For the economic evaluation of the process, estimated values of the respective investment costs (CAPEX) and operating costs (OPEX) are listed in Table 1. The economic data are derived from existing studies [21–26] and adapted to the current situation. Unfortunately, there are not sufficient scientific publications on the economic parameters. Therefore, many values had to be adjusted to the necessary levels based on the intended project size.

It is assumed that the wells as well as the pipeline infrastructure are existing, so there are no more costs for these initially. The steam reforming reactor for the improvement of the hydrogen yield with extraction of steam, CO and $CH_4$ is not considered necessary for the process. The steam reforming reactor is considered here in the context of economic efficiency, since it is used for hydrogen production; the methanol synthesis is given for information only.

If the costs for the process are given cumulatively over the respective reservoir pressure or two possible injection pressures per maximum recoverable hydrogen (see Fig. 3) it becomes clear that the process is economically feasible only if gas treatment plants

**Table 1** Investment and operation cost

| CAPEX | | OPEX | |
|---|---|---|---|
| Compressors for air and $CO_2$ | 10 Mill. € | Electrical energy (compaction, surface facilities) | 0.1 €/kWh |
| Gas conditioning unit | 10 Mill. € | Personnel costs | 500 Tsd. €/J |
| Hydrogen separators | 5 Mill. € | Others (Maintenance, etc.) | 300 Tsd. €/J |
| Steam reforming reactor | 20 Mill. € | | |
| Methanol synthesis unit | 20 Mill. € | | |

already exist at the surface. The energy costs as well as ongoing costs (maintenance, etc.) are of little importance with the assumed useful life of 5 years, the fixed costs for further process engineering plants represent the "game changer" aspect. The assumed utilization range is based on the capacity of the reservoir; after 5 years, it is presumed to be no longer energy-rich enough even for this process.

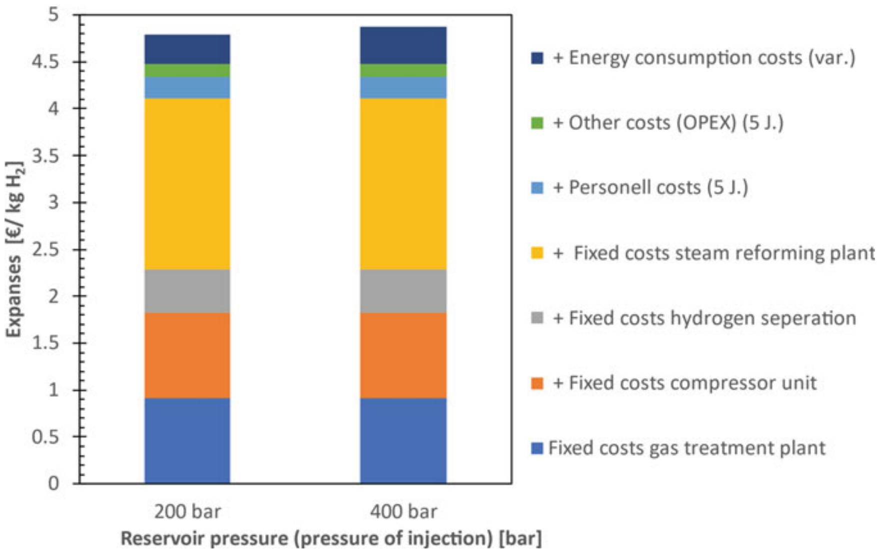


**Fig. 3** Investment, operation, and energy costs depending on reservoir pressure

## 5 Results

The results of the study are summarized in Table 2. Although the process itself has already been technically assessed at reservoir format, it still needs further research on sound (industrially meaningful) amounts of hydrogen production to be launched in energy market. Furthermore, natural gas reservoirs are not usable and the process is limited to reservoirs, which do not have a gas cap. With respect to reservoir properties, the process can be applied over a wide range, but reservoirs with faults and fractures are not preferred.

The advantages and drawbacks as well as risks of the process are summarized in Table 3. The advantages are the continued use of the chemical energy remained in the reservoir as well as the production of hydrogen using cost effective basic materials in an existing infrastructure. The biggest advantage of the process over other hydrogen extraction processes from petroleum reservoirs is clearly the already proven functionality. The disadvantages of the process are the potential cost for generators and conversion. Applicable technical and business models are still open for discussion, as they have high risks for field investments due to the inaccuracies they contain. These risks are complex and cannot be ignored.

## 6 Discussion

The method shown and proposed here is based on few observations of reservoir engineering phenomena as well as previously unpublished patent applications. The model calculation, in which different parameters such as yield and costs are defined, is based on strong simplifications that have been adapted to reality by the introduction of efficiency and safety factors. This publication is therefore only intended to present an current state of research and the challenges and possibilities of application.

The literature review conducted is based on a keyword and secondary source-based approach, which is used throughout the paper. Furthermore, references are also made to standard works and technically recognized publications. The patent search is primarily based on an evaluation of the relevant IPC (International Patent Classification) classes as well as related and dependent patents. Furthermore, numerical simulations and experiences are used.

## 7 Conclusions

Based on previous knowledge of thermal hydrogen formation in petroleum reservoirs within the framework of EOR (enhanced oil recovery) processes, a novel process using catalysts is demonstrated and presented in the publication. This process is based on a modified in-situ combustion, which is better geared to hydrogen production using specific catalysts. To evaluate the method for further research, a preliminary calculation is conducted on generic reservoirs. This calculation shows that the process can produce hydrogen economically in the reservoirs properly screened, if necessary technical plants exist in the fields selected and if the individual process steps are conducted appropriately.

It is necessary to investigate the method in more detail regarding its further applicability and to assess hydrogen via detector measurements in existing in-situ combustion operations. This would provide further information about the extraction of hydrogen or methane as a further reaction product.

**Table 2** Results of the study

| Parameter | Process evaluation | Explanation |
|---|---|---|
| Technical feasibility | ☑ | The technical feasibility was proven by [4] |
| Technology readiness level (TRL) | 3–5 | The technology is still in research based on laboratory tests and numerical simulations |
| Economic feasibility | ☑ | With existing infrastructure and knowledge, it can be economically feasible |
| *Reservoir types* | | |
| Petroleum reservoirs with primary gas cap | ☒ | The injected oxidation agent will otherwise directly migrate to the top of the reservoir and will not give the aimed result |
| Depleted petroleum reservoirs without gas cap | ☑ | |
| Bitumen reservoirs | ☑ | |
| Gas reservoirs | ? | Research is ongoing, but the energy in place is small |
| *Reservoir properties* | | |
| Depth (m) | 400–3000 | The depth is limited by the injection pressure |
| Faulted/fractured reservoirs | ☒ | In faulted and/or fractured reservoirs the burning is not controllable |
| Permeability (mD) | $> 50$ | Lower permeability for air injection |
| P (bar) | – | No limitation |
| T (°C) | 25–150 | Depending on reservoir temperature, the ignition is an autoignition or artificial |
| $S_O$ | $> 30\%$ | High oil saturation is necessary for a sufficient hydrogen yield |
| $S_W$ | $> 20\%$ | Water vapor is one of the most influencing factors, without water the process is not feasible |
| Carbonate matrix | ? | Effect of fractures and geochemical interactions needs to be investigated |
| Silicate matrix | ☑ | |

**Table 3** Pro, cons, and risks of the process

| Pros | Cons | Risks |
|---|---|---|
| • Utilization of remaining fuel(oil) as raw material<br>• Hydrogen and synthesis gas yield<br>• Air and water as favorable raw materials (environmental friendly)<br>• Existing infrastructure<br>• Reduced amortization costs<br>• Process feasibility proven! | • Compression effort<br>• Retrofitting expenses<br>• Gas separation/treatment needs<br>• Potential corrosion | • Irregular combustion (peak temperatures)<br>• Geomechanical damage<br>• Lack of further research<br>• Licensing and approval procedures (less experience)<br>• High temperature and material corrosion<br>• Side reactions |

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# Damage Tolerance Approach in the Concept of Quality Control Workflow of Passive CFRP Strengthening of Reinforced Concrete Structures

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**Abstract.** The use of Carbon Fiber Reinforced Polymer (CFRP) is one of the most popular methods of strengthening existing reinforced concrete structures nowadays. Many civil engineering structures (e.g. bridges) are strengthened in this way. Due to the reduction of costs and environmental impact through the decrease of construction waste and lower production of new construction materials (e.g. cement responsible for significant emission of $CO_2$), it is still economically and environmentally justified to strengthen existing structures rather than demolish old ones and build new ones. After many years of using CFRP strengthening techniques, more and more concerns are dictated by its lifetime durability, gradual deterioration as well as quality assessment of the bond between composite and concrete. Although available manufacturers' design guidelines for nondestructive evaluation strengthened reinforced concrete (RC) structures indicate possible inspection methods, in the practice, they are limited mainly to visual inspection and tap tests. So far, it is not clear if any acceptable level of defect size in FRP-bonded members exists; thus, if any air voids or delamination are detected, the laminate should be replaced with the new one. This process in the performed in situ technically simple tests relies mostly on the worker's perception. The lack of qualitative and quantitative guidelines for acceptable defect levels may lead to conservative conclusions and unnecessary economic and environmental loss. On the other hand, recent studies (Bialozor in An Investigation into the Influence of Bond Defects on the Behaviour of RC Beams Strengthened with CFRP, PhD dissertation, 2022, [1]; Zhou et al. in Compos. B 113:80–90 [2]) show that FRP strengthening systems are capable of remain a specific value of member capacity even when some defects exist in the bond. The main aim of this study is to highlight the issue of extending the lifetime of the passive CFRP strengthening system of RC structures by adopting the damage tolerance approach and chosen concept of quality assessment workflow by pushing existing strengthening to its limits, simultaneously maintaining structure in acceptable conditions in terms of safety or serviceability. Facing the fact of the common and massive use of FRP strengthening over the last three decades around the world, such a new approach in the area of quantitative diagnostic may be considered one of the basic tools for

The original version of the chapter has been revised: The authors' given names and family names have been updated. The correction to this chapter can be found at https://doi.org/10.1007/978-3-031-25840-4_66


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the extension of the life of structures and reducing the environmental impact of the construction sector.

**Keywords:** CFRP · Defects · Strengthening · Quality control

## 1 Introduction

After many years of using CFRP strengthening techniques, more and more concerns are dictated by its lifetime durability, gradual deterioration as well as quality assessment of the bond between composite and concrete. There are two basic scenarios when a current state of strengthening needs to be verified in the strengthening life-cycle. First of all, quality control is required to be done right after strengthening execution at the construction stage. It is mostly due to a risk of human-induced defects during application. Those defects can take various forms (see Fig. 1). Here, the defect can be understood as an accidental factor directly affecting the strengthening bond in such a manner that its current state cannot be considered desirable.

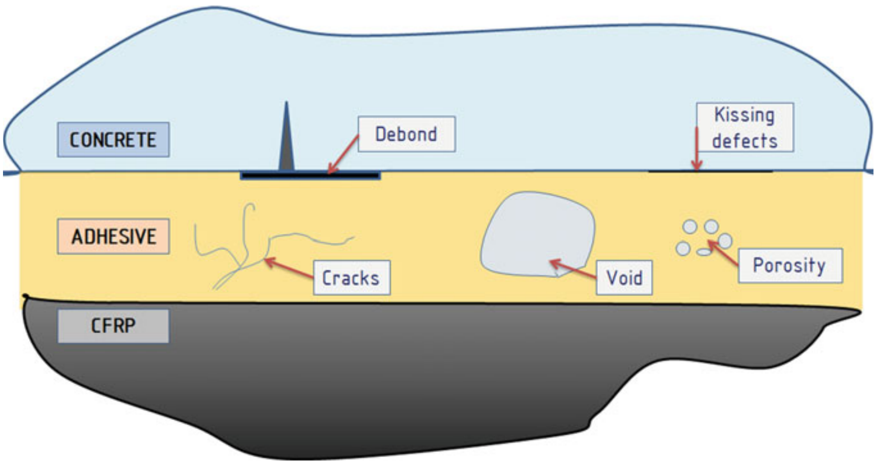


**Fig. 1** Types of defects in the CFRP—concrete interface [1]

Secondly, bond quality of strengthening bond interface is required during periodic inspections of existing structures to verify their state exposed to environmental conditions in long term. There are still no proper tools and workflow for in-situ quality assessment of CFRP—reinforced concrete connections during strengthening works. Moreover, there is a lack of qualitative and quantitative guidelines for acceptable defect levels. FIB bulletins [3] concerning *Externally Bonded FRP Reinforcement for RC Structures* present remedial measures for bonding defects relying on replacement FRP material or compatible resin injection if considerable voids are present. However, no quantitive limits have been included. To some extent, those are included in ACI *Guide for the Design* *and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures* [4] For wet layup systems, three levels of the delaminated area were distinguished: small—acceptable delaminations less than 1300 mm$^2$ and 5% of the total laminated area, simultaneously no more than 13,000 mm$^2$ per m$^2$; large—unacceptable delaminations greater than 16,000 mm$^2$ require FRP replacement and intermediate values that require repair in form of resin injection. Nevertheless, precured FRP systems are treated independently and have to be repaired and evaluated via professional authority. This document indicates also the need for the determination of the threshold for critical defects and their identification using non-destructive techniques.

Given the above, recent studies [1, 2] show that FRP strengthening systems are capable of remain a specific value of capacity even when some defects exist in the bond. As a consequence decisions made at this point may lead to conservative conclusions and may lead to unnecessary economic or environmental impact due to the application's totally new strengthening regarding the residual capacity of the existing one. The limits of the capacity of strengthened members with existing defects can be evaluated only at a specific point on the timeline because defects can change their size in-long-term perspective [5]. An assessment of the whole lifecycle of strengthening can be done for example by adopting a damage tolerance approach.

## 2 Damage Tolerance Approach

A measure of the impact of the defects on materials performance in related literature is defined via the term*:* defect criticality [6, 7]. This term is widely exploited in the case of composites control in aircraft design procedures where a damage tolerance approach was introduced [8]. Such an approach is related to the ability of the structural system to endure some level of existing damage without catastrophic failure. Until the defect is detected and repaired, it may reduce the residual strength of the structural component below the level of ultimate load, but is not allowed to drop below the design service load (see Fig. 2a).

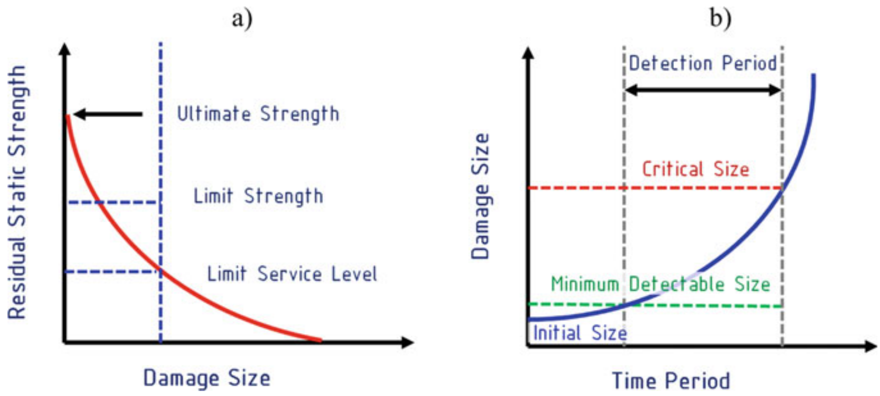


**Fig. 2** **a** Gradual lose of initial static strength due to damage size, **b** the timeline of damage size in damage tolerance approach in aircraft design [1]

The main aim of damage tolerance analysis is to prevent defect growth under any service loads that could drive a defect to a critical dangerous size (see Fig. 2b).

This objective can be achieved in a few co-related steps: determination of initial damage, determination of critical damage state and recognition of damage growth that let to set proper inspection frequency. When defect criticality of strengthened members was investigated even though in a limited range, recognition of damage growth still is rather unknown. Determination of initial damage is a widely exploited subject of non-destructive evaluation techniques.

## 3 Workflow Concept

Many studies are dedicated to the constant development of existing NDE techniques in a more and more automated manner. This creates new opportunities for a more convenient way to go through the decision-making process during inspections. An investigation into the structural performance of strengthened structural members with bond defects is also a part of a wider concept of the automated diagnostic workflow. An attempt to create such a workflow is a subject of research at Silesian University Technology [9, 10]. The main goal of this research is to develop a tool for diagnostic of strengthened engineering structures even in hardly accessible places, that gives information on the structural performance of the structure as feedback (see Fig. 3).

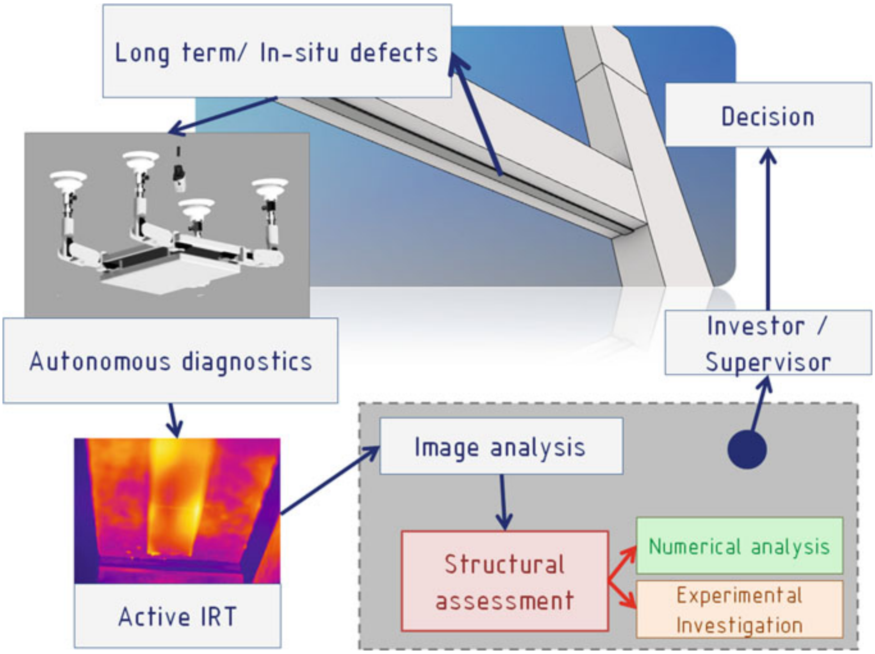


**Fig. 3** General workflow concept [1]

The creation of effective workflow is a multilevel challenge where a wide range of engineering branches need to be involved. There are many steps to develop: robotics, data acquisition, reliable defects detection method, data conversion, as well as structural analysis assessment that answers if the defect level is acceptable.

The team of the Silesian University of Technology has developed a proprietary method of diagnostics of structural reinforcements using its own technique based on thermography. The diagnostic module is transported to the level of strengthening, often on an elevated bridge structure, using a robotic platform (drone or wheeled robot). An automated diagnostic device, equipped with an appropriate fault mapping procedure, collects and processes data by entering them into a digital model of the structure and BIM (Building Information Model) space.

On the basis of these data collected in situ, the relationship between the degree of bonding of the reinforcing FRP laminate with the concrete surface is analyzed, taking into account the specificity of the static work of the structure and the work of the glued reinforcement, with particular emphasis on the defects of the anchorage zone and zones with the constant static moment.

On the basis of extensive numerical tests, the influence of detachments on the load-bearing capacity of the structure was determined.

## 4 Conclusions

In this study, the damage tolerance approach to assessing existing CFRP strengthened RC beams and the automated quality control workflow concept were presented. Adopting a prepared damage tolerance approach to FRP strengthening systems, on the one hand, let extend the strengthening lifetime and, on the other hand, opens new opportunities to study in this field. It is required to know how structural members behave when the defect is recognized under different load scenarios either in the short and long term, what is the speed rate of defect growth and consequence how to choose proper inspection intervals. Understanding these dependencies and automating and integrating diagnostic and technical assessment procedures in one digital space is a new approach to assessing the safety of a building structure and a new tool to extend the life time of a FRP-strengthened structure. It is also an important step in the fight to reduce the environmental impact of the construction industry in the context of reducing construction debris and the need to produce new materials for new construction.

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# Effective Biomass Delignification with Deep Eutectic Solvents

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**Abstract.** Efficient valorization of biomass is one of the most important aspects of circular economy. Obtaining valuable products from renewable materials, using ecological methods, is a key factor in natural environment protection. In many cases the first step of biomass valorization is removal of lignin from plant material. This process can significantly improve further transformations to final products, such as organic acids or monosaccharides. Deep eutectic solvents (DESs) are green chemicals, which have the ability to extract lignin from lignocellulosic material with high efficiency. In this paper we present an efficient method for lignin removal from plant material, using ecological deep eutectic solvents, based on choline chloride. We used waste biomass such as grass, rye straw and walnut shells. The best results were achieved in processes with DESs containing organic acids, such as lactic acid and malonic acid. Also, the impact of temperature of a process was examined—the largest amounts of extracted lignin were gained by delignification at 100 °C. The main goal of lignin removal from plant material is enhancing further transformation of biomass, e.g. enzymatic hydrolysis, in order to increase the yield of valuable products. We carried out the enzymatic hydrolysis of pretreated plant material with cellulase from *Aspergillus niger*. The effectiveness of biological transformations was improved, if delignification of biomass was previously performed. This effect was especially visible in case of soft material processing.

**Keywords:** Plant biomass · Biomass valorization · Deep eutectic solvents · Delignification · Enzymatic hydrolysis

## 1 Introduction

Plant biomass consists of three main components, which is cellulose, hemicelluloses and lignin. Cellulose is the most valuable raw material for further transformations to glucose and many other valuable compounds belonging to *Fine Chemicals*. The main problem in efficient biomass treatment is high lignin content in most plants. Lignin not


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only limits the access of enzyme to cellulose, but also can interact with the enzyme and inactivate it (deactivating effect of phenolic compounds), which decreases the efficiency of biomass transformations [1–3]. Because of that, lignin removal is necessary to achieve better results. Deep eutectic solvents (DESs) are a new type of ionic liquids, which have the ability to dissolve lignin, without any side effects on other parts of lignocellulose. Additionally, DESs are claimed to be much more ecological, than traditional solvents. They are obtained from natural components (such as choline chloride, betaine, lactic acid, citric acid), have lower toxicity and vapor pressure, and are biodegradable [4–6]. The next step of biomass valorization is its transformation to valuable products. It can be done with various methods, such as application of ionic liquids, acid and alkaline solutions or with biological agents. The last alternative is also compatible with green chemistry rules. By combining DESs pretreatment with enzymatic processing of plant waste, it is possible to develop ecological, environment-neutral system for obtaining chemical components, such as glucose, which has wide range of applications in many fields of industry.

The objective of this work was to evaluate the effectivity of different DESs, based on choline chloride, as lignin extraction media from plant biomass. Also, the role of delignification in further enzymatic treatment with cellulase was presented.

## 2 Materials and Methods

### 2.1 Materials

Grass (GR), rye straw (RS) and walnut shells (WS) were collected in Poland, air-dried and milled to obtain particles with size range 0.6–0.2 mm. Choline chloride (99%) was obtained from Acros Organics, lactic acid (85%) was from SigmaAldrich, malonic acid (99%) was form Apollo Scientific and citric acid (99%), ethylene glycol (pure), glycerin (pure), ethanol (99%) and acetone (pure) were purchased from Avantor Performance Materials Poland.

### 2.2 DESs Synthesis

DESs were prepared according to method described by Kandanelli et al. [7]. The abbreviations of each solvent with molar ratio of components are presented in Table 1. Choline chloride and hydrogen bond donor (lactic acid, citric acid, malonic acid, glycerin or ethylene glycol) were mixed in 80 °C with vigorous stirring, until transparent, stable at room temperature liquid was obtained. The water present in solvent was evaporated by rotary evaporator. DESs were stored at room temperature.

### 2.3 Biomass Delignification

2.50 g of biomass (grass GR, rye straw RS and walnut shells WS) was mixed with 50 ml of DES in a solid–liquid ratio 1:20 (w/v) in round bottom flask. Reactions were performed at 60, 80 or 100 °C in oil bath, with constant stirring (500 rpm), for 3 h. Each experiment was performed in triplicate. After delignification, samples were taken for

**Table 1** DESs applied in this work

| Hydrogen bond acceptor | Hydrogen bond donor | Molar ratio | Abbreviation |
|---|---|---|---|
| Choline chloride | Lactic acid | 1:2 | ChCl:Lac |
| | Citric acid | 1:1 | ChCl:Cit |
| | Malonic acid | 1:2 | ChCl:Mal |
| | Ethylene glycol | 1:2 | ChCl:Et |
| | Glycerol | 1:2 | ChCl:Gly |

spectrophotometric analysis, at 420 nm, with DES as a standard solution. Concentration of lignin was calculated based on calibration curves, prepared separately for each type of biomass. Yield of extracted lignin was calculated as follows:

$$Lignin\,extraction\,yield\ (\%) = \frac{Mass\ of\ extracted\ lignin}{Mass\ of\ lignin\ in\ raw\ biomass} * 100 \tag{1}$$

Preparing the material for enzymatic hydrolysis was prepared according to Chen et al. [8]. After delignification, 50 ml of mixture acetone:water (1:1 v/v) was added to reaction vessel, to lower the viscosity of solution and facilitate filtration. Undissolved biomass was separated from solution by filtration. Acetone and water were evaporated and DES with dissolved lignin was obtained. 100 ml of mixture ethanol:water (1:9 v/v) was added to DES solution and left overnight in order to precipitate extracted lignin. Then, lignin was separated from solution by filtration. Ethanol and water were evaporated from DES, which allowed to recycle it to another delignification process.

## 2.4 Enzymatic Hydrolysis of Pretreated Biomass

Pretreated biomass was subjected to hydrolysis with cellulase from *Aspergillus niger* in citrate buffer (50 mM, pH = 5.0), solid to liquid ratio was 1:40 (w/v). 0.8 U/mg of cellulase was added to the reaction mixture. Reactions were performed at 50 °C, in incubator (Benchtop Shaking Incubator 222DS) with stirring (150 rpm), for 24 h. After hydrolysis, samples were taken for HPLC analysis. Glucose concentration was determined from the calibration curve, and the yield was calculated from the equation:

$$Glucose\ yield\ (\mathrm{mg/g}) = \frac{Mass\ of\ glucose\ in\ sample * Volume\ of\ a\ sample}{Mass\ of\ biomass}$$

## 2.5 Analytical Methods

The yield of extracted lignin was measured by spectrophotometric method, according to Skulcova et al. [9], with slight modification. Measurements were carried out on UV–VIS spectrophotometer (Jasco V-650) at 420 nm.

Glucose concentration was measured by HPLC method. The apparatus (Agilent 1200 HPLC system) was equipped with Phenomenex ROA-Organic acid H+ column and refractive index detector. 5 mM sulfuric acid was used as an eluent. Analysis was carried out at 60 °C, with flow rate of 0.5 ml/min.

# 3 Results and Discussion

## 3.1 The Effect of DESs Type and Temperature of a Process on Delignification Efficiency

In this study, different DESs were investigated to choose the best one for biomass delignification, which would ensure the highest yields of extracted lignin. The temperature of a process also had major impact on the results. Figures 1, 2, 3 present the comparison of results, shown as delignification degree of three types of biomass (grass GR, rye straw RS and walnut shells WS) with different DESs at 60, 80 and 100 °C.

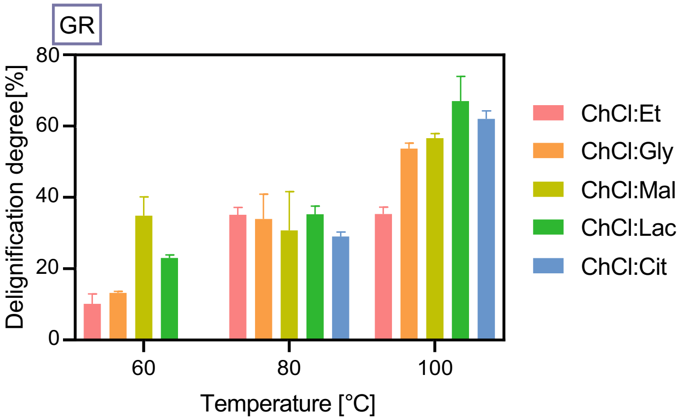


**Fig. 1** Delignification degree of grass (GR) with DESs, at different temperatures

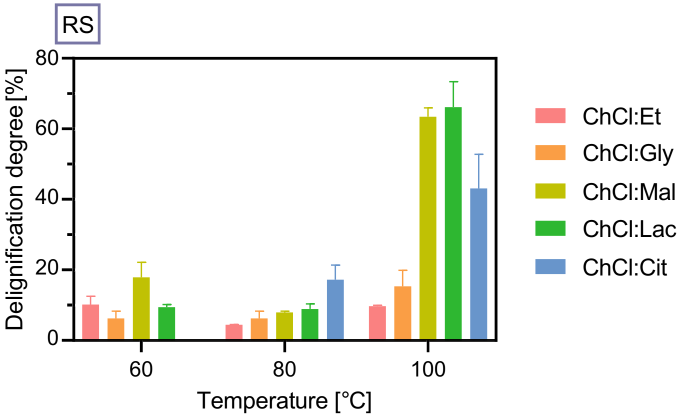


**Fig. 2** Delignification degree of rye straw (RS) with DESs, at different temperatures

As can be seen for all types of plant material, it was possible to obtain higher lignin yields, if DES was composed of organic acids: lactic acid or malonic acid, compared to

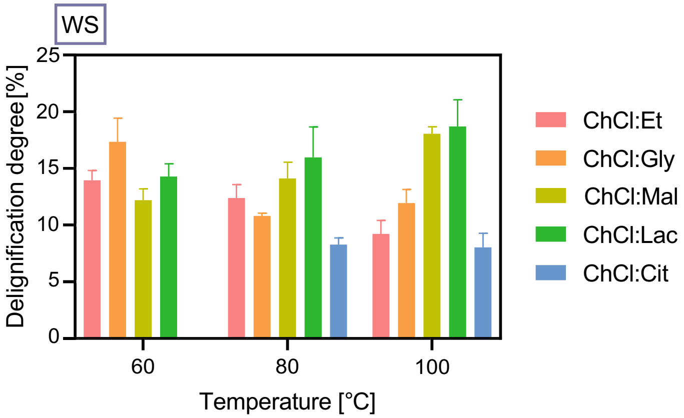


**Fig. 3** Delignification degree of walnut shells (WS) with DESs, at different temperatures

DES with polyalcohols. It might be connected with the possible mechanism of delignification—in acidic conditions, ether bonds, present in lignin structure, tend to break more easily [10]. The maximum GR delignification degree was 67.02 ± 6.96%, for RS 66.19 ± 7.20% and for WS 18.70 ± 2.35%. These numbers could be achieved in process at 100 °C, with DES ChCl:Lac. In the case of solvent with citric acid, which also provides acidic environment, the delignification degree was lower. It can result from the high viscosity of this DES. Because of that it was impossible to carry out the experiments at temperatures below 80 °C for ChCl:Cit.

High viscosity is the main drawback of DESs. Because of that, biomass delignification should be performed at higher temperatures, which enhances mass transport and increases the yield of extracted lignin [11]. Additionally, at higher temperatures, lignin can be degraded to phenolic monomers, which results in faster polymer removal [12]. As it was mentioned before, for GR and RS, the highest delignification degrees could be achieved at 100 °C. This trend is not so obvious in the case of WS pretreatment—the results are quite random and not directly connected to the temperature of a process. The possible reason for that is the type of material—walnut shells are hard type of biomass, which is the most difficult to process. It can be seen that the maximum delignification degree is much lower, than for other types of biomass.

We have chosen DES composed of choline chloride and lactic acid for further experiments.

### 3.2 Enzymatic Hydrolysis of Pretreated Biomass

In order to examine the effect of biomass delignification on further transformations, we carried out the enzymatic hydrolysis of plant material with cellulase from *A. niger*. Since the best delignification was obtained in the process with DES ChCl:Lac, at 100 °C, we chose these conditions to pretreat the biomass before enzymatic transformation. Figure 4 presents the comparison of the amount of glucose obtained in enzymatic transformation of biomass without pretreatment and after pretreatment with ChCl:Lac.

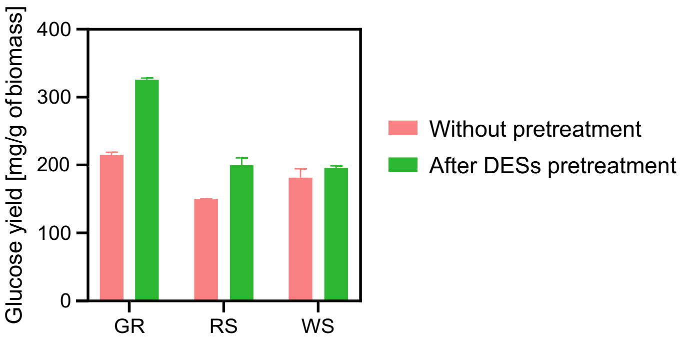


**Fig. 4** The comparison between glucose yields, obtained by enzymatic hydrolysis of biomass (grass GR, rye straw RS and walnut shells WS) without pretreatment and after delignification with DES ChCl:Lac

Results presented in Fig. 4 show, that for soft types of plant material, delignification had positive effect on enzymatic hydrolysis efficiency. It was possible to increase the amount of glucose, especially in case of GR processing. The yield of a product increased from 215.10 ± 3.61 mg/g to 325.89 ± 2.35 mg/g. In enzymatic transformation of RS, it was possible to get higher glucose amounts after biomass pretreatment, but the rise was not so significant, as in GR processing. In the case of WS, delignification with DES did not significantly improve the further efficiency of transformation to glucose. It is connected with the hardness of raw material [13–15]. It is worth mentioning, that during delignification of WS, the amount of removed lignin was not so high, compared to the other types of biomass.

## 4 Conclusion

Application of deep eutectic solvents in biomass delignification is an ecological and efficient method for plant material pretreatment. It was possible to achieve high extracted lignin yields, especially for softer biomass processing. The best results were obtained in the presence of DESs consisted of choline chloride and carboxylic acids The hardness of material is still a major obstacle to overcome during plant waste treatment. The content of lignin in plant material has crucial effect on the outcome of further biomass processing. Delignification is an effective method for biomass valorization, to produce higher amounts of valuable chemicals.

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# An Insulation Panel Made from Local Plant-Based Lightweight Concrete

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**Abstract.** Reduction of $CO_2$ emissions, energy consumption and waste production can be achieved by favorizing the use of building materials with low energy footprint [1]. This research proposes the use of local agri-food wastes, invasive plants and lime or clay-based binders in the preparation of lightweight composites as construction materials. More specifically, the influence of the type and quantity of local plant-based aggregates and local binders on the thermal properties was examined. The final aim is to select the most suitable design of aggregate/binder for the formulation of a Cretan lightweight concrete block ready to be applied in traditional and modern buildings. It has been demonstrated that the most suitable insulation block consists of arundo donax (giant reed) as aggregates and a local putty calcitic lime with natural pozzolan in a binder/aggregate ratio ranging from 1/4 to 1/3. These samples exhibit a thermal conductivity comparable to similar products on the market (0.07 W/m K $\pm$ 0.002).

**Keywords:** Agri-food wastes · Insulation panel · Putty calcitic lime

## 1 Introduction

Building sector according to the *2018 Global status Report—Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector* [2] represents 38% of total energy-related $CO_2$ emissions and 35% of final energy consumption. Moreover, construction and demolition waste accounts for more than a third of all waste generated in the EU [3, 4]. Furthermore, the production and transport of so-called conventional construction materials (concrete, cement, fired bricks, polyurethane insulation, etc.) requires a great deal of energy consumption.

Strategies to reduce the energy consumed in the manufacture of construction materials include the use of recyclable materials and especially bio-based materials from animals and plants. Bio-source materials is an effective solution to reducing carbon footprint due to their ability to sequester $CO_2$ [1].

Plant-based lightweight concrete began to develop in Europe at the end of the 90s. It is mainly composed of vegetable chunks and a mineral binder and has the advantage of being very light with thermal performance much superior to conventional concrete.


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Thus, when it is used in masonry, it is not necessary to add internal or external insulation on the wall. In the restoration sector, the mechanical and hygrometric behavior of the materials used for the elaboration of the plant-based lightweight concrete make it an appropriate solution for the thermal restoration of traditional and historic buildings. However, this material cannot be used as load-bearing material because of its law resistance to compression. Plant-based light-weight concrete is recyclable, requires low energy for its transformation into building material and constitutes a completely healthy material.

Nowadays, the most developed plant-based lightweight concrete in Europe is the Lime-Hemp Concrete (LHC) [5, 6], where application guidelines have been already established in some countries [7]. The use of LHC is very wide stemming from filling of form work on site, in projection on vertical wall or in prefabricated block. The LHC prefabricated blocks are composed of hemp shives (grinded woody part of the stem) and a lime-based binder. The binder of the Belgium lime-hemp block Iso-hemp [8] is a mix of aerial and hydraulic lime, the binder of the French lime-hemp block Chanvribloc [9] is composed of hydraulic lime. Both products have a density between 300 and 350 kg/m$^3$, a thermal conductivity around 0.07 W/m K and a compressive strength $< 0.5$ MPa [8, 9]. Many studies have also indicated the use of invasive plants and agri-food waste as vegetal aggregates [10–12].

The vernacular architecture is characterized by locally sourced building materials shaped with the know-how of the craftsmen [1], thus avoiding the energy consumed transport and similar appearance in the architectural style. In Crete, hemp production is still almost non-existent, despite the 2018 law authorizing its cultivation. This research is based on the study of lightweight concrete blocks made with local invasive plants or agri-food wastes aiming to replace hemp. The hydraulic lime is imported; therefore, in this study lime with pozzolanic admixture, as well as either clay soil or gypsum locally produced were also tested as binding materials [13]. Afterwards, the influence of the type and quantity of local plant-based aggregates and binders on the thermal properties of the samples were studied.

## 2 Materials and Methods

### 2.1 Binders and Aggregates

The choice of binder was motivated by the need to produce building materials with low $CO_2$ emissions, low energy consumption and utilizing waste materials. The first criterion was therefore to replace the cement binder with a less energy-intensive binder inspired by traditional local construction techniques. The second criterion was the use of local materials to avoid increase in the carbon footprint of the final product by transport. Quality clay is available in large quantities on the island of Crete as evidenced by the long know-how of the island in the field of ceramics [14]. The limestone formations of the island have long been known to produce a local aerial lime used in the preparation of mortars [15, 16]. This tradition is still alive, and some companies still produce putty lime of class CL90-SPL (Calcitic Lime–Slaked Putty lime) according to European standard EN 459-1. The putty lime is produced by the local company ASBEK (Fones, Apokorona, Crete). Clay and aerial putty lime were, therefore, selected as basic binding materials.

The red clay is coming from the village of Kefala (Apokorona, Crete) and has been selected for its high amount of clay. The rather slow process of lime carbonation can be accelerated by adding natural of artificial pozzolans, which allow the setting under hydrated conditions, decrease the setting time, and can improve mechanical properties and durability of lime mortars [17, 18]. According to previous research [18], the Greek natural pozzolan from the island of Milos, the "Pumice Pozzolan 0–75 μm" of the company Prolat, with a pozzolanic activity index according to ASTM C618 > 99% after 28 days [19], seems to be of the most effective pozzolans in the Greek market, therefore, it has been selected for the improvement of the binder in the mix design of this research. Each design with pozzolanic admixture complies with the ratio Lime/Pozzolans equal to 1/0.6 that have been successfully used in previous research [18]. Bibliographic research [20, 21], has led us to integrate gypsum into binder recipes. This choice is also motivated by the fact that the gypsum is produced on the island (Altsi, Sitia).

The island of Crete has a climate classified as dry sub-humid (Csa) according to Köppen climate classification. According to the European research programme Horizon 2020—SoilCare [22], 40% of the land is cultivated. In the area of Chania, 90% of cultivated land is cultivated with trees, 70% of which are olive trees, grapes and vegetables reach 5% and the 5% left are dedicated to other crops. If we want to use agriculture wastes for construction in Crete, it seems important to study the possibilities of the waste from the cultivation of the olive tree since it is, by far, the most widespread crop. Every year in winter, with the harvest of olives for olive oil production, a large quantity of olive leaves is removed from the harvest and made available (by mechanical sorting) to the shepherds for their animals. The quantities are such that a part could be used for making plant-based construction materials. After collecting olive leaves from an olive oil production site in the region, the leaves were washed twice with clean water.

The use of poaceous agri-food waste, the subject of study in numerous research projects for alternative construction materials in Europe and elsewhere [23, 24], does not seem to be possible in Crete due to the very low number of crops (the few wastes are used for animal husbandry). Another option for the use of poaceous waste as aggregates for this research is the invasive wild plants. A significant amount of wild invasive Arundo Donax (Giant reed) is found in Crete [25]. Arundo Donax is an herbaceous plant of the Poaceae family, its growth is very quick (until 5 cm a day in spring) and that is why it is considered important source of vegetable material for biomass and cellulose production [26]. Its rod of about 2 or 3 cm in diameter has nodes every 20 cm. It becomes very hard after drying and it is therefore preferable to grind it freshly cut to obtain chips less than 1 cm usable in plant-based concrete. For the grinding, a woodchipper Damac was used. After crushing, the chips go through a drying phase in a dry and ventilated place for two weeks so that they lose their light green color to their yellow color. This is to prevent rotting and the proliferation of molds. A final sieving phase is necessary to remove the larger pieces. For this research, a 1 cm mesh sieve was used.

The European Regulation 1967/2006 recognizes the importance of Posidonia Oceanica seagrass meadows for the ecosystem of Mediterranean Sea and more particularly on the Cretan coast [27]; therefore, no case of considering their use by extracting them from their natural environment exists. However, leaves of dead Posidonia Oceanica are accumulated on the beaches creating favorable areas for the cultivation of coastal plants and barrier to sea-shore erosion. In the touristic areas a removal of those algae is a common practice due to aesthetical reasons. An option could be to harvest the upper part of the dead algae in the winter taking care to not alter the ecological properties of the heap of algae. The algae were then rinsed 4 times in clear water and dried in the oven for 24 h at 70 °C.

In Fig. 1 the three types of local plant-based aggregates selected for the research are shown.

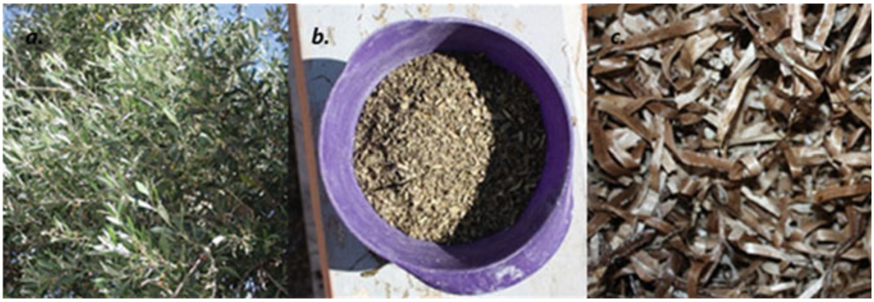


**Fig. 1** The plant-based aggregates of the project: **a** Olive Leaves. **b** Grinded stem of Arundo Donax. **c** Posidonia Oceanica

The mix design of the lightweight concrete samples consists of mixing the binder and water first and then adding the aggregates (see Table 1). All the ingredients are measured by volume, then mixed in an accurate way before placing into the molds (90 × 90 × 30 mm) to avoid the presence of voids (especially in the corners) and pressed, accordingly. A constant density between samples of same aggregates and binders is tried to be achieved for comparison purposes. The casted samples are kept for 24 h in the mold, then demolded and placed on the slice for drying in ventilated and dry conditions for 28 days (see Fig. 2).

## 2.2 Experimental Methods

A first selection of the samples to be further evaluated was carried out according to three major criteria:

- Macroscopic: The swelling or deformation of the sample.
- Cohesion: The cohesion of the sample. In each sample taken in hand a slight bending force was applied for 3 s. If the sample disintegrates, it is not selected for further research (see Fig. 3). The test is inspired by the biscuit test, used for the in-field evaluation and selection of earthen material [18].
- Density: the density of each sample was determined based on their mass and volume. For the plant-based lightweight concrete, different values of density are found in the literature ranging from 256 to 782 kg/m$^3$ [28]. Based on these results, for our study, if the density exceeds 800 kg/m$^3$, the sample is automatically eliminated.

**Table 1** Mix design for the samples tested

| Sample | Putty lime (L) (%v/v) | Natural pozzolans (P) (%v/v) | Gypsum (G) (%v/v) | Clay (C) (%v/v) | Density (kg/m$^3$) | Thermal conductivity λ (W/m K) |
|---|---|---|---|---|---|---|
| AD4-LP1 | 10 | 6 | 0 | 0 | 632 | 0.077 (± 0.0006) |
| AD3-LP2 | 12.5 | 7.5 | 0 | 0 | 794 | 0.109 (± 0.0007) |
| AD3-LP3 | 12.5 | 7.5 | 0 | 0 | 548 | 0.071 (± 0.0005) |
| AD4-LP4 | 10 | 6 | 0 | 0 | 669 | 0.100 (± 0.0005) |
| AD3-LP5 | 15 | 9 | 0 | 0 | 634 | 0.078 (± 0.0005) |
| AD3-LP6 | 12.5 | 7.5 | 0 | 0 | 562 | 0.072 (± 0.0005) |
| AD4-LP7 | 10 | 6 | 0 | 0 | 463 | 0.082 (± 0.0005) |
| AD4-C1 | 0 | 0 | 0 | 10 | 531 | 0.083 (± 0.0009) |
| AD4-G2 | 10 | 0 | 6 | 0 | 537 | 0.079 (± 0.0006) |
| AD4-G5 | 12 | 0 | 4 | 0 | 521 | 0.085 (± 0.0007) |
| AD4-G8 | 13 | 0 | 3 | 0 | 553 | 0.084 (± 0.0008) |
| AD4-G9 | 10 | 3 | 3 | 0 | 634 | 0.100 (± 0.0016) |
| PO3-LP | 15 | 9 | 0 | 0 | 547 | 0.096 (± 0.0010) |
| PO3-LP | 12.5 | 7.5 | 0 | 0 | 379 | 0.086 (± 0.0006) |
| PO4-C1 | 0 | 0 | 0 | 10 | 584 | 0.079 (± 0.0005) |
| OL3-LP | 15 | 9 | 0 | 0 | 632 | 0.077 (± 0.0006) |

The samples that were resisted the slide-bending force and the above-mentioned tests were further subjected to thermal conductivity measurements (λ: W/m K). This is an important measurement since it is directly related to the thermal performance of buildings and the performance of an insulating panel [29]. Thermal conductivity is the

**Fig. 2** Images of the samples AD3-LP2, AD3-LP4 and AD4-G8 dried in ventilated and dry conditions

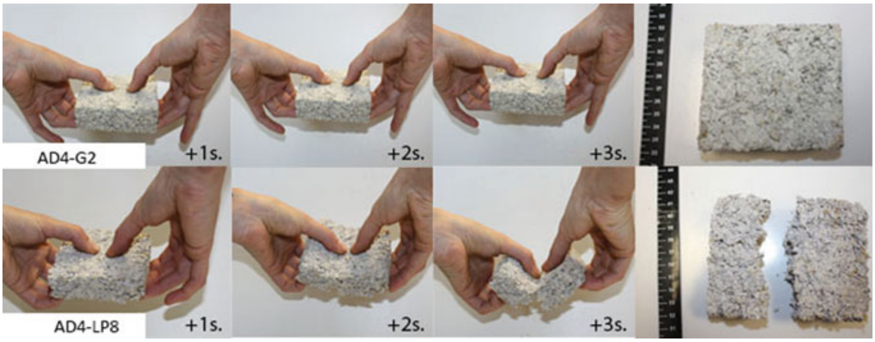


**Fig. 3** Test of cohesion for the sample selection

amount of heat that can be transferred into a material in each time. The lower the lambda, the more resistant the material to thermal conduction transfer.

Measurements of thermal conductivity were made with Hot Disk Instrument TPS 1500, thermal conductivity meter for testing building materials and insulation materials (Laboratory of Energy Management in the Built Environment, School of Chemical and Environmental Engineering, Technical University of Crete, Chania, Greece). The Hot Disk uses the Transient Plane Source method: a Kapton-insulated sensor which emits heat is placed between two plates of the same sample (90 × 90 × 30 mm). The measurements are based on the heat exchange over time. The results were analyzed with Fine Tune Analysis which seems to give more consistent results for insulation materials [30, 31]. The day before the measurement, samples were placed in the oven for 24 h at 50 °C.

## 3 Results and Discussion

### 3.1 Binders and Aggregates

Table 1 reports the mix design, density and thermal conductivity measurements of the most appropriate formulations that were selected for further evaluation.

In terms of workability and susceptibility to swelling and lack of cohesion, the Arundo Donax aggregate with lime-based binders (with or without gypsum), as well as the clay soil as binder seem to be more suitable for the implementation of lightweight concrete blocks.

Samples with same type of binder, such as lime with natural pozzolan, along with same aggregates were varied as for the percentage of aggregates included in the casting process. This parameter influences the density of the block and the greater the amount of aggregate the lower the density. Table 1 shows a clear correlation between density and thermal conductivity. By comparing samples with similar binder and aggregate, it can be concluded that the lower the density, the higher the thermal conductivity. We also note that in samples with a density below 600 kg/m$^3$, a thermal conductivity close to the control market products Chanvribloc and Iso-hemp ($\lambda = 0.07$ W/m K) was achieved, even though those products showed density of 300–350 kg/m$^3$. By comparing respective blocks differing in the type of aggregates, we may conclude that no significant differences in thermal conductivity were induced by using AD, PO or OL aggregates. Therefore, the type of aggregate seems to have a lower influence on thermal conductivity than the ratio binder/aggregate. Despite a lower density, samples with a clay-based binder have a higher conductivity than samples with a binder based on air lime and natural pozzolanic admixture. Adding gypsum to the binder does not significantly change the density but appears to increase the thermal conductivity of the sample (Table 1).

## 4 Conclusions

The work reported in this paper aimed to study the influence of the type and quantity of local plant-based aggregates and local binders on the thermal properties of the samples. First, it has been demonstrated that Arundo Donax (Giant reed) seems to be the most suitable aggregate between the three originally selected to produce local plant-based lightweight concrete.

Concerning parameters that influence the thermal conductivity of the samples it has been demonstrated that:

- Density has an important influence on thermal conductivity.
- Type of aggregate does not significantly influence the thermal conductivity.
- The addition of gypsum in the binder based on aerial lime gives poorer results in terms of thermal conductivity.
- Clay-based binder gives poorer results that lime-based binder in terms of thermal conductivity.

The final goal was to select the most suitable combination aggregates/binder for applications in formulation of a local plant-based lightweight concrete block to study its mechanical and hydric behavior in future research. According to the results of the measurements of thermal conductivity, two samples AD3-LP3 and AD3-LP6 have been selected due to their similar thermal conductivity to market products. Those samples consist of local Putty Calcitic Lime and Natural Pozzolanic Admixture "Pumice Pozzolan 0–75 $\mu$m" and aggregates of Arundo Donax in a binder/aggregate ratio equal to 20/80 or 25/75 according to the quantity of material compressed in the mold. The local plant-based lightweight concrete is intended to be used as filling material in the construction. Work is in progress to assess the mechanical properties of those samples and especially the resistance to the compression strength, which, according to experimental results surpasses 300 kPa, and is completely comparable to commercial lightweight concrete.

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# Investigating the Relation Between Raw Materials and Climate Change in the Literature

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**Abstract.** Raw materials are essential for the green and digital (twin) transition society needs to accomplish to reach climate targets and neutrality by 2050. This is because they supply renewable energy and digital technologies allowing climate-resilient development pathways. On the other hand, the extraction and processing of raw materials contribute to GHGs and therefore to climate change impacting the environment. The author explores the controversial discussion on the topic of raw materials and climate change in the literature on Web of Science and Google Scholar from 1900 to the present. Literature review, bibliographic coupling and natural language techniques reveal that the raw materials and climate change nexus is a current topic with over 57% of the literature being published between 2018 and the present day. Furthermore, it relates to interdisciplinary research and the interconnectedness of different disciplines and sectors. Therefore, a systemic approach is suggested when investigating this topic. The literature highlights that even though a transition to a renewable energy system will be mineral intensive, it is feasible to enforce resulting in reduced GHGs emissions when compared to fossil fuel-based scenarios.

**Keywords:** Raw materials · Climate change · Green transition · Sustainable development

## 1 Introduction

Raw Materials (RM) relate directly to Climate Change (CC) which is one of the main challenge humanity is facing nowadays. The last Intergovernmental Panel on Climate Change report warns that if the earth temperature will overshot the 1.5 °C increase, in comparison to pre-industrial levels, even for a limited time, human and natural systems will experience higher risks. Depending on the conditions, there will be an additional release of Green House Gasses (GHGs), which would be irreversible even if temperature will then decrees [1]. This will in turn exacerbate the temperature increase. Based on this awareness, the accomplishment and enforcement of the Paris agreement [2], national and regional regulation, like reaching the carbon neutrality by 2050, set by the European Commission [3], become more critical because the temporal window for acting narrows. At the same time, this process should support the Sustainable Developments Goals (SDGs) from the United Nations (UN) [4], while respecting the planetary boundaries set by nature [5].


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RM are essential for the green and digital (twin) transition because they are necessary for building renewable energy systems, infrastructure and digital technologies [6–8]. Looking from the climate scientists perspective, RM are mentioned directly in last IPCC report, for instance when discussing dematerialization in regards to the industrial system transition for a successful climate resilient society or when explaining the increased risk of emerging infectious diseases due to human activities like extraction of raw materials. Furthermore, RM are indirectly relevant in the report when discussing expansion of renewable energy technologies for climate resilient development pathways [1].

Therefore, RM play on one side, a fundamental role in the mitigation of CC, while on the other side their extraction and processing contribute to CC impacting the environment (e.g. through GHGs generation, water and land use). In fact, the mining industry accounts for up to 11% of global energy use [7]. Global iron, aluminum and copper productions seem among the metals contributing most to CC, due to their large yearly production volume ([9] in [10]). Some examples exist of assessment of the CC impact for some specific materials, in relation to their use for the energy transition. For instance [10] uses data in the literature of steel, aluminum, copper and concrete intensity for the case of France energy transition by 2050. These four materials are highly required for electricity generation systems in addition to a wide variety of other raw materials and metals, including Rare Earth Elements (REE) and critical raw materials needed for renewable energy generation, storage and infrastructure [7, 10–12].

In order to mitigate CC, technologies should contribute to a wider comprehensive systemic approach including economic, policy, behavioural and awareness actions [13]. As a transition towards a clean energy system is necessary for mitigating CC, we do know that it will be mineral intensive [7].

However, even though an higher demand for raw materials will exist due the energy transition to renewable sources, the pollutions and GHGs emissions of renewable technologies are small in relation to direct fossil fuel-fired plants [7, 14]. Hertwich et al. [14] assessed the worldwide scale deployment of renewable energy and their impact to respect to pollution and CC by performing a global, long-term integrated life cycle assessment (LCA). Results shows that the scenario including low carbon technologies provides the double of electricity while stabilizing or even reducing emissions with respect to the baseline scenario (in which emissions and pollutants double). Furthermore, according to the authors, even though the materials required per unit generation for low-carbon technologies is significantly higher than for traditional fossil generation (copper for photovoltaics: 11–40 times more; iron for wind power systems: 6–14 times more), it is feasible to support the world energy demand in 2050 by low-carbon energy systems. For achieving this, only 1 or 2 years respectively of global iron or copper production would be needed.

Both production and consumption of raw materials are drivers of the problem of climate change but their sustainable and responsible handling have also the potential to be even greater drivers of the solutions to the problem, contributing to CC mitigation.

Even though RM are considered fundamental for renewable energy, energy storage and digital technologies, [11, 15], and their impact on climate change has been in some cases assessed [7, 10], the two topics of RM and CC have rarely [7, 10] being directly associated and not yet reviewed in a broad perspective. This paper aims to build a bridge among different disciplines, by reviewing the linkage between RM and CC. It aims at facilitating the understanding and multidisciplinary collaboration on this topic among environmental scientists, economists, policy makers, mining engineers and material scientists. For this purpose, the paper continues with the methods section, which explains the methodology used for analysing the existing literature on the topics of RM and CC. It continues with the results and discussion sections, which report and discuss the findings of the publications funded (e.g. year, authors and journals of publication, science category and sector associated and main topics treated). The author then concludes with recommendations for further development and reflection remarks.

## 2 Methods

The author searches the literature on Web of Science and Google Scholar from 1900 to the present. Combining two search engines is not unusual [12], for overcoming the limitations of a single search engine [16]. Google Scholar is classified not to be, a scientifically robust search engine for reviewing the literature (and in fact defined not suitable as principal search system and for systematic literary reviews [16]), however, it is largely adopted by researchers and engineers in different research areas and can be beneficial for broaden the search scope. This is the case when researching the topic of RM and CC, it seems necessary to integrate the results of Web of Science with Google Scholar for accessing to technical reports [12], where a large amount of information and data are published (e.g. by industry and policy makers). Therefore, the author uses Google Scholar as supplementary search system to integrate the readings on the investigated topics but here reports only the results of the search on Web of Science, because of replicability purposes.

By searching for: raw material AND "climate change", 1121 publications appear on Web of Science and 425,000 on Google Scholar (search performed on 19.08.2022). The data were cleaned by excluding papers of irrelevant categories of medical and veterinary science (diminishing to 1069). Then the author applied the Boolean operator NOT for excluding additional not relevant publications while reading. In order to account for natural database grow and include new relevant publications, the search was updated up to 14.09.2022. The entire search string is retrievable at https://www.webofscience.com/wos/woscc/summary/34ae2310-8de8-4741-9b81-6627fa5de05a-4a0761b9/relevance/1.

Part of the data processing was performed with the support of VOSviewer [17] for extracting bibliographic couplings (e.g. co-authorship network) from the literature funded on Web of Science. Furthermore, the author also uses VOSviewer for creating a map based on a text corpus, extracting the terms form tittles and abstracts using natural language processing techniques [17]. The selection criteria were set with 10 minimum occurrence of each term.

Additional key words search among the results looked at which topics and sectors dominate in the publications as energy, industry, building and transport.

# 3 Results and Discussion

Results show 364 publications found on Web of Science, which were divided and classified per year, type of publication and Web of Science category. Furthermore, links between papers, authors and terms most used in the literature appear and are described below. Finally, some sectors' key words occurrences are correlated to global GHGs emissions.

## 3.1 Publication Year, Type of Publication, Category of Publication

The first relevant publication results in 1999, the number of publications grows with time (see Fig. 1). It is possible to notice a steep increment in the number of publications after 2016 and a pick in 2020. More than half of the research items (57%) were published between 2018 and today, confirming that the investigated topic is highly current. This also suggests the increasing interest from the research community and the importance of understanding the nexus between RM and CC. References [7, 10], especially in light of sustainable development [6] and the twin transition [8] towards climate neutrality.

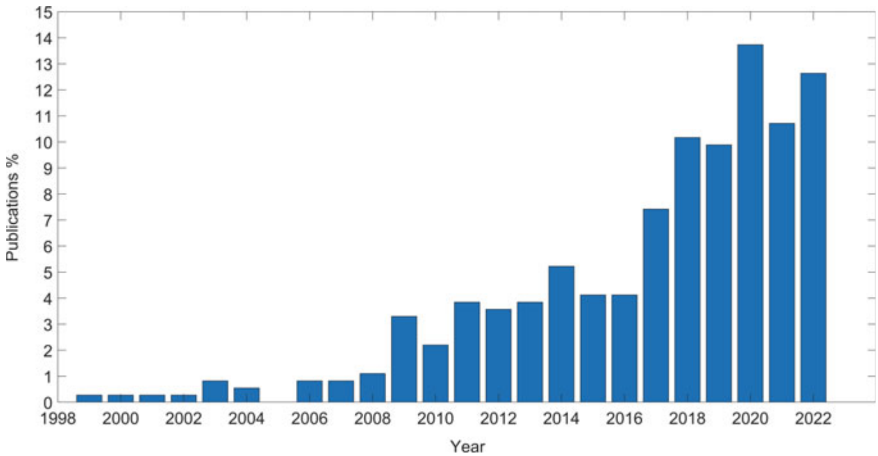


**Fig. 1** Publications (%) in Web of Science per year, period 1900–2022

The majority of the documents found are articles (70.6%), followed by proceeding papers (21.2%) and review articles (11%), and only a few book chapters (1.4%) appeared.

Most of the literature classifies as part of the Web of Science Category (see Fig. 2) Environmental Science (37.6%), Green Sustainable Science Technology (26.7%), and Engineering Environmental (24.7%), showing a high interest in the topic from the side of environmental scientists. However, several other areas seem relevant for the topic of RM and CC for instance Energy Fuels (20.3%) and Material Science Multidisciplinary (10.7%) as well as areas related to chemistry and the building and construction environment. The existence of several disciplines for which publication are relevant suggests the multidisciplinary and systemic nature of the topic of RM and CC.

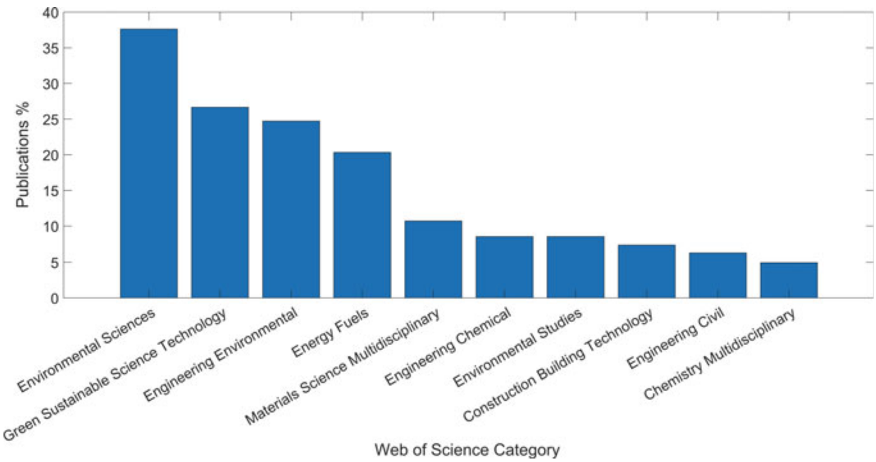


**Fig. 2** Publications (%) per Web of Science category, 10 most published areas

## 3.2 Bibliographic Coupling and Natural Language Processing

The most published authors are Heidrich O. and Hong J. L. with 5 publications, followed by Liu L. T., Rajaeifar M. A., and Shen L. with 4. Some working groups appear from the co-authorship map in Fig. 3. The relatedness of items on the map is based on the number of co-authored documents. The minimum number of documents per author is set to 2. Size of circle are proportional to normalized citation (accounts for newer publication having less time to be cited).

The journals publishing a higher number of papers are Journal of Cleaner Production accounting for 10.2% of publications, Sustainability (4.4%), International Journal of Life Cycle Assessment (3.8%), Renewable and Sustainable Energy Reviews (3%).

Figure 4 shows the results of the bibliographic coupling analysis. It links publications, which have cited reference in common (minimum common sources: 2). Relations among items on the map depends on the number of references they share. The dimensions of the circles are weighted for normalised citations. The Journal of Cleaner Production appears the most relevant for this topic, followed by Renewable and Sustainable Energy Reviews, Resources Conservation and Recycling, Cement and Concrete research. The predominance of the Journal of Cleaner Production and the presence of Sustainable Production and Consumption confirm the importance of responsible and sustainable production and consumption when researching RM and CC nexus.

To have an overview of the topics treated in the publications funded, the author created a map based on a text corpus (term map). Every circle represents a term from titles and abstracts of the publications, the higher the number of co-occurrence of two terms in titles and abstracts the closer they are located on the map. The size of the circle is proportional to the occurrence.

The illustration in Fig. 5 is not exhaustive the reader should notice that some interesting terms are missing for space limitations, even if included in the list of relevant words. This applies for instance to coal, metal, transport, supply chain, concrete, construction,

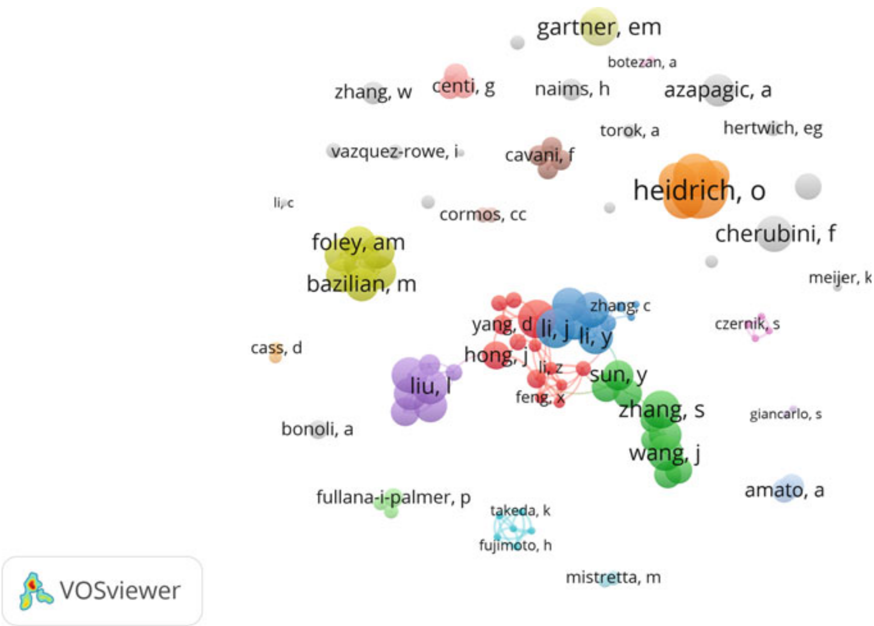


**Fig. 3** Co-authorship map. Links and colors indicate clusters due to co-authorship: visualization weighted for normalized citation, scale 2.0

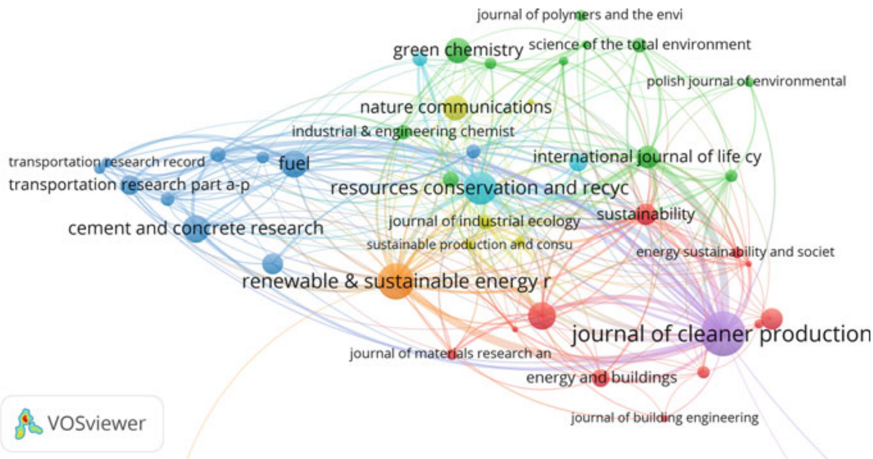


**Fig. 4** Bibliographic coupling map. The minimum number of sources shared: 2. Visualization weighted for normalized citation, scale 2.0

construction sectors, electricity, circular economy, oil, cement industry, cement production, steel, and carbon footprint. Three main clusters appear. The first (Cluster 1—red) relates to the economy, policy and development (e.g. country, Germany, Europe, company, population and policy maker). The second (Cluster 2—green) to environmental impact and methodologies for data analysis (e.g. ozone depletion, acidification, LCA and sensitivity analysis). The third (Cluster 3—blue) to the atmosphere and emissions (e.g. $CO_2$, methane, fuel, coal, temperature, biomass and storage). In addition, a fourth cluster (Cluster 4—yellow) emerges among the three around specific sectors like the building and construction sector, supply chain specifying minerals and materials like cement and concrete. The resulting clusters are however not exhaustive and terms are not always logically distributed for instance iron appears in cluster 3 while mineral is in cluster 2 and cement and concrete are in cluster 4.

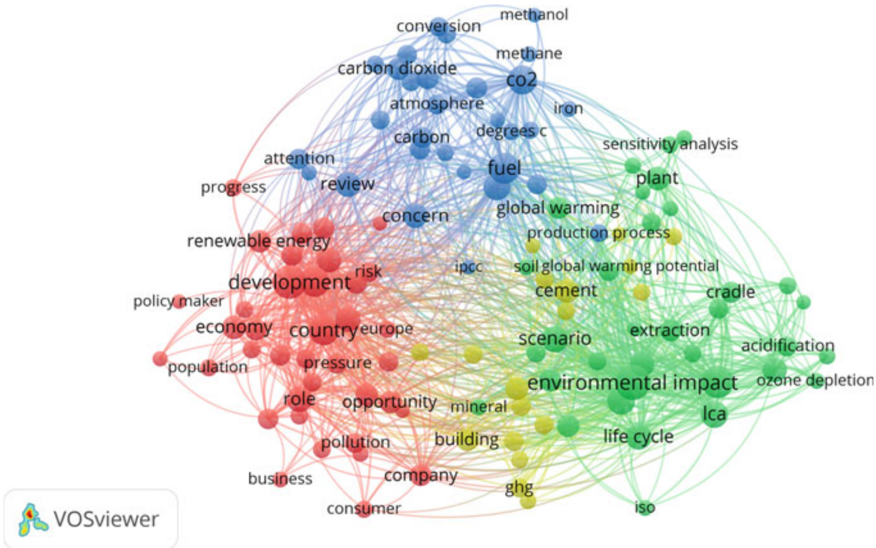


**Fig. 5** Map based on text corpus: terms co-occurrence map. Minimum terms occurrence: 10. Visualization weighted for occurrence, scale 2.0. Cluster 1 red (left), cluster 2 green (right), cluster 3 blue (up), cluster 4 yellow (center down and right)

According to [10], steel, aluminium, copper and concrete are highly impacting in terms of CC, through the research based on text data in this work, only the terms steel and concrete result significant in the literature appearing more than 10 times. This suggests that the potential of copper and aluminium in mitigating CC should be further investigated (e.g. recycling and optimization of material use). Generally, the author suggests further investigating the topics of secondary raw materials, urban mining and material efficiency, as suggested in the literature [18–21].

The reader should notice that terms related to production and consumption emerge like “production process” and “consumer”, showing the role that sustainable consumption and production (in the case of raw materials) can play in CC mitigation.

### 3.3 Publications and Global GHGs Emissions Per Sector

When comparing the number of publications and the global GHGs emissions by sectors in Fig. 6, (GHGs data from [22]), it appears that energy in general accounting for 73.2%

of GHGs is also the most researched topic. Industry (incl. energy use) is responsible for 29.4% of GHGs and is the second most used keyword however, more effort could be posed by the research community into mitigating emissions from this sector. Transport (16.2%) and construction (energy use in buildings 17.5%) follow having the topic of transport seeming more researched than building. Looking at specific materials, cement accounts for 3% of global GHGs emissions and is largely mentioned when compared with other terms, iron and steel for 7.2%, while waste alone accounts for 3.2%, and the term recycling is largely used.

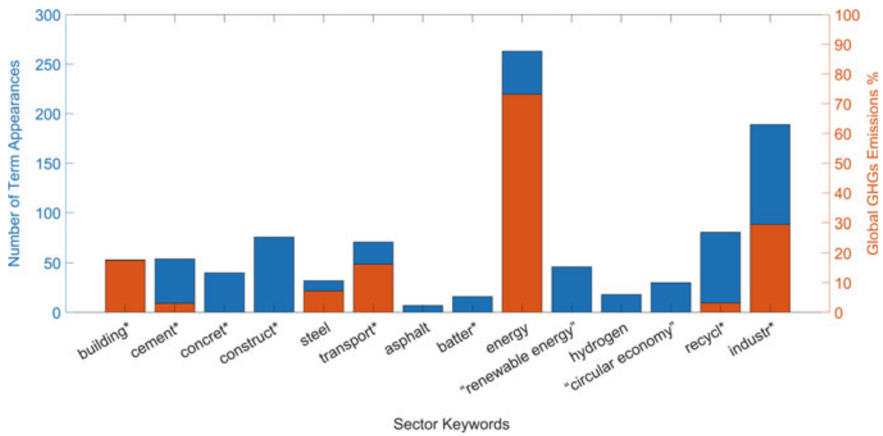


**Fig. 6** Keywords per sector occurrence (blue left y-axis). Global GHGs emission per sector (%) [22] (orange right y-axis)

## 4 Conclusions

The topic of RM and CC is a very current topic in the literature with 57% of publications occurring in only the last 5 years, indicating the growing interest in the topic from the research community. Interest comes from different research disciplines and science categories with the first being around environmental science however the aspects of energy fuels, material science, chemistry and construction are also of high importance. The fact that interdisciplinary aspects of several clusters of topics are touched like economy and policy, environmental impact, atmosphere and emissions and energy and building sectors indicates the multidisciplinary and systemic nature of the RM and CC nexus. While the topic of energy seems largely investigated, being also the sector responsible for the highest shares of GHGs emissions, specific materials responsible for high CC impacts like copper and aluminium have still high potential for further research. In fact, looking at the sectors most responsible for global GHGs emissions [22], energy and industry, accounting respectively for 73.2% and 29.4% of global GHGs emissions are also the most researched in the literature. While materials like steel, aluminium, copper and concrete are highly contributing to CC [10] but only the terms steel and concrete appear relevant in the research based on text data in this work, suggesting that the CC mitigation potential of copper and aluminium should be further investigated.

Looking at the limitations of this work, more search systems and databases could be used, for example, adding Scopus. Different and more searches in the databases could be performed by varying the query keywords and Boolean operators. It would be beneficial to integrate results from Google Scholar concerning technical reports.

The choices that our society will take in the next ten years will be crucial to determine the mid- and long-term effectiveness of the needed climate-resilient development for mitigating and limiting the climate change impact [1]. Climate resilient development pathways rely on the transition of energy and urban infrastructure systems, for which renewable energy expansion and thus raw materials are needed. As well as industrial system transition, which should include a combination of dematerialisation and decarbonisation key drivers, both involving raw materials demand and processing [1]. Therefore is clear that responsible and sustainable production and consumption of raw materials can play a key role in mitigating climate change while sustaining UN sustainable development principles.

This suggests further research in the field of RM and CC nexus. The author recommends further investigating topics of urban mining, recycling, renewable energy systems expansions and circular economy to drive the green transition through a responsible and sustainable production of RM. The author especially suggests interdisciplinary research for complementing interconnected areas like economics, environmental and social science with material science, mining and engineering. A systemic perspective should be considered when treating the nexus between RM and CC. RM are key in supplying the building of renewable energy systems, storage and infrastructure as well as digital technologies enabling the green and digital (twin) transition. The literature indicates that even though this transition will be mineral intensive, it is possible to realise resulting in reduced GHGs emissions when compared to fossil fuel-based scenarios. The transition towards climate neutrality by 2050 would limit the human-induced earth temperature increase now that the window for action narrows.

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# Monitoring Electrical and Weather Parameters in Photovoltaic Bifacial Systems

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**Abstract.** Currently, photovoltaic technology (PV) is moving towards technologies that improve the yields for a given resource, such as PV bifacial modules. The behavior and the measured data are not as widespread as mono-facial technology. Integration of bifacial photovoltaic modules into a building with natural ventilated façade may represent a step forward in the application of this relatively new technology. In this sense, monitoring the crucial parameters in order to analyse module/system performance is becoming crucial. The purpose of this paper is to design a monitoring system for bifacial modules, which can measure, display and store weather (ambient temperature, rear and front irradiances and wind speed) and electrical (current and voltage) parameters. The developed applications allow both; trace the current–voltage curve and track the global maximum power point algorithm.

**Keywords:** Solar photovoltaic · Bifacial · Monitoring

## 1 Introduction and Objectives

Photovoltaic technology (PV) is moving towards technologies that improve the yields for a given resource, such as trackers and bifacial modules. The later technology has improved their average efficiency from 14.7% in 2014 to 20% in 2020 [1]. Currently, market share for this technology is about 12%. However, it is predicted to increase about 30% by the end of the decade. It should be noted that at cell market, growth is expected from almost 20% in 2019 to 70% in 2030 [2].

Bifacial photovoltaic (bPV) is available to absorb sunlight from both sides (front and back) compared to mono-facial photovoltaic, nevertheless both have similar working principles. Bifacial PV behavior depends on the structure of cells and modules, there is a coefficient, bifaciality factor, which provides the 'output gain' from a bifacial module


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compared to mono-facial module. However, this factors may be influenced by external conditions of the system installation, its location, angular distribution of light, among others [3].

Similarly as mono-facial, bifacial system may be installed with different orientation and inclination angles. Vertical tilt in bPV may be interesting because soil losses (dirt or snow) are reduced. In this way, energy output increases under specific systems and conditions [4]. On flat green roofs areas may be an interesting option in several regards for photovoltaic systems, however, the practical application has found many difficulties because of goal conflicts. Vertical bifacial systems are an alternative way to avoid such conflicts and to combine the advantages of both approaches [5]. On the other hand, the results of an electrical and thermal simulation indicates if the bPV is used in natural ventilated façade, the power peak may be 2.9% higher compared to ventilated façade with an integrated mono-facial module with the same geometry [6].

In this way, experimental systems, in order to have real data, could be interesting for performing better analyses of these systems. The main objectives of this work is to develop a monitoring system for bifacial PV systems in order to provide measured parameters in vertical façade, which are useful for modeling of ventilated bPV facades. Moreover, the tool, due to the periodic measurements of the I-V curve, can be used also for monitoring and diagnostics of PV systems.

The manuscript has been organized as follows: Sect. 2 describes the bifacial modules, the monitoring system and the application developed in LabVIEW to provide real data. Thereafter, Sect. 3 presents some of the measured parameters provided by the monitoring systems of the natural ventilated bPV façade. Finally, the most relevant conclusions are given.

## 2 Experimental Set-Up and Methods

Two bifacial modules, temperature and air velocity sensors, electronics loads and data logger are located on the laboratories building of department of Electrical Electronic and Computer Engineering at University of Catania (Latitude 37.52 North, Longitude 15.07 East), Fig. 1.

The commercial bPV modules are installed in such way to create vertical screen ventilated façade with an azimuth and tilt angles 19° and 90°, respectively. Between the modules and the wall there is a distance of 25 cm to have a ventilated air gap. Moreover, a bottom opening of 25 cm and a top opening of 10 cm allow the natural airflow [6, 7]. Additional information of the main characteristics of the bifacial modules are listed in Table 1.

Each module is connected directly with a different electronics load, 6314A mainframe with 63105 module whose manufacturer is Chroma and EL 600VDC 1200W whose manufacturer is APM. The main characteristics of them are described in Table 2. Electrical parameters, array current, $I_A$ and array output voltage $V_A$ are measuring through 4-wire to measure the $V_A$ at module level, in this way, voltage drop developed in the wire will be avoided.

Weather parameters are also measured. Global front in-plane irradiance ($G_{i,f}$) and rear in-plane irradiance ($G_{i,r}$) though pyranometers. The latter is located between both


**Fig. 1** **a** Bifacial modules. **b** Electronic loads

**Table 1** General characteristics of bifacial module

| General characteristics | |
|---|---|
| Module type | 3SBA340A (Enel green power) |
| Number, type and arrangement of cells | Mono-crystalline, n-type PERT, 72 pcs in series (6 × 12) |
| $P_m$ temperature coefficient | − 0.38%/°C |
| $I_{sc}$ temperature coefficient | 0.048%/°C |
| $V_{oc}$ temperature coefficient | − 0.30%/°C |
| NOCT-nominal operating cell temperature | 44 ± 2 °C |
| Power @STC $P_m$ (W) | 340 |
| Power @BSTC $P_m$ (W) | 385 |
| Max-power voltage $V_m$ (V) | 39.1 |
| Max-power current $I_m$ (A) | 8.70 |
| Open-circuit voltage $V_{oc}$ (V) | 47.6 |
| Short-circuit current $I_{sc}$ (A) | 9.10 |
| Module efficiency $\eta_{STC}$ (%) | 17.2 |
| Bifaciality factor c (%) | ≥ 85% |

modules on the semi-transparent material, Fig. 1. This irradiance is the reflected one by the building wall behind the bPV façade. Ambient temperature ($T_{amb}$) and wind speed ($w_s$) are also measured. The accuracy and details of each sensors are possible to find in Ref. [7].

The monitoring system was controlled by a proper interface, which was developed in LabVIEW®. The virtual instrument (VI) allows communication with the data acquisition

**Table 2** General characteristics of electronics load

| | 6314A-63105 | EL 600VDC 1200W |
|---|---|---|
| Manufacturer | Chroma | APM |
| Operating voltage range (V) | 0–500 | 0–600 |
| Operating current range (A) | 0–10 | 0–90 |
| Power (W) | 300 | 1200 |
| Operating mode | CC, CR, CP and CV<br>Dynamic mode | CC, CR, CP and CV<br>Dynamic mode |
| CV resolution | 20 mV (0–80 V) | 0.5 mV (0–80 V)<br>1 mV (0–150 V)<br>5 mV (0–600 V) |
| CR resolution | 12 bits | 275 mΩ (0–80 V)<br>1100 mΩ (0–150 V)<br>11,000 mΩ (0–600 V) |
| Voltage masurement accuracy | 0.05% + 0.05% F.S | 0.015% + 0.015% F.S |
| Current masurement accuracy | 0.1% + 0.1% F.S | 0.04% + 0.04% F.S |

system (DAS) and records the monitored data. Users may develop a sophisticated VI for running electronics devices in an easy way, without advanced knowledge of DAS design using LabVIEW® [8]. The developed VIs are focused in managing tasks such as the communication with DAS, the control of the set points (voltage, current or resistance) of electronics loads and processed, stored and displayed the measured parameters.

Weather parameters are measured with DAS connected to PC through LAN network. The sampling interval of weather parameters is two seconds, while electrical parameters depends on the task. On the other hand, two monitoring PC are separately connected with the two electronic loads via a general-purpose instrumentation bus (GPIB) for controlling. Both electronic loads allow to use the Standard Commands for Programmable Instruments (SCPI) which is designed especially for programmable instruments. Therefore, SCPI is used to control and manage the electronic loads.

Two graphical user interface (GUI), Fig. 2, are used to measure weather parameters and electrical parameters for each module under real operating conditions. One monitoring system tracers the I-V curve each two minutes, while the other system may measure the IV curve or search the maximum power point (MPP).

The I-V curve provides the electrical output behavior of the module under real operating conditions, which mainly depends on in-plane irradiance and cell temperature. The main parameters which define the I-V curve are the short-circuit current ($I_{sc}$), when the voltage is zero, the open-circuit voltage ($V_{oc}$), when the current is zero, and the set point when the power is maximum ($V_m$ and $I_m$). Although for both electronic loads the voltage mode is available and it is possible to trace the IV curve modifying the voltage according to datasheets, in only one of them has been used this strategy. On the other hand, the I-V curve of the other electronic load is traced modifying the resistance value using resistance mode due to an instability, which was detected when voltage mode is

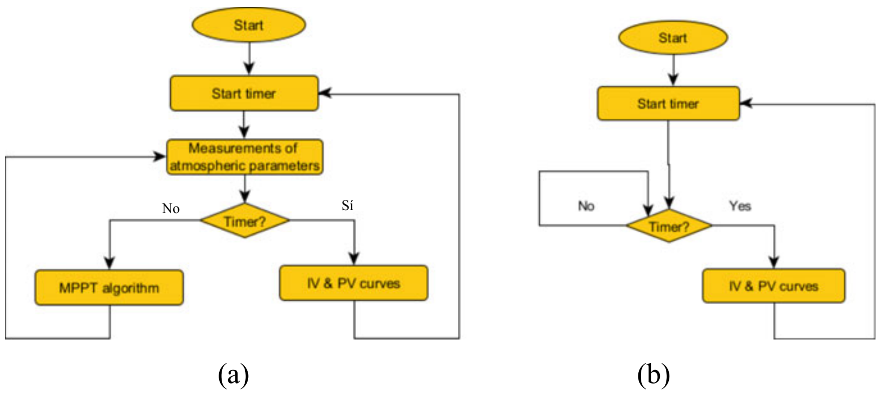


**Fig. 2** Flowcharts of **a** module #01 and **b** module #02

used. Nevertheless, both systems measure 100 samples (current and voltage) for each I-V curve. In addition, a synchronization between both PCs has been developed in order to measure IV curves at the same time.

The maximum power point tracking (MPPT) reaches the MPT according with the Global MPPT algorithm described in [9]. The algorithm is based on restricted voltage windows search, which one of its aims is avoided the energy losses.

Producer/consumer architecture was selected in both VIs because the data acquisition process and data storage process can run simultaneously, continuously and both processes can run at different speeds [10]. Producer and consumer subroutines are communicated through data queues, which work according to first-in/first-out (FIFO) as this architecture avoids data loss.

The measured parameters and calculated parameters are stored in (*.txt) file. There is one file for each day when MPPT mode is working. Meanwhile, when I-V curve mode is working, there is one file for each I-V curve; the recording interval considered depends on the system, two minutes or four minutes. Additionally, scripts using Matlab® have been developed to process the data. Figure 3 shows the graphical user interface.

## 3 Experimental Results

This section illustrates some of the measured parameters provided by the monitoring systems of the natural ventilated bPV façade.

Figure 4 shows the output power of the module ($P_A$) as well as the front and rear irradiances ($G_{i,f}$, $G_{i,r}$), for a cloudy day in August. The maximum values observed for these parameters were 198.3 W, 669.1 W/m$^2$ and 88 W/m$^2$, respectively. Meanwhile, Fig. 5 shows the ambient temperature ($T_{amb}$) and wind speed ($W_s$) observed during the survey period.

Figure 6 depicts two I-V and P-V curves elaborated during the survey. It is worth nothing that each curve corresponds to a single bPV, which in turn is connected to one electronic load. Both group of curves (I-V and P-V) are quite similar and the percentage error of the maximum power point is lower than 1%.

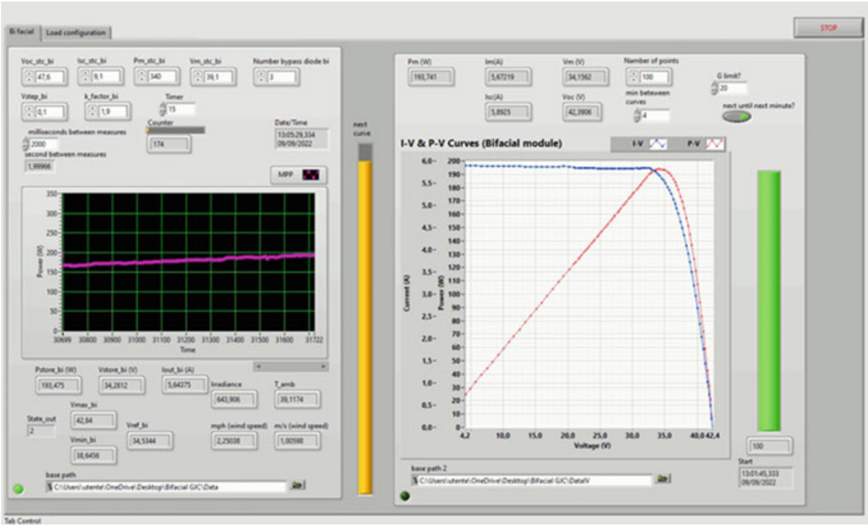


**Fig. 3** Graphical user interface for bifacial module monitoring

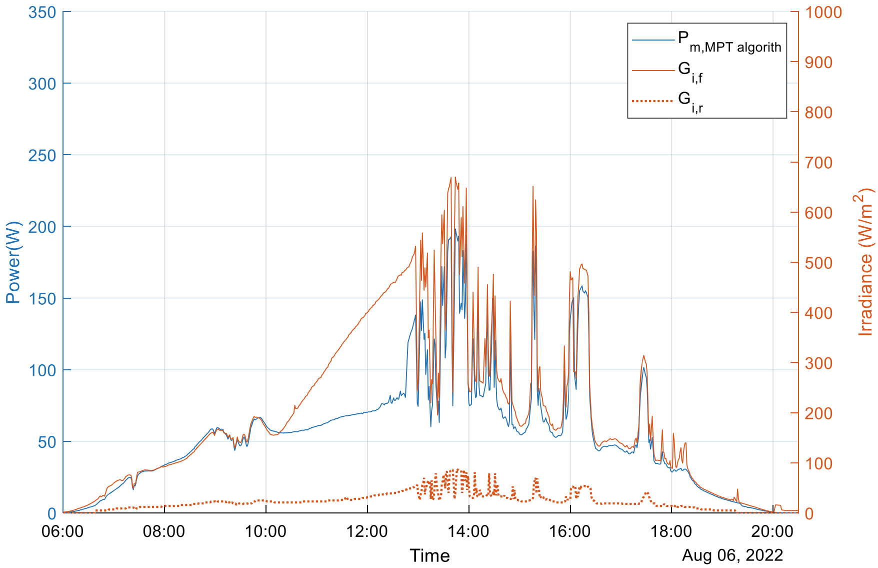


**Fig. 4** Output power and irradiance on 06/08/2022

The analysis carried out allow to evidence a very good reliability of the obtained results.

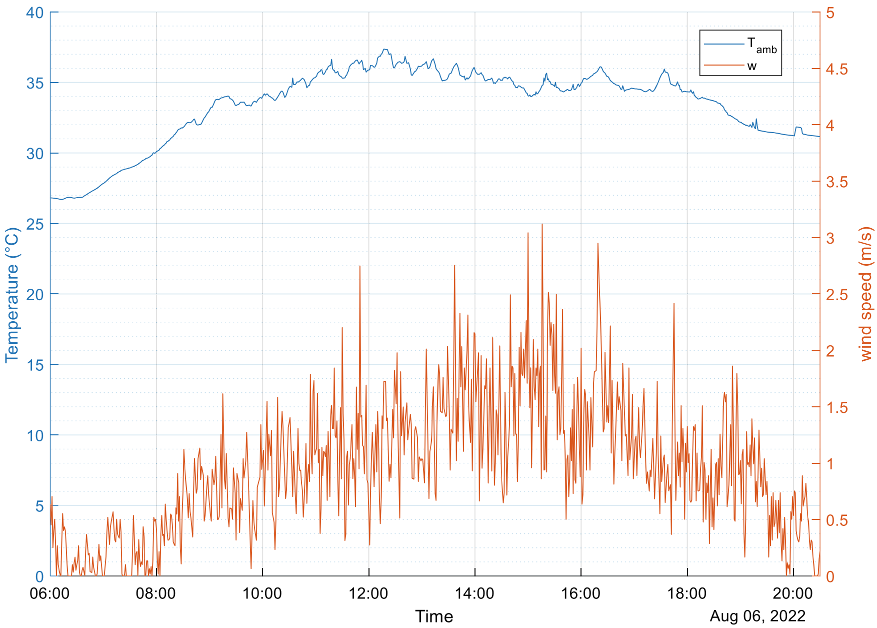


**Fig. 5** Ambient temperature and wind speed on 06/08/2022

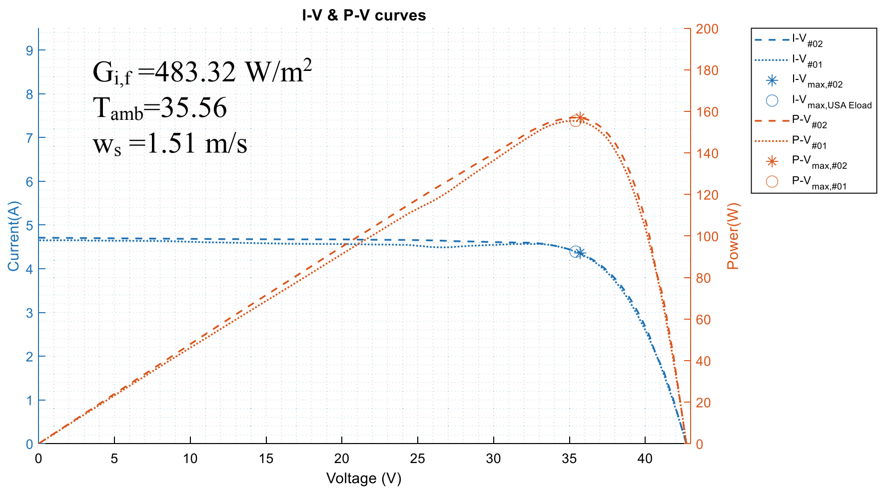


**Fig. 6** I-V and P-V curves on 06/08/2022 16:15

## 4 Conclusion

Application software in LabVIEW to collect electrical and ambient parameters, display and store the data. The functionality of such software has been experimentally tested on a vertical ventilated facade realized with two bifacial PV modules. The architecture of the proposed software allows evaluating separately the operating conditions on both modules. One of them can work as maximum power point tracking according to the Global MPPT algorithm and as current-voltage curve tracer. Both VIs can trace current-voltage curve. Due to the periodic measurements of the I-V curve, this tool can be used also for monitoring and diagnostics of PV systems.

Considering the peculiarities of the tested bPV system, it is useful to monitor weather parameters, such us rear irradiance, front irradiance, wind speed and ambient temperature. During the survey, such parameters were also measured with a two second of sampling interval.

Further studies, which are currently under progress, propose to analyse the electrical developed models, check the behavior of them under different weather conditions, which are located in natural ventilated façades.

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# Evaluation of Different Environmental Covariates Performance for Modeling Soil Salinity Using Digital Soil Mapping in a Susceptible Irrigated Rural Area

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**Abstract.** Soil is an indispensable resource for the development of the ecosystems, also working as a support for the human activities, being essential for the agricultural productivity. There are many soil degradation risks that cause a quality deterioration. One of the major risks is soil salinity, caused by the accumulation of salts both naturally and anthropically. For this reason, prevention measures are needed. To this end, soil properties inference and modelling result essential. Thus, the main objective of this research is to find the most useful environmental covariates for modeling soil salinity through the application of the Digital Soil Mapping (DSM) methodology in an irrigated rural area in Castile and León (Spain). For this purpose, 132 soil samples from two different laboratories were used, which contained electrical conductivity measured in saturated paste ($EC_x$). In addition, several environmental covariates related to soil salinity were employed to perform a statistical analysis through the combination of multiple linear regression (MLR) and generalized linear models (GLM). Afterwards, the best prediction model and its explanatory covariates were selected. The MLR showed $R^2$ values between 0.382 and 0.581 for the laboratories analyzed. In turn, all the models almost had the same main covariates, which were associated to remote sensing indices and topographic variables. Finally, it was concluded that the method is useful to determine the most important variables for modeling soil salinity, allowing more accurate predictions, identifying which susceptible areas need preventive measures and helping to achieve those SDGs targets that involve soil's conservation.

**Keywords:** Soil salinity · Electrical conductivity · Digital soil mapping

## 1 Introduction

Soil is an essential natural resource for the development of life in ecosystems, harboring large amount of biodiversity, functioning as a store and supply of water and nutrients and being the support for different human activities such as agriculture.


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The importance of soil is even highlighted in the 2030 Agenda Sustainable Development Goals (SDGs). Several SDGs involve directly and indirectly the soil into their targets. In turn, Goals 12 "Responsible consumption and production" and 15 "Life on land" mention the use of sustainable production system and agricultural practices for improving soil quality, also preventing its pollution through proper management of chemical and waste. In this way, it also seeks to curb the causes of soil degradation, such as salinization [1].

Therefore, it is necessary to carry out preventive measures, such as the development of cartography and models to predict how salinity will evolve. To this end, the Digital Soil Mapping (DSM) methodology and its derived models, such as the *scorpan* model, are proposed, which are based on the statistical inference of soil properties by searching for the statistical relationship between these properties measured in the field with different auxiliary variables or environmental covariates (climate, lithology, land use, vegetation, topography, etc.), finally extrapolating these relationships to those data lacking areas [2–5].

Thus, the main objective of this research focuses on the application of the Digital Soil Mapping (DSM) method in an irrigated area of Castile and León (Spain) to determine which are the most useful and relevant covariates for modeling soil salinity.

## 2 Study Area

The study area is located between the provinces of León and Zamora (Spain) (Fig. 1). It covers an area of 1500 $km^2$, with altitudes between 680 and 930 m and generally flat relief. The average annual temperature is between 10 and 13 °C, with rainfall between 400 and 500 mm and average annual ETP of up to 800 mm [6, 7].

The dominant lithologies correspond to the Pleistocene and Holocene, formed by alluvial deposits in terrace areas, and by sand, silt and clay in valley bottom areas and river plains. Among dominant soil types, Cambisols are found in terrace zones in the center and north of the study area, and Fluvisols in the floodplains. Finally, the main land use is associated to irrigated crops, with a predominance of maize (65,000 ha), with poplar plantations also standing out in the riparian areas [8].

## 3 Methodology

The DSM methodology was used for the study through the application of the *scorpan* model developed by McBratney et al. [2], which proposes the integration of different environmental variables into a function that allows, in this specific case, the prediction of soil salinity ($S_s$) (Eq. 1).

$$S_s = f(s, c, o, r, p, a, n) \tag{1}$$

These environmental variables, also called "soil-forming factors", comprise soil (s), climate (c), organisms (o), topography (r), parent material (p), age (a) and spatial position (n). In turn, these variables are defined by different environmental covariates [2].

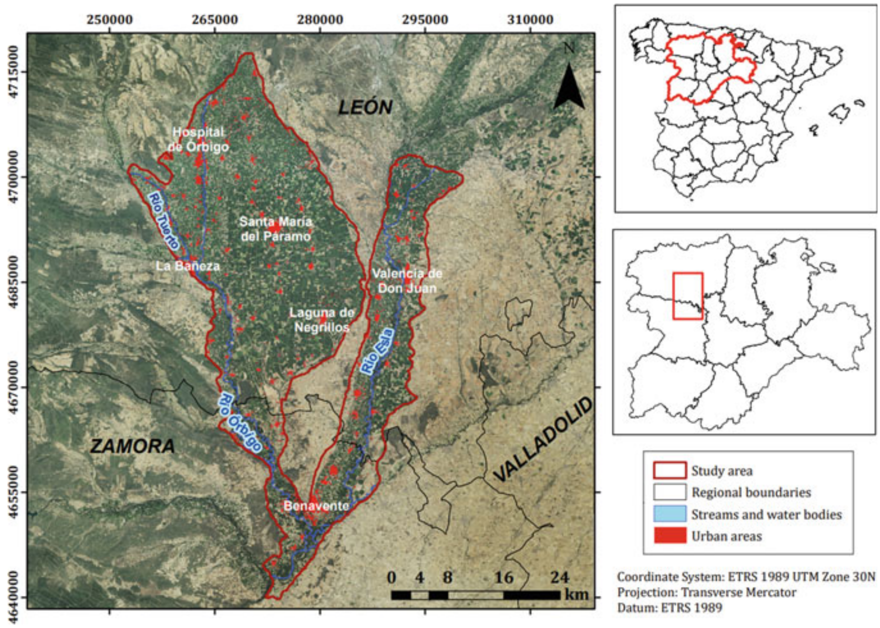


**Fig. 1** Location of the irrigated area in León and Zamora, Spain

In this way, based on soil samples with salinity data and the different environmental covariates related to it, a relationship is established that allows estimating the values in unsampled areas. To do this, a spatial overlapping of the soil samples on the mapping of the different covariates was first applied, which allows obtaining at each sampling point both the value of the properties of that soil, as well as the values of each of the environmental covariates used. After obtaining these values, the relationships between the independent variables (environmental covariates) and the dependent variable can be modeled using different statistical methods. In this study, the dependent variable associated with salinity is the electrical conductivity measured in the saturated paste extract ($EC_X$). In turn, the statistical technique that was applied was Multiple Linear Regression (MLR). The flow chart in Fig. 2 outlines the procedure followed.

### 3.1 Soil Data

The Soil Database of Castile and León, obtained from the Agrarian Technological Institute [9] was used to acquire soil data. This contains 914 surface samples from the first 25–30 cm of soil with measurements of electrical conductivity in the saturated paste extract ($EC_X$). However, for the irrigated area the number of samples was lower (132), analyzed also according to the laboratories of origin (Table 1).

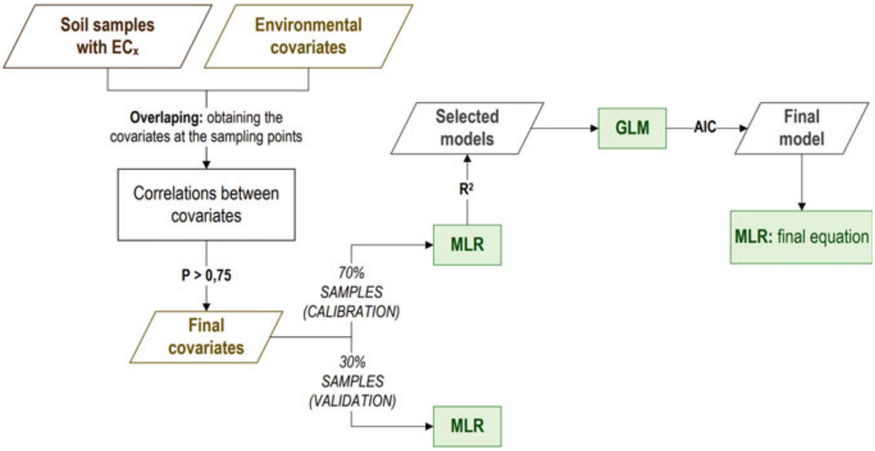


**Fig. 2** Applied methodology flow chart

**Table 1** Samples and $EC_X$ values range (minimum and maximum) for each laboratory analysed in the study area

| Laboratory name | Number of samples | Mean $EC_X$ | $EC_X$ range (dS/m) |
|---|---|---|---|
| Análisis Integrales | 77 | 0.30 | 0.2–0.70 |
| APPLUS | 55 | 0.26 | 0.2–0.69 |

## 3.2 Environmental Covariates

To obtain the environmental covariates, different data sources were used to derive a total of 24 covariates (Table 2). In the case of land use and lithology, as these are categorical variables, each of their classes was transformed into a binary numerical variable.

It should be noted that all covariates obtained are in raster format with a spatial resolution of 25 m × 25 m. There were covariates with high spatial resolution (≤ 25 m) and others with very low resolution (those ones related to climate). It is always better to change from a high resolution towards a low resolution. For this reason, among those covariates with high resolution, it was decided to work with 25 m. The climate variables in general do not show such high spatial variability. Thus, it was concluded that although it is not the best solution to change from 500 to 25 m, the inherent error could be affordable with the DSM method.

## 3.3 Statistical Analysis

After overlaying and extracting the values of the 24 covariates in the sampling points at the study area, a correlation analysis was carried out to reduce the number of environmental covariates, given that the number of covariates was very high. In this way, those whose Pearson coefficient (P) was greater than 0.75 were eliminated from the analysis, as they give redundant information.

**Table 2** Data sources and environmental covariates used in the study for the different soil forming factors

| Factors | Data sources | Spatial resolution | References | Covariates |
|---|---|---|---|---|
| Soil (s) | Sentinel-2 images | 20 m × 20 m | [10] | Carbonates index (CAI)<br>Clay index (CI)<br>Brightness index (BI)<br>Gypsum index (GI)<br>Salinity ratio (SI) |
| Climate (c) | Assessment of natural regime water resources model (SIMPA) | 500 m × 500 m | [11] | Mean annual temperature (ºC)<br>Mean annual rainfall (mm)<br>Mean annual ETP (mm) |
| Organisms (o) | Sentinel-2 images<br>CORINE Land cover (CLC)<br>Castile and León crops and natural land map (MCSNCyL) | 20 m × 20 m<br>–<br>10 m × 10 m | [10]<br>[12]<br>[8] | Normalized Difference Vegetation Index (NDVI)<br>Soil adjusted vegetation index (SAVI)<br>Enhanced vegetation index (EVI)<br>Land uses (2 classes) |
| Topography-relief (r) | Digital elevation model (DEM) | 5 m × 5 m | [13] | Elevation (m)<br>Slope (º)<br>Aspect (rad)<br>Standard curvature<br>Profile curvature<br>Planform curvature<br>Topographic wetness index (TWI)<br>Multi-resolution ridge-top flatness index (MrRTF)<br>Multi-resolution valley bottom flatness index (MrVBF) |

(*continued*)

**Table 2** (*continued*)

| Factors | Data sources | Spatial resolution | References | Covariates |
|---|---|---|---|---|
| Parent material (p) | Castile and León geological map | – | [14] | Lithology (2 classes) |

After this, Multiple Linear Regression (MLR) was applied using IBM SPSS Statistics 26 software. This technique is summarized by the following equation (Eq. 2), in which $Y$ is the dependent variable, $X_n$ are the predictors that explain the dependent variable, $\beta_0$ is the intercept or origin, $\beta_n$ are the coefficients that represent the weight and relationship of each environmental covariate with the dependent variable, and $\varepsilon$ are the residual values that cannot be explained by the model [15].

$$Y = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \ldots + \beta_n \cdot X_n + \varepsilon \quad (2)$$

Prior to its application, the dataset was segmented, with 70% of the samples being used for model calibration and the remaining 30% for subsequent validation. With the corresponding calibration samples, the MLR was applied using the "backward elimination" method. Although this method yields numerous models, only two models were selected, taking into account that the value of the coefficient of determination ($R^2$) was adequate considering its significance value, and that the number of covariates was as small as possible.

Subsequently, for the selection of the final model variables, Generalised Linear Models (GLM) were estimated using the covariates of each model chosen, obtaining a value of the Akaike Information Criterion (AIC). In this way, the model with the lowest AIC value was selected or, in the case where the value was similar for both models, the one with the lowest number of covariates was selected.

Finally, once the covariates that best explained the electrical conductivity in each case were known, another MLR was applied again, forcing only these covariates to be used in order to obtain the final equation.

## 4 Results

Due to the low $R^2$ coefficients achieved after working with all the available soil data in the study area, it was decided to work with two sample groups according to the analytical laboratory. The initial correlation analysis applied to the 132 soil samples showed similarities for both laboratories studied, discarding from the analysis the profile curvature and planform curvature variables, as well as a land use variable and a lithology variable.

Although the soil indices show high correlations, we worked with all of them since each one represents different edaphic characteristics. However, regarding the vegetation indices, NDVI and SAVI were discarded because their correlation with EVI showed a P value of 0.990. After this preliminary analysis, MLR was implemented.

- "Análisis Integrales" Laboratory

Two models were selected with $R^2$ coefficients of 0.587 and 0.581, respectively. After performing the GLM with these models, an AIC value of − 124.11 was obtained for both, and the second model ($R^2 = 0.581$) was finally chosen as it was the one that considered the fewest covariates. It can be seen that the indices, mainly soil indices, are the ones that best explain the $EC_x$, although topographic variables are also important (Eq. 3). This model showed a significance value of 0.000 ($p < 0.001$), so the results are statistically representative.

$$\begin{aligned}\mathbf{EC_x} = {} & -0.597 + \left(\left(4.682 \times 10^{-5}\right) \times \text{BI}\right) + (-0.036 \times \text{LAND\_USE}) \\ & + (0.053 \times \text{CURVATURE}) + (0.745 \times \text{CAI}) + (-0.043 \times \text{TEMP}) \\ & + (-0.004 \times \text{ASPECT}) + (0.037 \times \text{LITHO}) + (-0.461 \times \text{CI}) \\ & + (0.001 \times \text{ELEVATION}) + (0.566 \times \text{EVI})\end{aligned} \tag{3}$$

- "APPLUS" Laboratory

Again, two models have been selected whose $R^2$ values are 0.395 and 0.382, respectively. The GLM provides an AIC value of − 115.66 for both, with the second model ($R^2 = 0.382$) being selected because it has fewer covariates. The covariates associated with the indices have higher weight, followed also by those corresponding to the topography factor (Eq. 4). In this case, the significance value is higher than 0.005 ($p = 0.255$), so the results are not statistically representative.

$$\begin{aligned}\mathbf{EC_x} = {} & -0.470 + (0.049 \times \text{TEMP}) + (-0.001 \times \text{RAIN}) \\ & + (-0.081 \times \text{LAND\_USE}) + (0.021 \times \text{SLOPE}) + (-0.005 \times \text{ASPECT}) \\ & + (-0.010 \times \text{MRVBF}) + (-0.080 \times \text{CURVATURE}) + (0.280 \times \text{SI}) \\ & + (0.208 \times \text{EVI}) + (0.260 \times \text{CAI}) + \left(\left(-3.036 \times 10^{-5}\right) \times \text{BI}\right)\end{aligned} \tag{4}$$

## 5 Discussion

The results obtained show that the DSM method is useful to know which variables best explain and model salinity, since the obtained $R^2$ coefficients are quite good (0.581, 0.382). However, there is much uncertainty, which can be caused by the soil samples themselves, either by inhomogeneity of the measurements or by poor spatial distribution of the samples. It may also be due to the use of a high number of environmental covariates and to the error associated to them, as these come from several different data sources.

The indices derived from satellite images stand out, both those associated with the soil factor and the organism factor (Table 2), as well as the covariates corresponding to the topography factor. In the latter case, curvature is the most relevant.

Comparing these results with those obtained by other authors, they show similarities. Omuto et al. [16] applied MLR in a study area located in Lesotho, where they obtained an $R^2$ value of 0.460, which does not differ much from those obtained in this study (0.581, 0.382). Mosleh et al. [17] also applied MLR, resulting in a worse $R^2$ (0.110).

On the other hand, Taghizadeh-Mehrjardi et al. [18], although they used superlearning techniques, among all those statistical techniques was MLR which showed an $R^2$ of 0.230, which is slightly worse than the results of this study.

In turn, these authors corroborate the importance of both satellite image-derived covariates and topographic covariates for spatial modelling of salinity [16, 18, 19]. It is also worth noting that Mousavi et al. [4] concluded that the best results are obtained when both types of covariates are used. In their case, by applying MLR using only satellite indices they obtained an $R^2$ of 0.506, while using also topographic variables the $R^2$ value increased to 0.660.

## 6 Conclusions

Following the analysis and discussion in this research, the DSM was concluded to be a useful methodology to obtain the most relevant covariates in the soil salinity modelling; highlighting those associated with the topography factor, as well as the variables corresponding to the indices calculated from satellite images.

Soil salinity is an emerging future challenge in agricultural areas, especially in those that are more susceptible. Salinity threatens soil quality and crops productivity, which means a reduction in supply to the population. Given the previous, further research on this topic is required, using methodologies such as DSM to identify those susceptible areas and allowing to apply preventive measures in order to achieve the SDGs targets.

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# Virtual Exchange as a Sustainable Approach to Intercultural Learning

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**Abstract.** The purpose of this paper is to provide insight into Virtual Exchange, a relatively underdeveloped tool for the internationalisation of Higher Education Institutions (HEIs) that offers a sustainable, easily-accessible opportunity to enhance students' intercultural communicative competence (ICC). Several studies have reported a lack of authentic intercultural learning and skills in university students who come back to their home institution after a study abroad experience (Batardière in J Virtual Exchange 2, 2019, [1]). With this in mind, it has been argued that students need a preparatory phase to reflect and acquire skills to cope with the difficulties of studying abroad and the knowledge to fully benefit from the stay. In addition, students whose financial or personal situation does not allow them to go on exchange should also have the chance to become interculturally aware and skilled. This paper examines the sustainable component of virtual exchange (VE) and presents a newly designed model of exchange for undergraduate students of the EURECA-PRO alliance. This project is underway at the Universidad de León and is one of a few recent examples of online pre-mobility that can be found in Europe. It is a multicultural free programme, firmly committed to a sustainable accessible-to-all education that fosters the development of intercultural sensitivity, transversal or soft skills, democratic citizenship, foreign language learning, and collaborative learning. The results of the research will be expressed at a later time when data have been gathered and analysed.

**Keywords:** Telecollaboration · Virtual exchange · Sustainable education

## 1 Introduction

Can international programmes be more sustainable? Can students become interculturally aware while at the same time minimising the environmental impact of traditional study abroad experiences? International mobility programmes such as the Erasmus + Exchange have been on the rise in the last decades but the Covid-19 pandemic brought a new reality to the sphere of international education. One of the drastic changes that we underwent is the shift into a more digitized education. Videoconferencing tools became a widely-used instrument to confront this new reality but researchers had already been exploring this tool for decades. One of the most effective educational uses we can give these is the development of students' intercultural awareness, collaboration and communication skills by creating a virtual space where they can interact with people from


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other countries. Virtual exchange (VE) is an innovative practice whereby students who are geographically separated or belong to different cultural backgrounds collaborate and interact online to carry out tasks, activities or project work with the help of educators or facilitators [2]. Not only is VE a suitable option for those students who cannot afford to study abroad or those who are interested in multicultural contexts but it is also an environmentally-friendly option whose single resource is a stable internet connection. It allows HEIs to create a free, accessible-to-all option for their students. Virtual exchanges allow students to acquire the skills required to communicate in intercultural situations without travelling abroad. It certainly is not a replacement for physical mobility but it is an opportunity to learn and be sustainable.

## 2 Background

VE has been implemented in various forms. The most frequent VE implementation is as part of a university course or module for which students receive a certain number of credits or part of a grade. They have also been put into practice as programmes that aim at preparing students for physical international mobility under the name of pre-mobility [1, 3]. For decades, experts have argued that sojourners who embark on an exchange such as Erasmus + come back to their home institution without having really acquired the intercultural awareness, knowledge and skills that were expected from them and this, research shows, is due to a lack of preparation [1]. I argue here that pre-mobilities could be part of the solution. Not only do such programmes benefit students who need training for a study abroad but also offer an international experience to those who cannot afford to go on exchange for financial or family reasons, which students say are their main barriers [4].

The most recent implementation of this sort of exchange is the Gear Up! Virtual Exchange, designed by the Universidad de León to respond to the current needs of the institution: to prepare students for their study abroad experience, help participants develop transversal skills for the labour market and offer a free sustainable opportunity for undergraduate students who cannot study abroad to develop their intercultural communicative competence (ICC). Byram described ICC as having five skills, or savoirs: intercultural attitudes such as those of interest or open-mindedness, to decentre our own culture (savoir être), knowledge about one's own culture and that of the interlocutor's (savoirs), interpreting and relating skills (savoir comprendre), discovery and interaction skills (savoir apprendre/faire) and critical cultural awareness (savoir s'engager) [5]. This virtual approach to intercultural and language learning enables students to acquire a wider awareness of their own perspective of the world and that of others, as they are exposed to authentic intercultural interaction and negotiation of meaning with members of other cultures [6].

Other projects whose objective is to prepare students for intercultural interactions have been implemented at universities in Spain, Ireland, and Belgium. These are the I-Tell project [7], the VIP project and the Ready, Mobility, Go project [1]. This virtual preparatory phase seems to be a valuable option to increase the number of students who can experience and enrich their intercultural learning. The European Commission expects a minimum of 20% of European students to have a study abroad experience and we are still far from this number [8]. Although VE does not replace this form of mobility, it helps students towards acquiring a more intercultural, globalized, tolerant perspective of themselves and their society in one of the most sustainable forms possible.

Research shows that the benefits of participating in a virtual exchange are manifold. In addition to its sustainable component, VE offers a space where students can engage in interdisciplinary collaborative learning, allowing for the establishment of wider, more comprehensive networks and facilitating career advancement [9]. In view of the fact that participants are in contact with diverse nationalities and cultures and are forced to question their beliefs, they are more likely to develop a global mindset and critical thinking [9]. This educational strategy is also a tool to develop the communicative and intercultural spheres of their foreign language, thus helping participants to build a broader sense of self. Instead of developing their linguistic competence to, later on, become tourists, virtual intercultural exchange could help them to build confidence in a foreign language and reflect on their encounters with people from other countries [10].

## 3 The Sustainable Component in Virtual Exchange

Studying abroad is beneficial for most students and it can be a life-changing experience. However, this is an expensive form of education that not all students can afford for diverse reasons. Furthermore, when students go on exchange to improve a language or develop skills they would not acquire within their comfort zone, they are also contributing to climate change. It is inevitable that we contribute to the pollution of the air when we travel abroad, whether it be as part of university studies, business or leisure. This is not to say that traditional mobility programmes should disappear or decrease but we believe there is space for new, socially and environmentally sustainable, accessible-to-all options, like VE [11]. Not only can this tool help students develop their intercultural, communicative, linguistic and transversal competencies but if implemented appropriately, it is likely to enhance any physical international mobility. It can be implemented in a myriad of ways, based on discipline, skills to be developed, a foreign language to improve or even on the different educational levels (primary, secondary, etc.).

Nowadays there is a demand for greener methods and options to reduce our carbon footprint. There is a need to reduce emissions of waste and pollutants and implement low-carbon and climate-friendly strategies, as our traditional habits and industries are taking a high toll on our planet. The internationalisation of Higher Education Institutions (HEIs) is an area where sustainable measures can be of use. Educational videoconferencing can help to reach this goal. Nothing can compare to travel and its benefits but with the ever-increasing climate change we are undergoing, we must think of sustainable options that can complement this educational tool, be sustained in time and suit all students' necessities. VE is often based on video conferencing, which, in addition to saving travel time, cost and fuel, also helps save carbon emissions [12]. VE allows students to maintain an ecological balance and avoid the depletion of natural resources in the long term while providing a space for intercultural learning.

Besides travel expenses and the issue of carbon footprint, international mobility programmes require that students pay for accommodation, thus increasing the cost of their experience and decreasing the number of students who can afford these stays.

VE seems to be the perfect opportunity to help reduce these costs and increase the number of students who can afford intercultural learning, but it is no substitute for physical mobility, as both practices offer different benefits and life experiences [13]. Implementing intercultural online exchanges offers social equity, as every student can acquire new skills and valuable knowledge that they can benefit from regardless of their financial or personal situation. It caters for all and a larger number of learners. VE is an opportunity for universities to increase learners' awareness of sustainability and the impact of travel and environmental-friendly strategies on our planet.

It is worth mentioning that this practice has become more prominent since the Covid-19 global crisis, which challenged traditional modes of mobility and intercultural learning. VE can, in such cases where physical mobility is not possible, be also effective. Other groups of students who can take advantage of this educational tool are learners who are not sure they want to participate in such an experience and want to try it out beforehand or students whose language level or skills are not enough to face the challenges and demands of studying abroad.

Some already regard this sustainable approach as a proactive alternative that can suit some students whose necessities and affordances differ from those who embark on traditional mobility programmes [14]. This educational strategy can be maintained in time and afforded by most institutions and learners. So, why not consider it as an option either to prepare students for mobility, and thus increase study abroad experiences' value, or as a sustainable opportunity for students to benefit from intercultural learning?

## 4 A Sustainable Path to Intercultural Learning at the Universidad de León

One of the most recent implementations for the internationalisation of the Universidad de León is the Gear Up! Virtual Exchange for study abroad. This VE aims at preparing students for a study abroad experience and to offer an easily accessible opportunity for those students who cannot afford it or who are in their last year and whose chances are over. In this eight-week online intercultural exchange students are teamed up to collaborate and complete six different tasks related to the theme of study abroad and multicultural contexts. Participants must be undergraduate students of any discipline who want to study in another country or are eager to learn about other cultures. The vehicular language employed is English and students are guided and assisted by educators and facilitators to improve their communication and linguistic skills. Although the focus of this set of tasks is on intercultural interactions and language skills development, we also seek to help students enhance their transversal or soft skills, such as networking, teamwork, digital literacy, critical thinking, online communication, problem-solving or time-management skills. These competencies are highly esteemed in twenty-first century's labour market, will upgrade participants' employability prospects and correspond with the vision and demands of the EURECA-PRO alliance [15].

The European University on Responsible Consumption and Production [16], whose values align with those of the exchange, offers the Universidad de León a chance to recruit undergraduate students from universities that belong to this institutional partnership. Gear Up! provides institutions with an opportunity to become more intercultural, to create an international network that alumni can benefit from even after the interaction, and a chance to develop a virtual and integrated European campus [16]. It contributes to the alliance's goal towards an inclusive, sustainable, interdisciplinary community that is compromised with the future of our planet and the career prospects and skills of alumni. Students participating in this VE will be required to work on six telecollaborative tasks based on the progressive exchange model of telecollaboration [6]. This model generally asks students to complete tasks where they have to exchange information about their cultural background and perspectives, or discussions about shared texts [17]. The tasks cover the themes of cultural differences and stereotypes, useful tips for studying abroad, university life, public transport and health systems or accommodation across countries.

This online intercultural exchange will start in October 2022 and run until the end of November 2022, when data will be collected and analysed. Using a mixed-methods approach to research, we intend to examine the qualitative and quantitative data that will be gathered in various forms. Firstly, we will carry out pre and post-tests to delve into students' concerns, fears and knowledge of how to act in intercultural online contexts. The data from these tests will be analysed following a mixed-methods approach. We will also examine students' reflective e-portfolios, collected after their VE interactions. These data are complemented by short face-to-face interviews conducted with the vice-rector for Internationalisation and staff from the office of International Relations at the Universidad de León before designing the exchange model. All qualitative responses will be interpreted according to the principles of Thematic Analysis (TA) [18]. This qualitative analysis will be supported by a brief quantitative analysis with the tests and pre and post-exchange surveys that will be sent to all participants. We also intend to examine students' perspectives and attitudes after taking this VE and participating in a physical international mobility programme.

## 5 Reflections

With the many advantages that research on VE and telecollaboration has proven and the recent developments in the field [19], not putting this tool to good use would be a mistake. In the years to come, we hope to see virtual exchanges such as Gear Up! become an integral part of the curriculum, not only in foreign language classrooms, where this practice is more prominent but also in other disciplines where the internationalisation of education and the intercultural awareness of students seems to have been long forgotten and reduced to a privileged minority, as it is the case with medical students, for example [20]. Given the significance that international relations have in our modern, globalised society, virtual exchanges are now, more than ever, an opportunity to become cosmopolitan, open-minded, democratic citizens of the world while respecting the environment and being inclusive. VE is an innovative, sustainable and economical strategy to reach institutions' objectives of internationalisation. However, we must remember that its successful implementation requires the involvement and collaboration of diverse institutions and university departments.

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# Correction to: Damage Tolerance Approach in the Concept of Quality Control Workflow of Passive CFRP Strengthening of Reinforced Concrete

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In the original version of this chapter, the authors' given names and family names have been changed from "Białozor Rafał and Górski Marcin" to "Rafał Białozor and Marcin Górski". The correction chapter and the book has been updated with the changes.

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