Circular Economy and Sustainability

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Innovation, Quality and Sustainability for a Resilient Circular Economy

The Role of Commodity Science, Volume 2

Springer

Circular Economy and Sustainability

This book series aims at exploring the rising field of Circular Economy (CE) which is rapidly gaining interest and merit from scholars, decision makers and practitioners as the global economic model to decouple economic growth and development from the consumption of finite natural resources. This field suggests that global sustainability can be achieved by adopting a set of CE principles and strategies such as design out waste, systems thinking, adoption of nature-based approaches, shift to renewable energy and materials, reclaim, retain, and restore the health of ecosystems, return recovered biological resources to the biosphere, remanufacture products or components, among others.

However, the increasing complexity of sustainability challenges has made traditional engineering, business models, economics and existing social approaches unable to successfully adopt such principles and strategies. In fact, the CE field is often viewed as a simple evolution of the concept of sustainability or as a revisiting of an old discussion on recycling and reuse of waste materials. However, a modern perception of CE at different levels (micro, meso, and macro) indicates that CE is rather a systemic tool to achieve sustainability and a new eco-effective approach of returning and maintaining waste in the production processes by closing the loop of materials. In this frame, CE and sustainability can be seen as a multidimensional concept based on a variety of scientific disciplines (e.g., engineering, economics, environmental sciences, social sciences). Nevertheless, the interconnections and synergies among the scientific disciplines have been rarely investigated in depth.

One significant goal of the book series is to study and highlight the growing theoretical links of CE and sustainability at different scales and levels, to investigate the synergies between the two concepts and to analyze and present its realization through strategies, policies, business models, entrepreneurship, financial instruments and technologies. Thus, the book series provides a new platform for CE and sustainability research and case studies and relevant scientific discussion towards new system-wide solutions.

Specific topics that fall within the scope of the series include, but are not limited to, studies that investigate the systemic, integrated approach of CE and sustainability across different levels and its expression and realization in different disciplines and fields such as business models, economics, consumer services and behaviour, the Internet of Things, product design, sustainable consumption & production, bio-economy, environmental accounting, industrial ecology, industrial symbiosis, resource recovery, ecosystem services, circular water economy, circular cities, nature-based solutions, waste management, renewable energy, circular materials, life cycle assessment, strong sustainability, and environmental education, among others.

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Foreword

The weaknesses of the current economic, social, and environmental scenario, together with the impact of the COVID-19 pandemic that the humankind has faced, are increasingly stimulating an in-depth reflection on the organizational models that today's society is based upon. Those are mainly related to consumers' behaviours and to the productive models of businesses and organizations, as well as to the functioning of national and supranational socio-political systems.

Therefore, in the process of restoring stability, it is desirable that any form of circular economy (CE) system derive from the implementation of the relevant issues of sustainability, innovation, and quality, not only on the scale of production but, also, on that of use/consumption and disposal. Here comes the life cycle thinking (LCT) perspective that is based upon designing not just products but also products' life cycles that comply with the goals and targets of sustainable development. Doing so will make it possible to satisfy CE principles and loops, and so extend products' life cycles, and close resource loops through recycling processes. This is a huge challenge that should follow an approach based on exchanging and sharing knowledge, thereby going beyond the multidisciplinary and transversal approach that has always been a classic in Commodity Science. The latter is aimed at collecting the homogeneous and unitary body of research fields that revolve around the production of material, food, and energy commodities. This includes the study, analysis, and evaluation of both resources and technologies used for their extraction and transformation. It is also expanded to the assessment of the consequent implications on the total quality and use value of the goods and on the external environment with which they interact, including the environmental management and certification systems.

Commodity science can play multiple relevant roles in this regard, as it is highly attached to innovation, eco-design, quality, circular economy, industrial ecology, and sustainability. All of those relevant issues and related complex problems involve a holistic system approach, regulatory aspects, and empirical knowledge and demand the active participation of all stakeholders involved in the commodity's life cycle, including designers, technicians, practitioners, producers, company managers, and retailers. Therefore, it is recommended that the making of public decisions for promotion of aforementioned issues is supported and informed by scientifically sound quantitative information so as to discern values from facts and to help a fair attribution of responsibility along the entire supply chain and life cycle. Under this perspective, the XXX National Congress of Commodity Science can play multiple key roles, as it created a valuable platform to share and build upon knowledge and skills in a way to strengthen the already existing links among the key actors of the world of academia and research, industry, and politics discussion and study.

President of AISME (Italian Scientific Association of Commodity Science),
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Alessandro Ruggieri

Preface

The XXX National Congress of Commodity Science was held in Bari (Italy) on 27 and 28 October 2022; it was promoted by the Italian Academy of Commodity Science (AISME) and was hosted by the Department of Economics, Management and Business Law of University of Bari Aldo Moro. Its aim was to explore the relevant quality, innovation, circularity, and sustainability issues, in an integrated and multidisciplinary approach.

The Congress collected a total of 113 contributions, which can be considered as the sign of the relevance and importance of the research themes it was conceived to address.

The Congress hosted an opening session for institutional greetings, followed by a keynote speech on sustainable innovative energy production systems and an oral section conceived to an overview of the key findings from poster-presented research. In particular, the contributions received were assigned 21 oral presentations and 92 posters. The Congress was then structured into three plenary sections (each per thematic area), chaired by spokes-professors of the Academy, to host the aforementioned oral presentations. The latter were selected in a way to:

– Make sure that the Congress could provide sector operators with methodological tools enabling understanding of the current evolutionary dynamics, particularly in innovations and quality analysis and management
– Contribute to developing new growth models and paradigms towards paths for sustainable development strategies on the micro- and macro-dimension scale in the medium-term time horizon

This year's edition of the Congress was the 31st, with the first held in the early 1960s in Bari[1][#], which contributes to making it an event of undoubted historical significance. In Appendix 1, the reader will find all the Congress events that have

[1#] "Convegno sul tema: Progresso tecnologico e miglioramento della qualità", Bari, 12-13 settembre 1962. Atti in: Quaderni di Merceologia (Bari), 1, 1, Bari, Editore Cressati.

been organised since then. In all of this, it must be said that the commodity science school of Bari is undoubtedly one of the oldest and most prestigious in Italy; it all dates back to the School of Advanced Studies of Commerce that, when founded in 1886, was the fourth in Europe. Over the course of its history spanning more than 130 years, the school has contributed to advancing research both at the national and international level. This has been documented by a historical library with volumes dating back to the second half of the 1800s and a commodity science museum that contains vintage equipment and materials that were used and tested for original research development.

The Congress represented a platform for the exchange of knowledge and skills in all those research development fields which commodity science has always interfaced with, giving its important contributions, including material science, energy, agriculture, engineering, business management, quality management, innovations, and social equity. To that end, researchers, practitioners, managers, producers, and other stakeholders were positively involved in the Congress. In particular, the Congress managed to trigger a constructive dialogue with the territory and with economic, industrial, and political stakeholders on environmental, economic, and social issues related to natural resource exploitation and environmental pollution. In doing so, particular attention was paid to the aspects of innovation, quality, and sustainability that were assessed by Congress participants, with a holistic system perspective, through application of internationally recognised scientifically based methodologies capable of implementing sustainable aims and improving the economic-environmental performances of economic activities, including material flow analysis, life cycle assessment (LCA), and the multi-indicator environmental footprint accounting. This will contribute to the upswing and resilience of companies and societies, despite the undeniable difficulties deriving from the pandemic, the current geopolitical upheavals, and the consequent international economic crisis.

An adequate and timely transition towards a green economy could represent an important opportunity for local territories to improve their levels of quality, sustainability, and competitiveness in the medium and long term. This puts emphasis on the need for economic operators to comply with the obligations required by the reference legislation in the context of transitioning to sustainable circular forms of the economy; doing so will allow them to assess the possible future implications on their business activities. This can be relevant and useful for all public and private organisations operating in various economic sectors. Furthermore, dissemination of results from the Congress can represent an important knowledge-enhancement opportunity for all those entrepreneurs and producers who intend to undertake initiatives with reduced environmental and socioeconomic impact.

In the light of this, economic operators (i.e., managers, entrepreneurship, business associations, public decision-makers) and students were invited to take active part in the Congress for a profitable and mutual exchange of information on the Congress research themes. Furthermore, several business companies have supported this event; their names have been highlighted in a dedicated section in the continuation of the book.

In this context, it is worth highlighting that the Congress objectives and targets fully reflect the purpose recognised by the AISME founders of advancing and promoting commodity science development in the field of scientific and applied research and enhancing the knowledge of the whole commodity science subject and related key features, especially in the sector of public institutions. In doing so, the contributions of commodity scientists will be made increasingly available to producers and consumers as well as to the society as a whole. This can play an essential role in the implementation of technological innovation solutions for creation of production and consumption models that are urgently needed to move towards a society that respects the principles and objectives of sustainable development.

Thanks to the remarkable number of contributions and the numerous opportunities created for debating and sharing ideas, the Congress managed to address key environmental and socioeconomic issues. These can encourage good practices for implementation of circular economy models to best combine profitability with sustainable environmental management and quality of commodities.

The 113 conference papers went through a double-blind review and were put together to form this book titled *Innovation, Quality and Sustainability for a Resilient Circular Economy: The Role of Commodity Science* that is published by Springer Nature as part of the Circular Economy and Sustainability series. Considering the number of papers included and the resulting length of the book, the latter was split into volume 1 and volume 2, both comprising papers dealing with the most relevant and up-to-date issues of innovation, quality, and sustainability in a wide range of sectors.

Under this perspective, Volume 1 explores the sectors of agriculture, biomass, foods and beverages, consumers' awareness and behaviours, digitalisation, and tourism.

Volume 2, instead, investigates the waste management sector and several others related to energy, materials, and transports. In addition to this, Volume 2 reviews and builds upon the general important aspects of quality, circular economy, and sustainability.

Though it came to a national congress, there has been papers being contributed by authors' teams coming from European countries like Poland and Spain. Such puts emphasis upon the attention and interest that research themes like those addressed by the Congress spark on the international level. Furthermore, scanning through the 113 papers, the book editors could see that research development was often taken as the occasion to strengthen ongoing collaborations both at the national and international level and create new ones.

The collected papers explored the three themes the Congress was centred upon in a multitude of sectors. In this regard, from Fig. 1 there is evidence that "Agriculture, biomass, foods and beverages" was the most investigated one with a total of 37 papers, followed by waste management and a miscellaneous of general facts, with 14 papers each either way, whereas, as evident from Fig. 2, the majority of the conference papers (61%) investigated circular economy and sustainability–related issues.

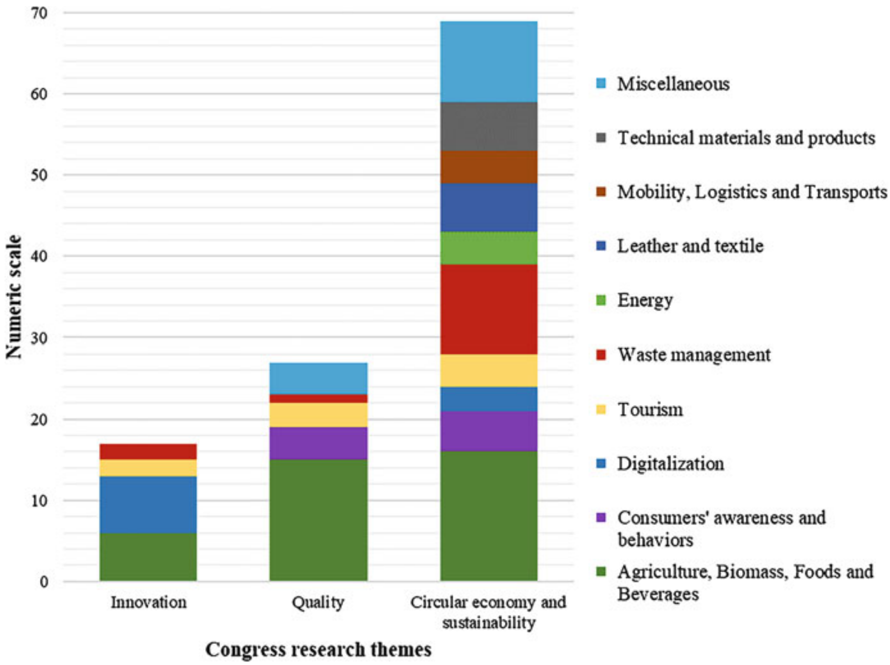

Fig. 1 Number of conference papers per thematic research area and investigated sector

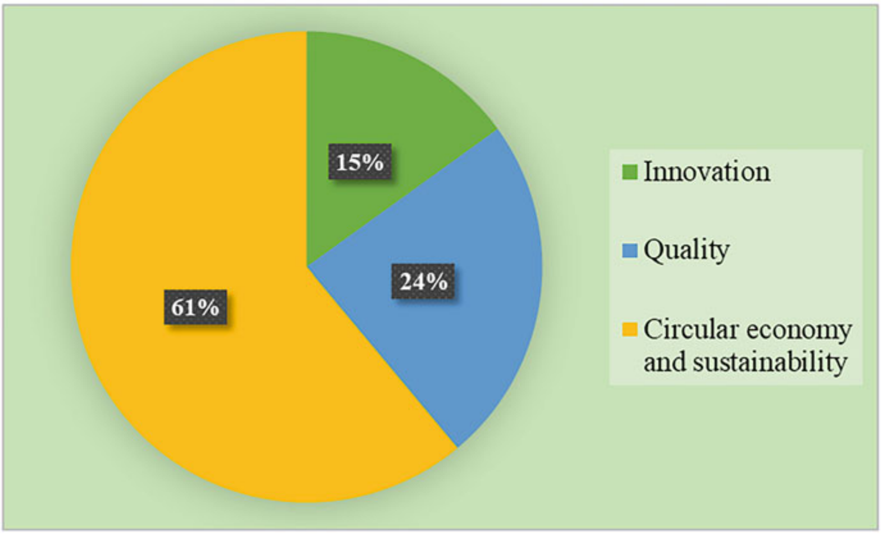

Fig. 2 Percentage distribution of the collected conference papers based upon the thematic area they have addressed

Based upon the number and quality of the contributions, it can be asserted that the Congress attained its main objectives of updating, advancing, and promoting interdisciplinary research on innovation, quality, circular economy, and sustainability.

The 113-paper collection is expected to make it possible for the Congress to advance knowledge on the subjects of quality of commodities and of ecological transition, with particular attention to the innovations and to the environmental and socioeconomic implications on the production, use, and consumption of material and energy commodities that are currently available on the market.

Finally, findings contained in this volume will contribute to guiding public and private decision-makers in the identification process of the most appropriate methods and timing in the processes of innovation for commodities' quality enhancement and of transition to a sustainable equitable efficient economy and providing economic operators with in-depth knowledge to deal more effectively and efficiently with the related implications and opportunities.

Bari, Italy

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We would like to deeply thank the sponsors for their support to the Congress. It was a real fortune for us to be able to bank upon your generous donors, which contributed to making the Congress possible.

Thanks for supporting us to create a platform for the exchange of knowledge on the relevant issues of innovation, quality, and sustainability, and on the measures to take to accelerate the transition to a sustainable, equitable, circular, post-fossil carbon society.

The Congress was just the beginning of a new joint collaboration journey, as we would be honoured to have the opportunity to work closely with your business in the future!

With gratitude
The Editors

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Part I
Waste Management: Innovation and Quality

Chapter 1
Development of an Innovative Controlled Drying Technology for the Recovery of Waste from the Wine Chain from a Circular Economy Perspective

Margherita Campo, Chiara Cassiani, Francesca Ieri, Silvia Urciuoli, and Annalisa Romani

Abstract The circular economy model applied to the wine industry is linked to the enhancement of waste from wine production, which is represented by grape leaves and grape pomace. Recent studies have described these waste products as rich in antioxidant and antimicrobial bioactive molecules, such as anthocyanins, flavonoids, procyanidins, and other polyphenolic derivatives. The presence of these molecules allows the recovery of waste from the wine chain to obtain semifinished and finished products applicable in different sectors. This work involved the development of an innovative soft and controlled drying technology, which was applied to grape skin and seeds through the use of a chamber characterized by the control of the process parameters, in particular temperature, humidity, ventilation, drying time, and sanitization with ozone and/or UVC radiation, to maintain the biological properties of the unaltered plant matrix. The ability of this process to preserve the content of active molecules of *Vitis vinifera* L. was indeed demonstrated by HPLC-DAD-MS characterizations and Folin-Ciocalteu spectrophotometric assays. The dried grape skin and seeds were subjected to controlled micronization to obtain innovative functional products for use in green agriculture, cosmetics, food, nutraceutical, and wine making, allowing them to respond to circular viticulture and industrial symbiosis models.

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Keywords *Vitis vinifera* L. · Polyphenols · Drying chamber · Byproducts · Circular economy

1.1 Introduction

Winemaking of *Vitis vinifera* L. produces wastes consisting of solid residues (pomace), lees, and wastewater. White wine vinification, carried out without maceration of skins, produces stalks and pomace; red wine vinification leads to obtaining stems and pomace after the period of maceration. A considerable amount of organic solid waste is produced during the crushing and pressing processes and wine clarification. After pressing to obtain juice/must, pomace contains mainly grape skins, seeds, and some pulp residue. It is estimated that only in Italy are 0.1–0.3 million tons/year of seeds produced from the winemaking process (Accardi et al. 2013). The waste of the vines is also from foliar pruning and thinning of the bunches, i.e., stalks, unripe grapes, grapevine shoots and leaves (Beres et al. 2017). The circular economy model applied to the wine industry is linked to the enhancement of waste from wine production, which is represented by grape leaves and grape pomace. Recent studies have described these waste products as rich in antioxidant and antimicrobial bioactive molecules such as anthocyanins, flavonoids, procyanidins, and other polyphenolic derivatives (Ruggieri et al. 2009; Lucarini et al. 2018; Romani et al. 2020). A large number of scientific studies have demonstrated that polyphenols have a variety of beneficial effects on human health, particularly in treating diabetes mellitus, CV diseases, dyslipidemia, and cancer (Latruffe and Rifler 2019).

The presence of these molecules allows the recovery of waste from the wine industry to obtain semifinished and finished products applicable in various product sectors. Starting from the waste, it is possible to obtain secondary raw materials that can be used in the wine production chain or in different supply chains, which can create new business opportunities by applying the principles of the circular economy.

This work involved the development of an innovative soft and controlled drying technology, which was applied to grape skin and seeds through the use of a chamber characterized by the control of the process parameters to keep the biological properties of the plant matrix unaltered.

The dried grape skin and seeds were then subjected to controlled micronization to obtain innovative functional products for use in green agriculture, cosmetics, food, nutraceutical, and wine making, allowing them to respond to circular viticulture and industrial symbiosis models. The ability of this whole process to preserve the content of active molecules and the antioxidant capacity related to *Vitis vinifera* L. has been demonstrated by HPLC-DAD-MS characterizations and Folin-Ciocalteu spectrophotometric assays.

1.2 Material and Methods

1.2.1 Production of Micronized Powders

Grape skin and seeds were dried by using the following procedure (Romani et al. 2020). From 100 kg of fresh material, the dried product was obtained in yields of 33–98%. The drying process was optimized using a drying chamber equipped with real-time process control. The characteristics of the drying chamber relate to the control of the times for carrying out day and night cycles, control of temperature and humidity with the aid of special internal and external probes, ventilation and dehumidification units for better heat distribution, regulation of the intensity of luminous flux emitted by UV devices, and sanitization of the product through ozone (O_3) and/or irradiation with ultraviolet light (UVC). The drying process can be remotely monitored using an internet network connected to a computer or a smartphone, and furthermore, the setting of the drying program can be programmed via the user interface tablet. For micronization, a granulometry of 1.8 mm was set.

1.2.2 HPLC-DAD-MS Analysis

The analyses for the qualitative and quantitative evaluation of bioactive compounds of powders and extracts were obtained using an HP-1260 liquid chromatograph equipped with a DAD detector (Agilent-Technologies, Palo Alto, USA). The HPLC system was interfaced with an Agilent MS system equipped with an ESI source (Agilent Corp, Santa Clara, CA, USA). Analyses were acquired in full-scan mode, and the mass range was set to m/z 100–1500 in both positive and negative modes. Analytical columns and chromatographic methods are described in Romani et al. (2020). Polyphenols found in the extracts were identified by comparing retention times and UV/Vis spectra with those of authentic standards. Each compound was quantified at the selected wavelength (240, 280, 330, 350, and 520 nm) using a five-point regression curve and applying the correction of the molecular weights (Romani et al. 2020).

1.2.3 Evaluation of Antioxidant Activity by the Folin-Ciocalteu Spectrophotometric Assay

The total antioxidant capacity was evaluated by using the Folin-Ciocalteu method on extracts from the two samples. Five hundred microliters of water and 125 μL of Folin-Ciocalteu reagent were added to 125 μL of suitably diluted extract, and the solution was kept for 6 min in the dark. Subsequently, 1.25 mL of Na_2CO_3 at 20% in H_2O was added, and then, the solution was brought to a volume of 3 mL with water.

The solution was left in the dark for 85 min and then centrifuged for 5 min at 5000 rpm. The spectrophotometric reading was carried out at 725 nm using a Lambda 25 spectrophotometer (PerkinElmer, Waltham, MA, USA) and using the extraction solvent (70:30 hydroalcoholic solution pH 3.2) as a blank. The results are expressed in mg of gallic acid (GAE) per g of powder.

1.3 Results and Discussions

This work involved the development of an innovative soft and controlled drying technology, which was applied to grape skin and seeds through the use of a chamber characterized by the control of the process parameters, in particular temperature, humidity, ventilation, drying time, and sanitization with ozone and/or UVC radiation, to maintain the biological properties of the unaltered plant matrix. The dried grape skin and seeds were subjected to controlled micronization to obtain, as a final product, a powder with 1.8 mm granulometry. The ability of this process to preserve the content of active molecules and the antioxidant capacity related to *Vitis vinifera* L. has been demonstrated by HPLC-DAD-MS characterizations and Folin-Ciocalteu spectrophotometric assays. The results of the quali-quantitative analysis of the polyphenolic content in the two micronized powders are shown in Table 1.1.

Table 1.1 Quali-quantitative HPLC/DAD/MS analysis of polyphenols in the micronized powders, data expressed in mg compounds per gram of sample

Polyphenols	Seeds	Skin
Gallic acid	0.08	0.07
Other procyanidins	0.25	0.25
Catechin dimer B3	1.67	1.66
Epicatechin	0.31	0.29
Catechin trimer	2.44	2.27
Epicatechin gallate dimer	0.81	2.29
Catechin tetramers	23.82	3.02
Epigallocatechin dimer	13.37	2.31
Catechin/epicatechin trimers digallated	43.26	35.53
Delphinidin-3-glucoside	0.01	0.14
Cyanidin-3-glucoside	0.00	0.00
Petunidin-3-glucoside	0.01	0.19
Peonidin-3-glucoside	0.00	0.06
Malvidin-3-glucoside	0.05	0.69
Delphinidin-3-acetylglucoside	0.00	0.03
Cyanidin-3-acetylglucoside	0.00	0.06
Petunidin-3-acetylglucoside	0.01	0.04
Malvidin-3-acetylglucoside	0.00	0.06
Malvinidin-3-caffeoylglucoside	0.01	0.27
Total polyphenols	86.11	49.21

Total polyphenols are 86.11 and 49.21 mg/g, respectively, in micronized seeds and skin, with a prevalence of oligomeric procyanidins and a lower content of anthocyanins, given their previous use for vinification that caused the migration of a consistent amount of these latter into the wine. The antioxidant activity of the samples, related to the total phenolic and polyphenolic content and assessed by the Folin-Ciocalteu in vitro spectrophotometric assay, was 69.8 and 28.2 mg/g GAE, respectively, in micronized seeds and skin. The high content of polyphenolic compounds and the related antioxidant activity by the Folin-Ciocalteu assay highlight the good degree of optimization of the process parameters and the possibility of using them to obtain innovative functional products for use in green agriculture, cosmetics, food, nutraceutical, and wine making, allowing us to respond to circular viticulture and industrial symbiosis models.

1.4 Conclusions and Future Perspectives

In this study, an innovative and sustainable process was designed and optimized to obtain dried micronized powders from waste and byproducts of wine production. The presence of bioactive polyphenolic secondary metabolites was monitored by HPLC/DAD/MS analysis to assess the ability of the drying and micronizing systems to keep them unaltered; moreover, total antioxidant activity related to phenol and polyphenol content was assessed by in vitro spectrophotometric assay with Folin-Ciocalteu reagent.

The possibility of customizing the process allows for drying waste material from different plant matrices in addition to grapes (olive, kiwi fruit, pomegranate, artichoke, tomato, lotus, citrus, and apple), limiting the degradation of thermolabile bioactive compounds. Furthermore, the versatility of this system for controlled drying and micronization makes it potentially associable with other processes within biorefineries and multifunctional platforms for an integrated and sustainable exploitation of enological byproducts. The innovative powders optimized in this study can be considered functional antioxidant ingredients due to their chemical characterization. The content of bioactive molecules makes these powders the secondary raw materials useful in various product sectors, such as food, feed, oenological, nutraceutical, cosmetic, and agronomic sectors. This turns into a new business opportunity for companies, especially in sectors other than wine production.

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Chapter 2
Reduction of Food Waste and Donations of Surplus Food in Retail Stores: A Survey Proposal

Alfredo Ernesto Di Noia, Giuseppe Martino Nicoletti, Giulio Mario Cappelletti, and Carlo Russo

Abstract Efforts against food waste by reducing food surplus and increasing donations for humanitarian purposes are priorities in retail to achieve a sustainable food system from environmental, economic, and social points of view. The UN has adopted the 2030 Agenda with an SDG 12.3 target, which foresees that "by 2030, to halve the global food waste per capita at the retail level. . . ." The EU has adopted Target 12.3 as part of its transition to a circular economy and reinforced it in the "EU Farm to Fork." Improving management procedures to reduce food surplus is now recognized as a priority in retail. There are operational and management barriers in finding qualitative and quantitative information. In fact, there is a widespread tendency among retailers not to make the data (quantitative and economic) and their operational/managerial procedures publicly available.

In this paper, we aim to define a survey proposal aimed at measuring the degree of importance attributed by corporate management and store managers to the causes, situations, management practices, and critical factors to fight food waste by increasing the donations of surplus food. This is to overcome the barriers to obtaining qualitative improvement in future business strategies.

Keywords Surplus food · Food donations · Food waste · Survey · Business strategies · Retail store

2.1 Introduction

Efforts against food waste by reducing food surplus and increasing donations for humanitarian purposes are one of the priorities in retail to achieve a sustainable food system from environmental, economic, and social points of view. The UN has adopted the 2030 Agenda, which includes the SDG 12.3 target. This target foresees

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that "by 2030, to halve the global food waste per capita at the retail level." The EU has adopted Target 12.3 as part of its transition to a circular economy and reinforced it in the "EU Farm to Fork." Improving management procedures to reduce food surplus is now recognized as a priority in retail.

However, there are operational and management barriers to finding qualitative and quantitative information. In fact, there is a widespread tendency among many retailers not to make the data (quantitative and economic) and their operational/managerial procedures publicly available.

In this paper, we aim to define a survey proposal aimed at measuring the degree of importance among corporate management and store managers to the causes, situations, management practices, and critical factors to fight food waste by increasing the donations of surplus food for humanitarian purposes in retail stores. This is to overcome the barriers to obtaining qualitative information that can be used for the improvement of future business strategies.

2.2 Review of the Literature

Food surplus (FS) is food or agricultural and agri-food products that, without prejudice to the maintenance of hygiene and safety requirements of the product, are unsold for various reasons. One of these could be the lack of demand generated for commercial or aesthetic reasons or due to the proximity of the expiration date. These food products are still edible and can potentially be destined for human or animal consumption through food donations (FD) to charitable organizations.

However, in the absence of a possible alternative use, this food is destined to be disposed of and become food waste (FW), following a specific waste hierarchy. For some years, in Italy, specific legislation has been envisaged "to fight against food waste." The most recent is Italian Law No. 166/2016, which provides for bureaucratic and tax measures aimed at the retail sector to facilitate promotional strategies and FD to the needy in collaboration with charities (Di Noia and Cappelletti 2019). Attention to retail has increased because it plays a strategic role in reducing FW, despite having a marginal role in their generation (Cicatiello et al. 2020). This role for retailers depends on the high influence of production and consumer preferences, as well as representing the physical place where different players in the food supply chain intersect (Gruber et al. 2016). Furthermore, the theme of FW can manifest itself in different ways according to the dimensional typologies of retail stores: hypermarket, supermarket, discount store, or convenience store (Teller et al. 2018).

On the one hand, retailers have long taken measures to reduce FW (Horoś and Ruppenthal 2021). On the other hand, there seems to be a tendency among retailers not to make their data or managerial practices public. This trend could depend on the need to not disclose negative results and encourage "green telling" (Caldeira et al. 2019; Huang et al. 2021). In Italy, for many years, the Coop Italia Società Cooperativa (Coop) has analyzed, elaborated, and achieved very satisfactory results in the reduction of FS and FW (Invernizzi et al. 2017), so much so much so that it is considered a best practice case for Italian and European retail, as well as in FD (Cappelletti et al. 2020; Rutten et al. 2013). However, some retailers may not be encouraged to donate due to the potential ineffectiveness of the anti-waste law. This ineffectiveness depends on the marginal importance of the bureaucratic facilitations introduced by the aforementioned law (Busetti 2019). A further cause of ineffectiveness is the lack of a reduction in the waste tax (Franco and Cicatiello 2021). In addition, the development of FDs could also encounter considerable difficulties due to the lack of charitable organizations. In fact, to collect FDs near the deadline, especially for perishable food, considerable infrastructure (e.g., refrigerators, warehouses), human resources, and adequate vehicles are required to cope with the timely collection of these food products (Sert et al. 2018).

2.3 Material and Methods

We defined questions for a proposed survey to investigate the perception of the importance of different administrative reasons, situations, management practices, and critical factors relating to FS and FW. The closed-ended questions are as follows:

– What are the main administrative reasons used in retail stores for the classification of food surpluses at the point of sale? (Table 2.1).
– How important are the following main situations that can be an occasion for the generation of surplus food (or potential waste) in the management of the retail store? (Table 2.2).
– How important are the following management practices for an effective fight against FW? (Table 2.3).

Table 2.1 Main administrative reasons used in retail stores for the classification of food surpluses at the point of sale

Cod.	Main administrative
1	Broken packages
2	Damaged products
3	Expired products
4	Accidental damage to the product caused by personnel
5	Accidental damage to the product procured by customers
6	Broken refrigerator
7	Failure of other systems
8	Food donations due to the proximity of the expiration date
9	Food donations due to the proximity of the date “best before”
10	Food donations for slight damage to packaging (without compromising sanitary requirements)
11	Other

Sources: Authors’ elaboration from Invernizzi et al. (2017)

Table 2.2 Situations that generate surplus food (or potential waste) in the retail store

Cod.	Situations
1	Procedures for placing orders (continuous and/or promotional)
2	Limited predictability of actual customer demand and undesirable customer behavior
3	Poor skills, motivation and commitment of staff and/or leadership
4	Products too close to expiry dates (when delivered)
5	Excessive minimal packaging of products
6	Procedures for correct rotation from warehouse to shelf (e.g., nonobservance of the first-in first-out principle)
7	Deterioration due to the intrinsic characteristics of the product (e.g., fruit and vegetables)
8	Other

Sources: The table was elaborated from Invernizzi et al. (2017) and Teller et al. (2018)

Table 2.3 Management practices for an effective fight against food waste

Cod.	Management practices
1	Correct formulation of orders for different product categories
2	Study demand patterns and in-store behavior
3	Improvement of company and personnel management policies
4	Permanent inventory at the point of sale, with the control of the relative shelf life and the correct rotation from warehouse to shelf
5	Purchase/offer of products with appropriate packaging
6	Activation of promotional sales practices at the end of product life and/or at the end of the day, especially for perishable products (e.g., vegetables)
7	Organization of an effective donation service of surplus food for social humanitarian purposes (both human and animal)
8	Other

Sources: Invernizzi et al. (2017) and Teller et al. (2018)

Table 2.4 Critical factors allowing the optimization of the donation of surplus food for humanitarian purposes

Cod.	Critical factors
1	Effectiveness of the anti-waste law for FD
2	High awareness of the ethical and environmental reasons for FD
3	Excellent organizational skills of the company for FD
4	Wide availability of infrastructures, equipment, and economic resources for the management of FD
5	Other

– How important are the following critical factors allowing the optimization of the donation of food surplus for humanitarian purposes? (Table 2.4).

We assigned a score from 1 to 5 according to the following rating scale: 1 (indicates that administrative action is not at all important), 2 (unimportant), 3 (important), 4 (very important), and 5 (extremely important). In addition, we have provided for the possibility of an open response to further stimulate the interlocutor to provide information.

We developed a questionnaire with Google Forms © to be administered over a period of 1 month to both retail store managers and corporate management of a large-scale retail trade. Finally, we have inserted a section with questions relating to personal data related to gender, age group, work experience, and level of education.

2.4 Results and Discussions

The questionnaire envisaged in the study includes several sections. Table 2.1 investigates the perception of the importance of the main administrative reasons for FS in a retail store. Table 2.2 analyzes the main situations that can lead to the generation of food surplus (or potential waste) in the management of the point of sale. In particular, the most important situations were selected, both in the real data from the coop (Invernizzi et al. 2017) and in Teller et al. (2018), for all retail store formats.

The following questions allow us to identify the causes that could generate FS and therefore to foresee the adoption of consequent corrective measures. In Table 2.3, the management practices in the two aforementioned studies have been identified to address specific situations (Table 2.2). In this way, it is also possible to verify the consistency of the degrees of importance perceived in the direct relationship between situations and management practices. Finally, the critical factors (Table 2.4) that allow for the optimization of the donations of FS for humanitarian purposes have been elaborated. In this sense, it is possible to investigate the limits of FD (Busetti 2019; Sert et al. 2018; Herzberg et al. 2022).

2.5 Conclusions and Future Perspectives

In this paper, we propose a survey to evaluate the perception of the importance of retail store managers and corporate management. This is in order to satisfy the probable request of the retailers not to make public the data relating to the FS, FD, and FW. The results of the survey would allow identification of the main causes used for the classification of FS and FD. Furthermore, the results could highlight the perception of importance in relation to the different main situations that can be managed to avoid FS generation at the point of sale. From the foregoing considerations, it is evident that knowledge of the perceived importance of relative management practices would allow us to promptly orient company choices. The survey provides a strategic tool for improving the awareness of business decision makers.

Further research will concern the implementation of the survey after its improvement in collaboration with retail store managers and corporate management.

Finally, the results of the survey and the actual data on the fight against food waste will allow us to verify the usefulness of this management approach.

Authors' Contributions A.E. Di Noia carried out the bibliography and the collection and processing of the data. G. Cappelletti and A.E. Di Noia carried out the application of the methodology; G.M. Nicoletti and C. Russo reviewed the paper.

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Chapter 3
Enhancement of Waste from the Agri-food Chain as Innovative Ingredients for the Formulation of Functional Foods and Their Impact on Chronic Kidney Disease

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Abstract The largest Italian agri-food chains are represented by the production of extra virgin olive (EVO) oil and wine. Their production leads to a great amount of agri-food wastes that can represent an innovative and sustainable source of

Annalisa Romani died before publication of this work was completed.

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secondary raw materials that can be used as ingredients for functional foods. In this study, production chain wastes from EVO oil and wine, such as olive leaves, free oil olive pulp, grape skin, and grape seeds, were selected and characterized for the content of antioxidant compounds by HPLC-DAD-MS analysis. Using innovative technologies, micronized powders have been obtained from waste rich in antioxidant bioactive compounds, used as functional ingredients for the formulation of two bars based on EVO oil, rich in polyphenols, fruits, and vegetables. The bars were analyzed to evaluate their total antioxidant capacity and the antiradical activity. The formulated bars were tested for their functional action in a preliminary in vivo study on renal patients who took bars and performed adapted physical activity. The preliminary results show that the association of adapted physical activity with the consumption of functional bars rich in antioxidant and bioactive compounds leads to an improvement in body composition and other clinical parameters.

Keywords Antioxidant compounds · Functional food · Waste recovery · *Olea europaea* L. · *Vitis vinifera* L.

3.1 Introduction

Recent studies have shown that waste from the agri-food chain is rich in bioactive molecules (Romani et al. 2020). In Italy, the production of extra virgin olive (EVO) oil and wine leads to large quantities of waste. The vegetable matrices *Olea europaea* L. (Olea) and *Vitis vinifera* L. (Vitis) are chemically characterized by the presence of molecules with high active and biological value, such as polyphenols. Regarding the active molecules of Olea, we found that hydroxytyrosol, tyrosol, oleocanthal, oleacin, oleuropein, verbascoside, and ligstroside have high antioxidant and antiradical power (Romani et al. 2019). We found these molecules in EVO oil that are directly linked to the health claim of EFSA 432/2012 relating to the prevention of oxidation of blood lipids and consequent cardiovascular diseases. Some of the same molecules have also been identified in the byproducts of the olive oil supply chain, including olive leaves (oleuropein) and free oil olive pulp (hydroxytyrosol) (Romani et al. 2016). Vitis is also characterized by the presence of bioactive molecules belonging to the class of anthocyanins and procyanidins. All these molecules are linked to important functional properties, mainly antioxidant and antiradical properties, which allows these waste products to have important value and potential to be used as innovative secondary raw materials in several product sectors. Some possible applications of these products are in the food sector both as a functional antioxidant ingredient and as a natural preservative in place of chemicals. Further uses can be in the cosmetic, nutraceutical, agronomic, feed, and phytotherapeutic sectors. Recent studies have shown how the action of active molecules of the Olea europaea L., such as hydroxytyrosol, oleacin, and oleocanthal, in synergy, can assist in the therapy of patients suffering from chronic kidney disease (CDK) (Noce et al. 2021). Considering the antioxidant molecules that characterize the selected plants in this work, Olea and Vitis, it is possible to hypothesize that these innovative ingredients can be used for the design of functional food for sport and well-being but also as an integration in the diet for CDK patients.

3.2 Material and Methods

3.2.1 HPLC-DAD-MS Analysis

Qualitative and quantitative analyses of bioactive compounds of micronized products and EVO oil extract were performed using an HP-1260 liquid chromatograph equipped with a DAD detector (Agilent-Technologies, Palo Alto, USA). The HPLC system was interfaced with an Agilent MS system equipped with an ESI source (Agilent Corp, Santa Clara, CA, USA). Analyses were acquired in full-scan mode, and the mass range was set to m/z 100–1500 in negative and positive modes. Analytical columns and chromatographic methods are described in Romani et al. 2020. Polyphenols found in the extracts were identified by comparing retention times and UV/Vis spectra with those of authentic standards. Each compound was quantified at the selected wavelength (240, 280, 330, 350, 520 nm) using a five-point regression curve and applying the correction of the molecular weights (Romani et al. 2020).

3.2.2 Composition of Innovative Bars

Two functional bars were designed starting from innovative ingredients from the recovery and enhancement of waste from agri-food chains. In particular, two vegan and organic bars have been formulated based on fruit, vegetables and secondary raw materials from Olea and Vitis; both bars are characterized by EVO oil as the main fat source, with a content of minor polar compounds (MPC) equal to 775.98 mg/L (HPLC-DAD-MS analysis). The two bars designed are green and blue; the green bar is characterized by the presence of a functional ingredient from Olea, micronized olive leaves and micronized free oil olive pulp, and the blue bar is characterized by the presence of innovative products from the recovery of wine making waste, such as micronized grape skin and grape seeds. The two bars have a weight of 32 g and a caloric content of 122 kcal/bar. Table 3.1 shows the compositions of the two innovative bars formulated.

Table 3.1 Composition of innovative bars

Name	Ingredients
BB	Dates, Thompson grapes, cashews, almonds, plums, acerola powder, cabbage powder, beetroot powder, açai powder, blueberry powder, rhubarb powder, kiwi powder, carob flour, micronized grape film, micronized grape seeds, EVO oil
GB	Dates, cashews, Thompson grapes, figs, apple, fennel powder, cabbage powder, celery powder, spinach powder, barley grass powder, carob flour, kiwi powder, grape skin micronized, grape seeds micronized, micronized olive leaves, micronized free oil olive pulp, EVO oil

BB blue bar, *GB* green bar

3.2.3 Total Antioxidant Capacity (Folin-Ciocalteu Assay)

The total antioxidant capacity of two bars was evaluated using the Folin-Ciocalteu method adapted to the samples. 500 μL of water and 125 μL of Folin reagent were added to 125 μL of appropriately diluted extract and reacted for 6 min in the dark. Subsequently, 1.25 mL of Na_2CO_3 at 20% in H_2O was added, and then, the solution was brought to a volume of 3 mL with water. The solution was left in the dark for 85 min and then centrifuged for 5 min at 5000 rpm. The spectrophotometric analyzes was carried out at 725 nm using a Lambda 25 spectrophotometer (PerkinElmer, Waltham, MA, USA) and using the extraction solvent (70:30 hydroalcoholic solution pH 3.2) as a blank. The results are expressed in mg of gallic acid (GAE) per g of bar.

3.2.4 Antiradical Activity (DPPH Assay)

A further investigation carried out on the samples under study was the evaluation of the antiradical properties. The method chosen is a spectrophotometric method based on the use of the radical DPPH • (radical 1.1-diphenyl-2-picrilidrazil).

Through this test, it is possible to obtain information on efficiency by evaluating the percentage of antiradical activity after 20 min of contact with the DPPH radical. 1ml of aqueous solution of samples, suitably diluted, was added to 1 mL of an ethanolic solution of DPPH • (obtained by solubilizing 4.0 mg of DPPH • in 100 mL of ethanol). Absorption was measured at 517 nm immediately and after 20 min using a Lambda 25 spectrophotometer (PerkinElmer, Waltham, MA, USA) versus 70:30 hydroalcoholic solution pH 3.2 as a blank.

The reducing activity A.R.% was calculated by applying the following formula (Eq. 3.1):

$$\mathrm{AA}(\%) = \frac{A_{t0} - A_{t20}}{A_{t20}} \times 100 \tag{3.1}$$

3.3 Results and Discussion

3.3.1 HPLC-DAD-MS Characterization of Byproducts from Olea europaea *L.*

The byproducts of the olive oil supply chain were analyzed by HPLC-DAD-MS, including micronized olive leaves and free-oil olive pulp. The main molecules of these two products are represented by oleuropein for the olive leaves and hydroxytyrosol for the free oil olive pulp. Many studies have shown the functional value of these two molecules reacting to their antioxidant and antiradical power (Romani et al. 2019). The tables below show the qualitative and quantitative characterizations of the analyzed samples (Tables 3.2 and 3.3).

3.3.2 HPLC-DAD-MS Characterization of Byproducts from Vitis vinifera *L.*

The byproducts of the wine chain, including micronized grape skin and grape seeds, were analyzed by HPLC-DAD-MS. The main molecules of these two products are represented by procyanidins and anthocyanins, and many studies have shown the functional value of these two molecules reacting to their antioxidant and antiradical

Table 3.2 Quali-quantitative HPLC-DAD-MS analysis of polyphenols in the micronized powder of olive leaves, data expressed in mg/kg

Compounds	mg/kg
Hydroxytyrosol	0.60
Verbascoside	2.71
Luteolin 7-O-glucoside	5.11
Oleuropein	29.55
Oleuropein aglycone	5.32
Total polyphenols	43.30

Table 3.3 Quali-quantitative HPLC-DAD-MS analysis of polyphenols in the micronized powder of free oil olive pulp, data expressed in mg/kg

Compounds	mg/kg
Hydroxytyrosol glycol	340.00
Hydroxytyrosol	1845.50
Tyrosol	450.36
Oleoside	316.17
Verbascoside	1269.68
Verbascoside derivatives	728.93
Oleuropein	4142.81
Luteolin glucoside	815.00
Luteolin derivatives	174.00
Total polyphenols	10082.45

Table 3.4 Quali-quantitative HPLC-DAD-MS analysis of polyphenols in the micronized powders, data expressed in mg/g compounds in each of the analyzed powders

	GSE	GSK
Gallic acid	0.072	0.052
Other procyanidins	0.772	0.08
Catechin dimer B3	1.446	0.416
Epicatechin	0.281	0.012
Catechin trimer	2.082	0.435
Epicatechin gallate dimer	0.552	0.192
Catechin tetramers	24.694	15.875
Epigallocatechin dimer	1.03	7.6
Catechin/epicatechin trimers digallated	27.307	28.368
Delphinidin-3-glucoside	0.009	0.017
Cyanidin-3-glucoside	0	0.002
Petunidin-3-glucoside	0.014	0.024
Peonidin-3-glucoside	0	0
Malvidin-3-glucoside	0.048	0.09
Delphinidin-3-acetylglucoside	0.003	0.002
Cyanidin-3-acetylglucoside	0.005	0.009
Petunidin-3-acetylglucoside	0.004	0.005
Malvidin-3-acetylglucoside	0.004	0.009
Malvinidin-3-caffeoylglucoside	0.014	0.036
Total polyphenols	58.335	53.224

GSE micronized grape seeds, *GSK* micronized grape skin

Table 3.5 Total antioxidant capacity (TAC) mg GAE/32 g and antiradical activity (AAR %)

	TAC	AAR%
BB	250.12	84.49
GB	207.47	80.53

BB blue bar, *GB* green bar

power (Romani et al. 2020). The tables below show the qualitative and quantitative characterizations of the analyzed samples (Table 3.4).

3.3.3 Total Antioxidant Capacity (Folin-Ciocalteu) and Antiradical Activity (AAR%)

The two bars designed based on Olea and Vitis powders from circular agriculture standardized in active compounds and high quality EVO oil were analyzed to evaluate their biological activities. The total antioxidant capacity (Folin-Ciocalteu) and the antiradical activity (AAR%) were evaluated. As shown in Table 3.5, both bars have optimal values, proclaiming marked antioxidant and antiradical activity, both exceeding 80% AAR. These values allow us to state that the secondary raw materials coming from the recovery of agrifood chains rich in active compounds and in association with high quality EVO oil can be considered innovative ingredients to be used for the food, nutraceutical, cosmetic, agronomic, and feed sectors.

3.4 Conclusions and Future Perspectives

The study represents an example of a circular model for the recovery of waste from the agri-food chain and the development of innovative functional ingredients starting from secondary raw materials. The recovery and controlled transformation of the byproducts of wine and EVO oil production have made it possible to apply the principles of the circular economy and to obtain new innovative products to be used in different sectors, including food, nutraceutical, agronomic, feed, and cosmetic sectors. The selected sector is functional sports-wellness nutrition. Two bars based on fruit and vegetables were designed by adding active powders of olive leaves, free oil olive pulp, grape skin, and grape seeds. The association of these innovative ingredients with the EVO oil with a high MPC content has made it possible to obtain two functional antioxidant products, thanks to the synergy created between the active molecules present in the formulation. The antioxidant and antiradical activity has been tested in vitro with the Folin-Ciocalteu and DPPH test, but these two bars have been also selected for an in vivo study entitled "Evaluation of the possible energetic and beneficial action induced by the association of a food supplement with sports activities for the treatment of uremic sarcopenia" in collaboration with the Tor Vergata University of Rome and the University of Foro Italico in Rome. Preliminary results show that the association of physical activity and the intake of functional bars rich in antioxidant active compounds lead to an improvement in body composition and parameters, such as blood pressure and lipid metabolism, improving the health of the affected patient, from chronic kidney disease and subsequent uremic sarcopenia. A study is underway that includes a larger patient population to demonstrate the hypothesis proposed in the pilot study (Grazioli et al. 2022).

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Part II
Waste Management: Circular Economy and Sustainability

Chapter 4
The Study of Variables That Influence the Implementation of a Waste Cycle Tracking System: A Literature Review

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Abstract The new economic paradigm of the circular economy aims to recover, sustain, and increase the value of waste, supporting the concept of sustainability, a key point of the new blockchain models outlined by the 2030 Agenda. Our analysis proposes the study of variables that influence the implementation of a waste cycle tracking system. This type of research is relevant to several fields, both academic and professional, as the conceptual understanding of the narratives of traceability drives practical application through the study of strategies, monitoring tools, and technologies among which the blockchain emerges (Saberi et al, Resour Conserv Recycl 130:80–81, 2018; Steenmans and Taylor 2018). To date, this technology is an essential tool for the traceability of all economic resources, particularly in the context of the circular economy, which lays the foundation for the development of a model in which the entire life cycle of products is aimed at lasting as long as possible. The use of this technology in the waste sector represents an application of supply chain management on which much attention has been given in recent years (e.g., Kouhizadeh, Sarkis, Sustainability 10:3652; 2018; Saberi et al, Int J Prod Res 57: 2117–2135, 2019). The methodological approach used is qualitative, as we proceed with a literature review that investigates the variables, in particular blockchain technology, which may influence the application of a traceability model whose purpose is to ensure the certainty and transparency of the individual processes involved. The review also outlines application gaps and future areas of research. The following article could enhance the use of this technology and offer insights into the study of other technological variables that are always applied within a yet unknown waste traceability model.

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Keywords Blockchain · Circular economy · Sustainability · Waste management · Technology · SDGs12

4.1 Introduction

This contribution starts with some important questions that help us to outline a theoretical framework as well as to define some fundamental concepts: What do we mean by waste? When and how does waste become a second raw material (SRM), and what are the criticalities of this process? The concept of waste finds its definition in the Italian legislation, which in Art. 183 of Legislative Decree No. 152 of April 3, 2006, of the Consolidated Environmental Law states: "Any substance or object that the holder discards or is obliged to discard." The important novelty of the Consolidated Environmental Law (TUA) is the great importance given to the prevention, production, and recovery of waste. In terms of the waste hierarchy defined by the Waste Framework Directive (2008/98/EC), a directive on waste and its management, secondary raw materials represent materials and products that can be reused as raw materials through simple reuse, recycling, or restoration. In the vision expressed by the EU in the new action plan for the circular economy, which is part of the European Green Deal 2030, in the context of a circular economy, a development of economic growth that is not connected is no longer conceivable to a rational and proportional use of resources, and what is discarded as waste must be recovered and enhanced. The review also asked what role technology plays as a driver and tool for the transition to sustainable waste management. In particular, we discuss the capacity of blockchain (Mercuri et al. 2021) to support political objectives by encouraging sustainable waste management, offer clarity on product and waste property rights, and maintain the anonymity and privacy of institutions and individuals. The ultimate challenge is dedicated to the disclosure of results and future prospects.

4.2 Review of the Literature

The literature review process highlighted the importance of blockchain technology (BCT) (Saberi et al. 2019), which has proven useful in managing the waste cycle and tracking and in the relationship with the environment. The origin of this technology dates back to 2008 with the cryptocurrencies of Satoshi Nakatomo. It has been noted that blockchain could have a high potential to support the "circular economy" (CE). The CE is defined as a chain recycling strategy that aims to eliminate waste generated in production and consumption, transforming the traditional linear production system into a circular circuit system (Kirchherr et al. 2017). New enabling technologies, including the Internet of Things (IoT), blockchain technology (BCT) and artificial intelligence (Lasi et al. 2014; Saberi at al. 2018) can be useful for implementing the circular economy (CE) and sustainable supply chains (Bai and Sarkis 2020; Kouhizadeh et al. 2020). In particular, the capabilities of cyber-physical

Table 4.1 Limits and/or application advantages of blockchain in waste management

Authors/year	Scope of application	Limits and/or benefits of application
Gong et al. (2022)	Marine plastic debris	It improves the transparency of recycling value chains and makes them more acceptable to the supervision of society and consumers
Wozniak et al. (2021)	Supermarkets and distributors	It ensures reliable, scalable, and transparent tracking
Voorter and Koolen (2021)	Buildings	Better data management and leads to a smoother transition to circular practices in the construction industry
Cheng et al. (2021)	Batteries for energy vehicles	The decentralization and anti-tampering features of the blockchain can guarantee the safety and reliability of the relevant data, realizing the traceability management
Sahoo et al. (2021)	Electronics	Blockchain technology increases accountability, transparency, and trust in the system
Ahmad et al. (2021)	Medical equipment	It allows the exchange of information between all the actors involved in waste management in a completely safe, transparent, traceable, and reliable way

systems, IoT and BCT, provide further insights into creating an efficient waste management system (Bhardwaj et al. 2016; Kouhizadeh & Sarkis 2018). The four potential benefits of adopting BCT in the CE (Esmaeilian et al. 2020) are greater incentives through the use of tokens that have the function of rewarding those who engage in greener behavior; greater attention/visibility, which allows the manufacturer to monitor and verify the entire life cycle of the product; improvement of the efficiency of the whole system; and cross-network restations (Esmaeilian et al. 2020) (Table 4.1).

4.3 Material and Methods

The following literature review was conducted through a single database, Scopus, one of the leading multidisciplinary databases for peer-reviewed literature (Geraldi et al. 2011). The choice to use only this database is based on the fact that it seems to be a suitable tool both for searches by the main publishers, including Elsevier, Springer, Emerald, as well as for other publishers (Reim et al. 2015). For a selection focused on our study, 22 keywords were employed, using the Boolean variables "or" and "and." "OR" was used for the nine digital technologies, while "AND" was used to limit the field of interest, namely, that of waste and the waste cycle. In the first phase of the search, 173 articles were found, refined through practical screening criteria. Conference articles, working papers, commentaries, and book review articles were excluded, and only journal articles were considered (Seuring and Müller 2008), which were not classified either by bands or by "subject area." Further exclusion criteria of the search were the language; in fact, all articles written in a language other than English were not considered, and the time-span reference was

2015–2022, since the starting year coincides with the year of the subscription of the Agenda 2030 program, a development plan for sustainability. Eventually, 53 articles were identified and considered relevant for the analysis. This system resulted in the exclusion of 120 items. All the data extraction, such as authors, title, year, DOI, abstract, and keywords, were exported in an Excel text shared with the research group. Of the remaining 53 articles, both quality and originality were assessed, and the cited references were used as research insights.

4.4 Results and Discussions

From the following analysis, it emerges that the circular economy is based on sustainability, which is essentially based on three factors: economic, environmental, and social (Purvis et al. 2019). Blockchain technology (BTC) in the supply phase chain can help reduce the amount of waste and improve efficiency. The entire path of the waste can be monitored from source to discharge, ensuring transparency and traceability. The underlying principle is to enhance the recycling of materials through collaboration between companies and citizens. With the help of this technology, exchanges are ensured, the authenticity of data and the chronology of the entire supply chain is guaranteed, as well as the certainty of the circularity of the products. The use of BTC plays a central role in business models, as it allows the creation of connections in the various processes that follow each other, promoting the emergence of a unique model of waste circularity that brings benefits, increases company profits, and contributes to improving environmental sustainability. For BTC implementation to be successful in terms of both performance and efficiency, it is necessary to have professionals within one's workforce who can efficiently manage the new technologies, thus contributing to a true digital integration of processes.

It is possible to identify the main advantages and limitations arising from the adoption of blockchain in waste systems. Advantages include disintermediation, process automation, reduced transaction costs, and information security, while limitations include lack of privacy, duplication costs, security models, and low flexibility. An additional difficulty in its implementation is found with the lack of standard and unambiguous worldwide regulation affecting data processing and privacy regarding waste tracking. In fact, there is no single codified traceability model that is applied and shared by all in the same way, and its creation could favor the transfer and handling of waste between different countries.

4.5 Conclusions and Future Perspectives

A fully traceable circular economy model, with proposals, interventions, and objectives to be achieved, increases the possibility of recovering MPS and using them in different production sectors. However, there are critical factors for operators in the sector regarding the use of secondary raw materials. From the quality point of view, the lack of a common standard at the European level leads to uncertainties in the quality of the MPS, which makes the sustainability of the recycling cycle difficult. For their commercialization, it is necessary to facilitate their circulation beyond national borders within the EU. On the demand side, to create a dynamic market for SRM, public policies are needed to encourage the use of recycled materials in products and infrastructure. Finally, the presence of harmful chemicals in recycling streams has led the European Commission to require the tracking of chemicals. From the perspective of a circular system, in which waste becomes a product/resource, the real challenge lies in technology, especially blockchain, which affirms the transparency, security, traceability and usability of data, enabling the creation of a green transition to the circular economy. Possible research perspectives could be the analysis of how new professional figures can contribute to achieving virtuous goals for waste companies by relating them to the investments that the companies themselves make for the purpose of technological innovation in their operational processes.

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Chapter 5
Quantification of Fugitive Methane Emissions from Landfills: An Open Issue

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Abstract Methane fugitive emissions from landfills represent a significant source of climate-altering gases emitted into the atmosphere globally. The recent Communication COM (2020) 663 reports that in the EU, 53% of anthropogenic methane emissions come from agriculture, 26% from waste, and 19% from energy. Landfills therefore represent an important emission sector, on which it is necessary to continue investing in innovation and technology to limit fugitive emissions, especially of methane. In Italy, Legislative Decree 36/2003 has imposed an obligation on landfill operators to quantitatively characterize biogas but does not indicate which technique should or can be used for monitoring. Quantifying landfill biogas flow is a complex exercise with varying degrees of uncertainty. This paper illustrates the main methods currently developed to perform this difficult task. For each method, measurement characteristics, instrumentation needed, advantages, and limitations identified for each are reported. From the analysis of the results, it can be stated that at present, there is absolutely no quantification method that is preferable to others; it is necessary to proceed with further research also considering the new instruments that technology makes available.

Keywords Methane · Landfill · Biogas · Flux measurement

5.1 Introduction

The various techniques available for quantifying CH_4 emissions from landfills operate on very broad spatial and temporal scales: measurements can be made from the surface of the landfill up to several kilometres away and take minutes, weeks, or months. Regarding the spatial scale, directly measuring emissions on a

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portion of the surface allows the interference of any surrounding CH_4 sources to be excluded but makes the subsequent extrapolation step, which is necessary to represent a large area that is characterized by heterogeneous emissions, more difficult. Methods that measure at greater distances are better than the previous ones for quantifying site-wide emissions but are more sensitive to potential surrounding sources. The timescale, on the other hand, plays a decisive role in the feasibility and quality of flux measurements, as landfill emissions are well known for their extreme temporal variability even in the very short term. It follows that each technique is characterized by its own spatial and temporal resolution, with its own advantages and limitations: defining these aspects is of fundamental importance for understanding the status of the main existing quantification methods.

5.2 Material and Methods

The data were collected from a bibliographical search carried out online on the Scopus bibliographical database, published by Elsevier, collecting material through specific keywords provided as input to the search engine and then selecting the sources according to both their year of publication and the techniques discussed to quantify emissions. The study is not based on a systematic literature review, but for each of the identified methods, data were collected following some criteria regarding the spatial and temporal resolution, measurement characteristics, instrumentation needed, and the advantages and limitations associated with each.

5.3 Results

The table below shows the main flux quantification methodologies, sorted in ascending order according to spatial resolution and each described in terms of its special features (Table 5.1).

Table 5.1 Spatial and temporal resolution of flux quantification methodologies

Flux quantification methodology	Spatial resolution	Temporal resolution
Concentration gradient measurement	$<0.5\ m^2$	10–20 min
Dynamic concentration measurement	$<0.5\ m^2$	A few minutes
Flux chambers	$0.5–1.0\ m^2$	A few minutes
Eddy covariance method	$<1000\ m^2$	30 min
Radial plume mapping (RPM)	*h* (10–50 m); *d* (<200 m)	Hours
Tracer gas dispersion method (static)	A few km	Hours or days
Tracer gas dispersion method (dynamic)	A few km	2–6 h or days
Differential absorption LiDAR method	400–800 m	Hours or days
Inverse dispersion modelling method	From 500 m to a few km	Hours

Concentration gradient measurement: Concentration gradient measurement is a technique performed on small-volume samples aspirated through probes inserted into the soil at varying depths and then analysed to derive a concentration value. Developed by Gebert et al. (2011), it has been used in various emission studies (Gonzalez-Valencia et al. 2016; Pratt et al. 2013) and to assess CH_4 emissions from a landfill (Bogner et al. 1995).

Advantages and limitations: capable of providing information on mechanisms influencing emissions, such as rapid changes in atmospheric pressure, wind speed, and emissions, resulting from simultaneous convection and diffusion. It can identify point sources and estimate CH_4 oxidation. The technique is characterized by a low spatial resolution (sampling area $<0.5\ m^2$), while the temporal resolution (sampling duration between 10 and 20 min) conflicts with the rapid variations in emissions from a landfill. It does not allow measurements at critical points (cracks in the cover or leachate pits), and the diffusion coefficient is complex to estimate. It is also labour-intensive.

Dynamic concentration measurement, proposed by Guerrieri and Valenza (1988), consists of a Cu probe (inserted inside a steel tube perforated in the end section), embedded in the soil, and connected by pump to an IR spectrophotometer. After a few minutes of pumping at constant flow, the gas concentration in the mixture stabilizes, and this concentration is directly proportional to the gas flow in the soil according to Eq. (5.1):

$$\varphi = \mathrm{MC_d} \tag{5.1}$$

where φ is the gas flux through the soil ($g\ m^{-2}\ s^{-1}$), C_d is the dynamic concentration ($g\ m^{-3}$), and M is an empirical constant determined in the laboratory.

Advantages and limitations: much faster than the concentration gradient measurement, otherwise sharing the same advantages. The limitations are also the same, but this technique differs from the former due to its inapplicability when the layers to be traversed are not very thick (<1.0 m). The empirical coefficient M depends not only on the geometry of the sampling system but also on the permeability of the soil, and since it is estimated by means of laboratory tests, it is highly skewed and unrepresentative.

Flux chambers: This is a methodology that estimates the flux of CH_4 from a surface by measuring the changes in CH_4 within a chamber over a given time interval during which it is in contact with the soil (Eq. 5.2):

$$F = \frac{\mathrm{d}C}{\mathrm{d}t}\frac{V}{A} \tag{5.2}$$

where F is the flux ($g\ m^{-2}\ s^{-1}$), $\frac{\mathrm{d}C}{\partial t}$ ($g\ m^{-3}\ s^{-1}$) is the concentration change over the time interval, V is the chamber volume (m^3), and A is the base (m^2). Widely used to quantify gas emissions from landfills (Lucernoni et al. 2016; Rachor et al. 2013; Abichou et al. 2011; Bogner et al. 1995), it is distinguished according to whether there is continuous insufflation of air inside it (dynamic) or not (static).

Advantages and limitations: Very simple to use, concentrations can be measured with an FID or IR detector. The method can detect even modest fluxes of CH_4 and is to date the reference technique for estimating the flux of trace gases contained in nonmethane volatile organic compounds (NMVOCs) (Scheutz et al. 2008). It is time-consuming and labour-intensive, requiring appropriate geostatistical techniques. It does not lend itself to advective fluxes, and surface perturbation can affect emission. It has a spatial resolution limited to the footprint surface of the chamber.

The eddy covariance method is based on the theories of turbulent transfer in the surface boundary layer of the atmosphere and has been applied in several landfill studies (Xu et al. 2014; Mcdermitt et al. 2013; Schroth et al. 2012). The measurement requires the determination of the mean vertical component of wind speed and the mean CH_4 concentration from time series collected by anemometers and FTIR or TDLAS detectors, respectively. The gas flux is then calculated using the following Eq. (5.3):

$$F = \overline{w}'\overline{c}' \tag{5.3}$$

where F is the flux (g m^{-2} s^{-1}), $\overline{w}'$ is the average vertical component of wind speed (m s^{-1}), and $\overline{c}'$ is the average gas concentration (g m^{-3}).

Advantages and limitations: provide large-scale emission estimates and are suitable for flat sites with uniform emissions. It allows continuous measurements over long periods of time, providing information on temporal variability and average emissions. However, it requires assumptions of horizontal site homogeneity and atmospheric stationarity, which are only fulfilled if time windows of less than 60 minutes are considered (Kaimal and Finnigan 1994; Finnigan et al. 2003).

Radial plume mapping (RPM): Developed in the late 1990s, it uses a combination of concentration measurements and wind profiles to obtain a surface emission rate from an upwind area. It can be used in two configurations: horizontal (HRPM) or vertical (VRPM), the former capable of detecting hotspots and the latter of quantifying flows. A laser beam is aimed at reflectors positioned at different heights (10–50 m) and distances (up to 200 m); each section provides an average CH_4 concentration: a 2D concentration profile is thus modelled on the cross-section of the plume. By combining these data with wind speeds, the surface emission rate can be measured (Goldsmith et al. 2012).

Advantages and limitations: capable of identifying point sources and estimating emission fluxes, lending itself to preliminary screening for remediation. Limitations are low spatial resolution (limited laser range) and high temporal resolution (several hours), incompatible with landfill flows. Upwind and downwind measurements would have to take place simultaneously (increasing the costs of the test), and the results are complex to interpret. Determining the precise area contributing to the measured emission is equally complex.

The tracer gas dispersion method consists of releasing a tracer gas from a position upwind of the emissive surface and measuring the CH_4 and tracer concentrations downwind in each time interval. A distinction is made between stationary and dynamic, depending on whether measurements are made with instruments (FTIR or TDLAS detectors) placed at fixed points or equipped on a vehicle moving along a road.

Advantages and limitations: The main advantage is the simplicity of the analysis (provided the CH_4 and tracer gas are well mixed). It makes it possible to estimate the total emissions of a landfill (including point sources) and is not affected by errors related to site topography, as it can be applied to landfills of all sizes. Recent studies recommend measuring at least 10 points, recommending an average number of 15 samplings (Fredenslund et al. 2019; Mønster et al. 2014). The disadvantages of the technique concern its dependence on meteorological conditions (wind direction and speed), which are necessary to ensure proper mixing, as well as the need for suitable road access. It is unable to discriminate between the different sources contributing to the emission, leading to possible quantification errors. The instrumentation is expensive and requires specialized personnel. A further disadvantage is that measurements are carried out over hours (2–6 h) or a few days, so the temporal variation of the emission is a major disturbing factor on the quality of the data.

Differential absorption LiDAR method (DIAL): This is based on the analysis of the electromagnetic spectrum emitted by a surface. It uses different types of sensors, and the data obtained are processed through image analysis, returning thematic maps where each colour is associated with a piece of information. Measurements are taken both downwind and upwind of the landfill: the flux emitted from the surface is obtained by difference.

Advantages and limitations: They provide total emissions from the entire site or portions. They also have a good spatial resolution (400–800 m), depending on atmospheric conditions. The main disadvantage of the DIAL method is the cost and computational burden of analytical modelling and data management. It requires suitable roads, and the measurements depend on the wind (it must be stable to measure the flow accurately) and present infrastructure. Measurements are conducted over hours or days.

With reference to a mobile version, very few studies are available to date on its use in landfills (Innocenti et al. 2017; Bourn et al. 2019; Robinson et al. 2011).

Inverse dispersion modelling method: By measuring CH_4 concentrations on a leeward plane at the surface and combining them with meteorological data, the flux can be calculated using atmospheric gas dispersion models (e.g. Riddick et al. 2017). Several models have been specially developed for this purpose, such as LASAT (Janicke Consulting, Überlingen, Germany) and WindTrax (Thunder Beach Scientific, Nanaimo, Canada).

Advantages and limitations: It can provide estimates of site-wide emissions even from critical points such as embankments and biogas collection systems, which are often difficult to intercept using traditional methods. On the other hand, it requires large quantities of high-quality data as inputs for good emission estimates, such as atmospheric stability, surface turbulence and wind speed. Optimal conditions would require the landfill site to be in a flat area, with a road cutting through the downwind plume at a suitable distance.

5.4 Conclusions

An analysis of the techniques used to date for the quantification of methane fluxes from landfills has shown that each method has its strengths and weaknesses and that, at present, it is not possible to say that there is absolutely one quantification method that is preferable to others. This issue therefore remains open; however, technological innovations introduced in various sectors seem promising in the search for a more concrete solution, such as the use of drones equipped with appropriate sensors.

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Chapter 6
Sustainable Organic Waste Management in Small Communities: Evidence from Life Cycle-Based Evaluations

Gabriella Fiorentino, Tiziana Beltrani, Lorenzo Cafiero, and Flavio Scrucca

Abstract Organic waste or biowaste is the largest component in municipal solid waste and, therefore, one of the main landfilled waste fractions with the consequent issue of greenhouse gas emissions. On the other hand, it represents a valuable resource that can be harnessed and returned to productive use in the framework of a circular economy approach, according to the EU Waste Framework Directive. This paper presents the results of an environmental and economic life cycle assessment of specific organic waste management actions in two reference territories representative of "small communities", paving the way for a deeper understanding of the benefits that can be gained by means of local composting. Life cycle evaluation results showed that improvement potentialities are high, especially in terms of environmental impacts and externalities, confirming life cycle-based evaluations as very valuable tools for decision-makers to better understand the benefits and costs of waste management policies. The results also confirmed that, both from an environmental and economic point of view, a "local" waste management system, in which transportation is reduced, is particularly strategic, as well as a "tailored" management system that affects other specific territorial hotspots, such as the temporary storage of waste.

Keywords LCA · LCC · Sustainability · Organic waste · Biowaste · Waste management

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6.1 Introduction

Organic waste or biowaste consists of food and garden waste; it represents the largest component in municipal solid waste (MSW), with a share of 34%, and is one of the main landfilled waste fractions, with an expensive management system that also creates significant greenhouse gas emissions (EEA 2020). On the other hand, biowaste is a valuable resource that can be harnessed and returned to productive use, being turned into compost to improve and fertilize soil to provide food for people and animals. The European Commission pushes a policy of diverting as much biowaste as possible from the residual municipal waste, that is directed to landfilling, to recycling at the source, by home or community composting, or to a separate collection, where biowaste can be transformed into a soil improver by composting or into biogas by anaerobic digestion treatment.

In this context, the NETWAP project (a cross border cooperation initiative developed within the Priority Axis 3 "Environment and Cultural Heritage" of the Interreg Italy Croatia Programme, https://programming14-20.italy-croatia.eu/web/netwap) was aimed at defining a new approach for the autonomous and sustainable waste management in small communities, generally intended as the ones with relatively small permanent population scattered across the reference territory, which lie quite away from the main logistic routes and which are characterized by a lack of main infrastructures for waste management, foreseeing procedures for: (1) stimulating waste reduction and boosting recycling through measures basically regarding three different levels of stakeholders' involvement, i.e. societal level (information and awareness), political level (legislative acts), and economic level (incentives and disincentives) and (2) promoting local small-scale composting and reducing the use of landfills through the promotion and implementation of autocomposting, community composting, and local composting.

This research shows the results of the sustainability evaluations carried out in the framework of the NETWAP project for the pilot actions implemented in two reference territories to assess the environmental and economic benefits derived from the specific actions proposed for the management (local composting) of organic waste.

6.2 Material and Methods

6.2.1 Small Communities Case Studies

The first case study is represented by the small community of Fossalto, a small hilltop village located in the southern part of Italy (Molise Region), with a municipal territory extending over an area of approximately 28 km^2 and a total population of 1258 inhabitants. The organic waste is collected door-to-door and then transported to a composting facility consisting of an active phase by dynamic biocells, completed in static cells and followed by a curing phase managed by aerated piles. In the countryside, compostable waste is partly used as feed for pets and courtyard animals and partly as feed in domestic composters. The second case study is the small community of Ist, an island located in the north-central part of the Zadar archipelago in Croatia, with an area of 9.65 km^2 and a resident population of 182 inhabitants, which strongly increases during the summertime, reaching 3–4 thousand tourists. Waste separate collection is carried out by means of a door-to-door system twice per week, and collected waste is transferred to a deposit station (or reloading station) on the island, where it is temporarily stored in press containers and thus prepared for transport to the mainland via a ship concessionaire. Organic waste is not separately collected, but included in the unsorted waste that is finally landfilled.

In the framework of the NETWAP project, a Dizio Inoxa electromechanical composter, model EcoKompos T30 with a biowaste input capacity of 25.5 t/year, was installed in both territories.

6.2.2 Comparative Life Cycle Analysis

This comparative study was performed to analyse the environmental and economic impacts of different management strategies for the organic fraction (OF) of municipal solid waste (MSW) produced in Fossalto and Ist Island (for each pilot, the baseline scenario was compared with the NETWAP scenario). The aim of the study was to provide decision-makers with potentially useful recommendations for local waste management planning in small villages. The target audience is thus represented by all the interested stakeholders and decision-makers, such as the public administration.

Regarding LCA, in agreement with the ISO standards 14040–44 (ISO 2006a, b) and the ILCD Handbook (EC 2010), the attributional modelling principle was chosen, and a gate-to-cradle approach was applied, considering the production of a soil improver (Ekvall et al. 2007). The functional unit (FU) is the treatment of 1 ton of organic waste produced. In the case of Ist Island, since the OF is not separately collected, it was assumed that 20.28 tons of kitchen waste is produced yearly, based on the estimated composition of mixed waste (namely, 30.9% according to HR 2020) and considering an average amount of mixed MSW of 65.62 tons collected between 2018 and 2020 (*versus* a total amount of 43.14 tons/yr, in the reference year of 2020, for Fossalto). Both datasets were provided by the municipal administrations of Zadar County and Fossalto. The boundaries of the investigated systems are schematically depicted in Fig. 6.1.

The system boundaries were extended to encompass the whole organic waste chain: from the generation of waste (a zero burden approach was assumed, not including the generation of waste or the life cycle of the products before they became waste) to the treatment in the baseline scenario (Montagano composting facility for Fossalto, Diklo landfill in Zadar for Ist) or in the NETWAP scenario (electromechanical composter for both pilots), through collection and transportation, up to the

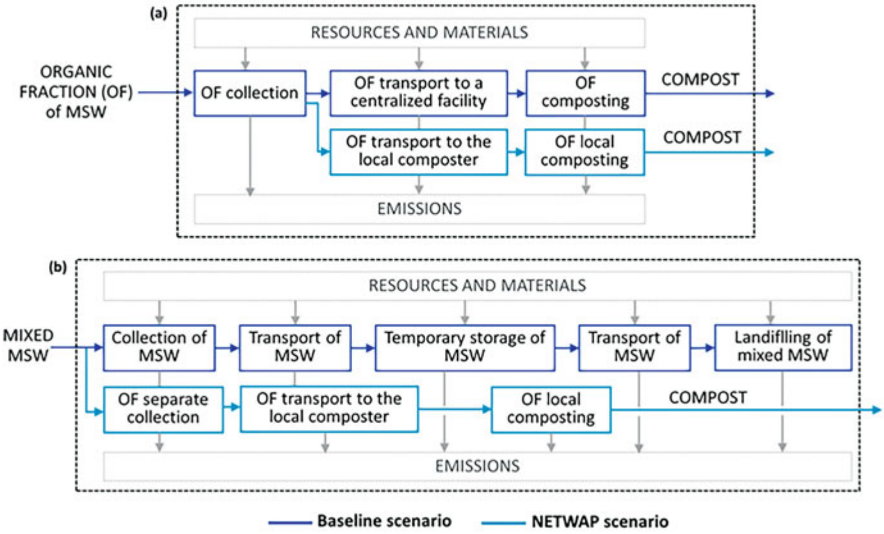

Fig. 6.1 System boundaries of (**a**) Fossalto and (**b**) Ist Island pilot actions

final disposal of residual waste. Finally, to evaluate the potential benefits linked to the different waste management strategies, a system expansion (or avoided burden approach) was also performed, including the avoided production of fertilizers for crediting the production of compost (1 ton of compost was assumed to substitute 23 kg of N fertilizer, 9.5 kg of P fertilizer, and 9 kg of K fertilizer, according to Ripa et al. 2017).

Regarding LCC, an environmental LCC (eLCC) was carried out by applying the Environmental Priority Strategies (EPS) approach (version 2015dx) for the calculation of the externalities (Baumann and Tillman 2004), consistent with the performed LCA.

Foreground data, i.e. specific information about material and energy flows related to the collection, transportation and treatment of the MSW organic fraction, were provided by Fossalto and Ist Island municipalities. For the NETWAP scenario, since only preliminary experimental data were available, data referring to energy and material requirements, emissions, and compost production were gathered from a previous composting campaign based on an electromechanical composter, similar to those installed in the pilot territories. For background data, the EcoInvent v.3.5 database (allocation at point of substitution, dataset of unit processes) was chosen. Data about the treatment of organic waste in a composting industrial plant were derived from the EcoInvent database, as well as the environmental impacts generated from infrastructures and transport.

The ReCiPe Midpoint (H) impact assessment method, included in the professional software SimaPro v.9.0.0.48 (PRé 2022), was selected to investigate the following midpoint impact categories (Goedkoop et al. 2009): global warming potential (GWP, in kg CO_2eq), fine particulate matter formation potential (PMFP, in kg PM2.5 eq), terrestrial acidification potential (TAP, in kg SO_2eq), freshwater eutrophication potential (FEP, in kg P eq), marine eutrophication potential (MEP, in kg P eq), human carcinogenic toxicity potential (HTP_c, in kg 1,4-DCB), mineral resource scarcity potential (MRS, in kg Cu eq), and fossil resource scarcity potential (FRS, in kg oil eq).

For eLCC, impacts from emissions and use of resources that cause significant changes in any of the safeguard subjects (i.e. areas of protection: ecosystem services, ES; access to water, AW; abiotic resources, AR; human health, HH; biodiversity, BD) were investigated. The results of the impact assessment method are monetary values (monetarization) of environmental impacts from emissions and use of resources, indicated as damage costs and expressed as ELU (Environmental Load Units). One ELU represents an externality corresponding to 1 € that an average OECD (Organisation for Economic Co-operation and Development) inhabitant, having the impacts on her/himself, is willing to pay to avoid environmental damage.

6.3 Results and Discussion

The relative impacts generated by the treatment of 1 ton of organic waste in the baseline and NETWAP scenarios of Fossalto and Ist Island on a selection of impact categories are shown in Fig. 6.2.

Concerning the baseline scenarios, the impacts generated in Fossalto are generally higher than the impacts in Ist Island, except for MEP and MRS impact categories, which are the ones mostly affected by landfilling and by the temporary storage of waste. The transportation of waste by truck is the main hotspot in the baseline scenario of Fossalto, while the transportation by ship needed for the organic waste in Ist Island does not affect the investigated impact categories at the same level.

In the NETWAP scenarios, the reduction of the impacts is particularly relevant in the MRS impact category (83% for both Fossalto and Ist Island), and similar reductions are also achieved in the GWP category (50% in Fossalto *versus* 58% in Ist). A relevant difference can be noticed in the HTPc impact category: in Ist Island, the reduction of the impact amounts to 73%, due to the change of treatment that organic fraction undergoes, while it is limited to 5% in Fossalto. Analogously, the impact on the MEP category is totally cancelled in the Ist pilot, while it is only reduced by 38% in Fossalto. In contrast, Fossalto gains slightly higher savings than Ist Island in the PMFP, TAP, and FRS impact categories.

Regarding the generated externalities, the environmental damage costs are shown in Table 6.1 for the baseline and NETWAP scenarios. The total environmental damage cost of baseline scenarios amounts to 5847 ELU/FU in Fossalto *versus* 7645 ELU/FU in Ist Island, while the values are reduced to 877 ELU/FU and 1147 ELU/FU in the Fossalto and Ist Island NETWAP scenarios, respectively. In all the

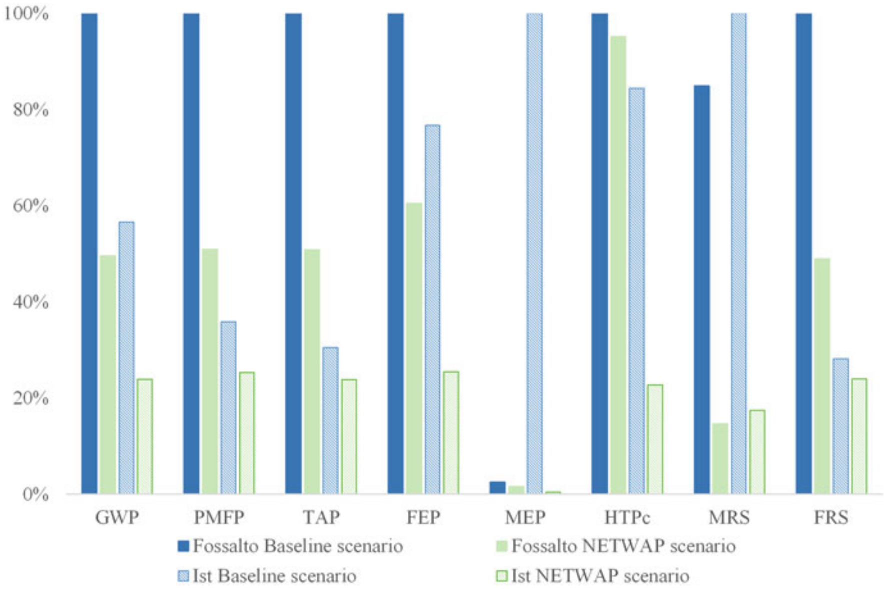

Fig. 6.2 A comparative analysis of the baseline and NETWAP scenarios investigated in the Fossalto and Ist Island pilots territories

Table 6.1 Environmental damage costs for the baseline and NETWAP scenarios in Fossalto and Ist Island, referring to the selected FU (1 ton of treated organic waste)

Safeguard subject	Unit	Fossalto baseline	Fossalto NETWAP	Ist Island baseline	Ist Island NETWAP
Ecosystem services	ELU	10.47	5.42	2.68	2.60
Access to water	ELU	0.65	0.33	0.16	0.16
Biodiversity	ELU	0.04	0.02	0.01	0.01
Human health	ELU	473.36	222.12	132.54	111.51
Abiotic resources	ELU	5362.15	649.21	7509.17	1032.78
Total	ELU	5846.67	877.10	7644.57	1147.05

investigated systems, the safeguard subject of abiotic resources determines most of the external costs. In detail, the effect of the materials used for the containers of the deposit station, where organic waste is temporarily stored on the island, is strong enough to make the externalities of Ist Island higher than in Fossalto. Nevertheless, since most of the externalities are generated by the transportation of waste, as already highlighted for the environmental impacts by LCA, the implementation of the NETWAP pilot actions lowers the total damage costs generated in both territories.

6.4 Conclusions

This study analysed the waste management systems in two reference territories representative of “small communities”, considering the baseline scenarios and the scenarios proposed within the NETWAP project. The results showed that a “local and tailored” management system is characterized by significant improvements in terms of environmental impacts and externalities. The solution proposed within the NETWAP project not only reduces or eliminates common waste management hotspots (i.e. waste transportation by truck and by ship), but also affects other specific territorial hotspots, such as the temporary storage of waste and landfilling. The results, in general, also confirmed life cycle-based evaluations as very valuable tools for decision-makers to better understand the benefits and costs of waste management policies.

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Chapter 7
Valorization of By-product and Industry Waste for Date Palm Fruit by Recovering Bioactive Molecules and Possible Applications: A Circular Economy Model

Mohamad Khatib, Pamela Vignolini, Chiara Cassiani, Paolo Fiume, Nadia Mulinacci, and Annalisa Romani

Abstract Date palm was domesticated between 3000 and 4500 B.C. in Mesopotamia. In 2020, the global production of dates reached 9.45 million metric tons. Date fruit production and the linked processing industry generate a large volume of by-products and waste. The by-products and waste contain valuable amounts of bioactive compounds, but little attention has been given to understanding their chemical composition and properties. The aim of this study was to investigate, by HPLC-DAD-MS and ^{1}H-NMR analyses, the chemical composition of polysaccharides and polyphenols of by-products and waste from the production process of bioethanol via fermentation of date palm fruits. Cinnamic acids, luteolin, and chrysoeriol derivatives were identified. The total phenolic content in the different samples ranged from 15.6 to 92 mg/g. Two main polysaccharide fractions (F1 and F2) were collected from each sample: F1 and F2 ranged from 4.5% to 9.2% and from 3.5% to 12.5% weight with respect to the date fruit by-products, respectively, and they contained 24–52% and 5.6–8.7% galacturonic acid, respectively. The different compositions of the two polysaccharide fractions were confirmed by the percentage composition of acetic acid and methanol linked to galacturonic acid.

Keywords HPLC/DAD/MS · Fibre · Polysaccharides · NMR · Galacturonic acid

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7.1 Introduction

Date palm belongs to the *Arecaceae* family and includes approximately 200 genera and more than 2500 species (Hussain et al. 2020). Date palm was domesticated between 3000 and 4500 B.C. in Mesopotamia. The global production of dates is witnessing a noticeable increase from 8.4 million metric tons in 2017 to 9.45 million metric tons in 2020 (FAO 2020). Moreover, the global demand for dates and fruit-derived products, together with interest in the production, utilization, and industrialization of date palm fruit, has recently increased due to the ability of this fruit to promote human health through various mechanisms involving antihyperglycemic, anti-inflammatory, antihyperlipidemic, antiangiogenic, and antioxidant properties and against liver dysfunction (Fernández-López et al. 2022). Date palm fruit production and the linked processing industry generate a large volume of by-products and waste that must be disposed of. Additionally, the by-products and waste contain valuable amounts of carbohydrates 60–70% (predominantly glucose and fructose) and other nutrients such as fats, proteins, ash, and phenolic compounds (Elleuch et al. 2008); in addition, they contain dietary fibres such as pectin, hemicellulose, and lignin (Fernández-López et al. 2022; Elleuch et al. 2008). Furthermore, the recovery and production cycle for by-products and waste may be both economically and environmentally beneficial. In this context, to generate a sustainable economy, proper waste management strategies are needed. However, little attention has been given to understanding the chemical composition and properties of these by-products and wastes. The by-products contain high quantities of dietary fibre and reducing sugars, making it an excellent carbon source for biological activities or fermentation. Moreover, there is increased interest in the bioactivities of polysaccharides, such as immunoregulatory, antidiabetic, prebiotic, antioxidant, antitumour, antifatigue, and anti-inflammatory activities (Liu et al. 2015; Yu et al. 2018). The aim of this study was to shed light on the chemical composition of polysaccharides and polyphenols of by-products and waste from the production process of bioethanol via fermentation of date palm fruits with *Saccharomyces cerevisiae*. The phenolic composition was determined by HPLC-DAD-MS analyses, while 1H-NMR analyses, before and after chemical hydrolysis, allowed us to acquire structural information on the main date's polysaccharides.

7.2 Material and Methods

7.2.1 Plant Materials

All samples were received from Arar Farms, Jordan, in 2021. We received five samples: date fruit (var. Medjool), flesh of date palm fruit, and three date extracts. The first extract (Ext-1) was obtained by adding 1 L of water to 300 g of date palm fruit and stirring on the heating plate for 30 minutes to reach 80 °C. The second extract (Ext-2) was obtained after cooling Ext-1 to 25 °C and adding 2 g/L of regular Baker's yeast to ferment and keep at 25 °C for 3 days. The third extract (Ext-3) was obtained after the distillation process of Ext-2 to remove the ethanol. Date fruit (by-products of medjool) and flesh of date palm fruit were manually separated from seeds and stored at −20 °C until time analysis.

7.2.2 Extraction of Phenolic Compounds

The flesh of date palm fruit and freeze-dried extracts (Ext-1; Ext-2; Ext-3) have been used for the extraction of polyphenols. The extraction was carried out under magnetic stirring at room temperature for 12 h using acetone:water 90:10 (v/v) with a 1: 40 (w/v) drug/solvent ratio. The final solution for each extract was filtered with Whatman No. 1, dried under vacuum, and dissolved in EtOH/H_2O (1:1 v/v) before HPLC-DAD-MS analysis.

7.2.3 Extraction and Fractionation of Polysaccharides

The solid residue recovered after extraction of polyphenols by acetone was treated with EtOH 75% (v/v) under magnetic stirring for 4 h. The solid residue was freeze-dried and used to prepare a decoction by applying a previously described procedure (Khatib et al. 2017). After centrifugation of the decoction, we obtained two fractions of polysaccharides (F1 and F2) and a precipitate (solid residue F3) for each treated sample. The related fractions were pooled and freeze-dried to evaluate the % yields. All the polysaccharide fractions were dialysed at the cut-off (9–12 KD). The dialysed fractions were then freeze-dried for further analysis by ^{1}H-NMR.

7.2.4 ^{1}H-NMR Analyses

The ^{1}H-NMR data were obtained on a Bruker Advance 400 instrument (Bruker, Bremen, Germany). The polysaccharide fractions (F1 and F2) for each extract of date palm fruit (Ext-1–Ext-2–Ext-3) were analysed before and after dialysis at a concentration range between 4.5 and 6 mg/mL. The quantification of galacturonic acid, methanol, and acetic acid was performed according to Giner et al. (2016).

7.2.5 HPLC-DAD-MS Analysis of Phenolic Compounds

The HPLC/DAD/MS analyses were performed by an HP 1260 MSD (G6125B) mass spectrometer provided with both DAD and MSD detectors and an API/electrospray interface (Agilent Technologies, Palo Alto, CA, USA). The experiments were carried out in positive and negative ionization mode applying the following fragments: 100 V and 150 V, and in full spectrum scan (150–1000 Th), using a 250*4.6 mm i.d. 5 μm Luna C18 column (Phenomenex), and the mobile phase was formic acid/water at pH 3.2 and CH_3CN.

7.2.6 Antioxidant Activity with the Folin–Ciocalteu Test

The antioxidant activity with the Folin–Ciocalteu spectrophotometric in vitro test was measured by the procedure described in (Campo et al. 2016). The phenol content of the sample is expressed as GAEs (gallic acid equivalents), as mg/g of dried fruit and dried extracts.

7.3 Results and Discussions

By HPLC-DAD-MS analyses, it was possible to recognize several cinnamic acids, glycosylated derivatives of luteolin and chrysoeriol (Table 7.1); after fermentation, only small quantities of these compounds remained. Regarding the total phenolic content by Folin–Ciocalteu, it ranged from 15.6 to 17.6 mg/g on dried date fruit and Ext-1, respectively. After the fermentation process of date palm fruit, the total phenolic content was higher in Ext-2 (91.9 mg/g on dried extract) than in Ext-3 (73 mg/g). Some authors reported that the increase in the total phenolic content during fermentation could occur through the release of free phenolic compounds (Adebo and Medina-Meza 2020).

Table 7.1 Phenolic compounds of palm date fruit tentatively identified by MS spectra according to the molecular ion in negative ionization mode and to the literature

Compounds	$[M-H]^-$	References
Syringic acid hexoside and derivatives	359	Hilary et al. (2020)
Caffeic acid hexoside	341	Hilary et al. (2020)
Di-caffeoyl shikimic acid and derivatives	497	Hilary et al. (2020)
P-coumaroyl hexose	325	Farag et al. (2014)
Sinapic acid hexoside	385	Farag et al. (2014)
Apigenin dihexoside	593	Farag et al. (2014)
Caffeoylshikimic acid and derivatives	355	Hilary et al. (2020)
Luteolin-7-O-hexosyl(6-sulphate) and derivatives	527	Abu-Reidah et al. (2017)
Isoquercitrin sulphate	543	Abu-Reidah et al. (2017)
3-methyl-isorhamnetin-7-O-hexosyl(6-sulphate)	477	Abu-Reidah et al. (2017)
Chrysoeriol hexoside sulphate and derivatives	541	Abu-Reidah et al. (2017)

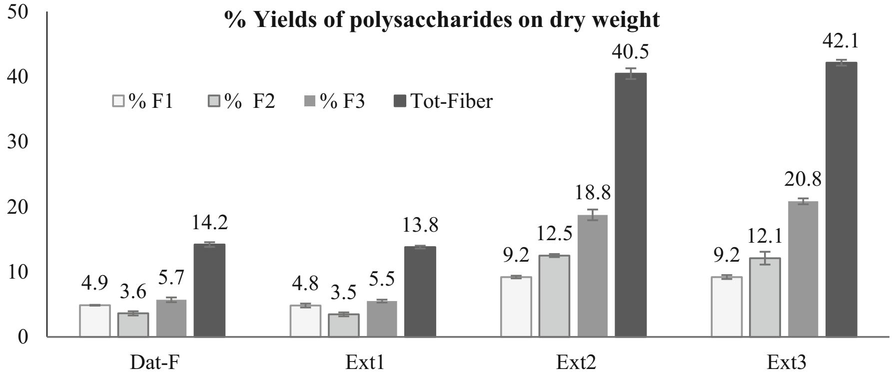

Fig. 7.1 Polysaccharide content expressed on % dry flesh (Dat-F) and on dry extract for Ext-1, Ext-2, and Ext-3

The polysaccharides recovered after decoction and lyophilisation were analysed by ^{1}H-NMR before and after acidic and basic hydrolysis to determine the content of galacturonic acid and the % of methylated and acetylated groups, respectively. All the fractions (F1 and F2) were analysed in 10% D_2O (Fig. 7.1). The ^{1}H-NMR spectra of the F1 and F2 fractions collected from the date palm fruit were very similar. Almost all the F1 fractions of flesh date palm fruit (Dat-F) and Ext-1 showed an intense singlet at 3.73 ppm, as also observed in the spectrum of two commercial pectins (data not shown). This indicated the presence of several *O*-methyl (CH_3O-) groups linked to galacturonic acid units, as observed for several natural pectic polysaccharide structures, and acetyl (CH_3CO-) groups at 1.85 and 2.04 ppm (Fig. 7.2). A decrease was observed in the intensity of signals of the CH_3O-group and acetyl (CH_3CO-) group at 1.85 and 2.04 ppm because part of the galacturonic acid is consumed during the fermentation process.

To confirm the presence of pectic polysaccharides in date palm fruit, the amount of galacturonic acid was determined in the collected fractions after acidic hydrolysis at 100 °C (Giner et al. 2016). The quantity of galacturonic acid was evaluated by ^{1}H-qNMR by using maleic acid as an internal standard. The signals in the anomeric region of the spectrum of fractions F1 and F2 in Dat-F, Ext-1, Ext-2, and Ext-3 after hydrolysis were attributable to the anomeric proton of the α (4.2 ppm) and *β* forms (3.5 ppm) of galacturonic acid (2 M D_2O by H_2SO4), as also confirmed by the spectrum of the pure standard of galacturonic acid. The total amount of galacturonic acid in the collected fractions was determined by evaluating the sum of the two signals (Table 7.2).

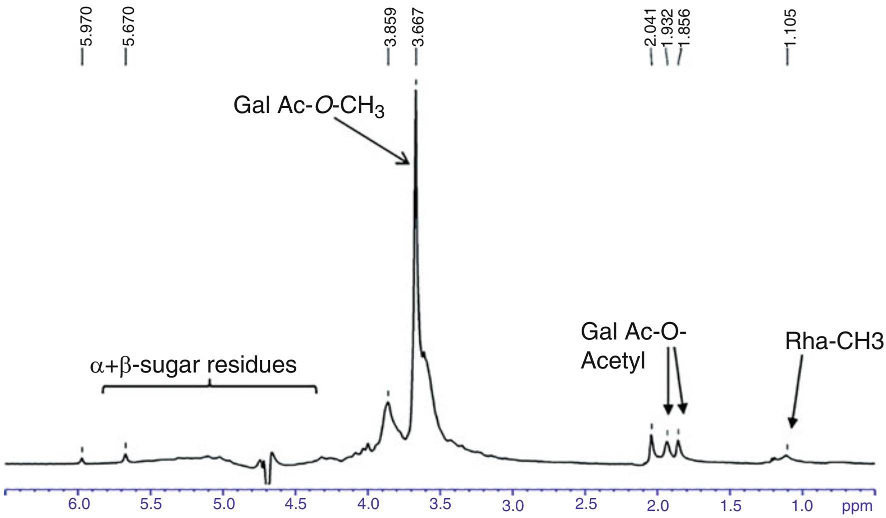

Fig. 7.2 [1]H-NMR spectra in 1 mL of Dat-F1 in 10% D_2O after dialysis. O-Acetyl, singlet of the acetyl groups; Gal A-O-CH3, singlet of the methoxy group of galacturonic acid units

Table 7.2 Amount of galacturonic acid (Gal-ac), methanol, and acetic acid evaluated after alkaline hydrolysis; all values were determined by 1H-qNMR and were expressed as the mean of triplicates for each of the F1 and F2 samples

	% Gala-ac	%MeOH	% AcA
DaF-F1	52.2 ± 0.69	4.25 ± 0.18	3.83 ± 0.19
Ext-1-F1	49 ± 0.83	4.22 ± 0.17	3.71 ± 0.15
Ext-2-F1	31.12 ± 1.5	1.88 ± 0.03	4.87 ± 0.77
Ext-3-F1	24.2 ± 0.43	1.37 ± 0.13	2.44 ± 0.30
DaF-F2	5.8 ± 0.54	0.42 ± 0.06	1.66 ± 0.06
Ext-1-F2	5.6 ± 0.35	0.45 ± 0.08	2.25 ± 0.53
Ext-2-F2	8.7 ± 0.62	0.17 ± 0.23	2.68 ± 0.31
Ext-3-F2	6.02 ± 0.73	0.13 ± 0.07	1.76 ± 0.21

7.4 Conclusions

The present study aimed to optimize suitable methods for sample preparation and analysis for the chemical characterization of polyphenols, monosaccharide, and polysaccharides and bioactive secondary metabolites of date palm fruit and its waste and by-products from the production process of bioethanol via fermentation with *Saccharomyces cerevisiae*. The results obtained by HPLC-DAD-MS and [1]H-NMR analysis and by spectrophotometric tests suggest interesting perspectives concerning further studies for an in-depth characterization of the investigated compounds; possible ways to optimize and standardize the pilot-scale fermentation and distillation process to produce ethanol; and recovery and reuse of waste and by-products for applications in different sectors. The use of date palm fruit as a source of new ingredients for food formulations or for future research aimed at investigating the biological properties of date polysaccharides requires a better knowledge of its composition.

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Chapter 8
Valorization of Pomegranate Waste and By-Products for New Models of Circular Economy

Chiara Vita, Margherita Campo, Gabriele Simone, Patrizia Pinelli, and Annalisa Romani

Abstract In the current context of affirmation of the concept of the circular economy as a new paradigm of sustainability, the present research aimed to enhance and innovate the pomegranate supply chain. From the perspective of optimizing a multifunctional platform, two samples were studied obtained from pomegranate waste: a lyophilized aqueous extract from the pericarp and a micronized powder obtained by grinding the pericarp after freeze-drying. The HPLC-DAD-MS chemical characterization revealed a content of hydrolysable tannins of 23.1% by weight for the lyophilized extract and 20.8% for the micronized pericarp. The antimicrobial activity was evaluated on five fungi of agricultural and food interest (*Alternaria* sp., *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *Mucor* sp., *Penicillium digitatum*, and *Pythium ultimum*). In all cases, we observed an inhibition of the fungal mycelium proportional to the sample concentrations, with average higher efficacy for the lyophilized extract compared to the micronized powder. These results will allow to assess the possible applications of waste and by-products from pomegranate processing to obtain, within integrated platforms

Annalisa Romani died before publication of this work was completed.

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for the recovery of active ingredients with functional properties, innovative semifinished and finished products for use in diversified commodity sectors.

Keywords Pomegranate · Circular economy · Multifunctional platform · Hydrolysable tannins · Natural antimicrobials · Natural antioxidants

8.1 Introduction

Pomegranate (*Punica granatum* L.) is a dicotyledonous angiosperm plant belonging to the *Punicaceae* family, which is widespread mainly in arid and semiarid regions of Iran, the Himalayas and northern India, China, the United States, and the entire Mediterranean region due to its ability to adapt to adverse conditions. The varieties widespread in Italy, such as Tondo verde, Dolce di Sicilia, and Dente di Cavallo, are more suitable for the climate of the specific area (Passafiume et al. 2019). In recent years, scientific studies have shown a preventive action of the fruit and its extracts against numerous chronic and genetic diseases, such as cancer, type 2 diabetes, arteriosclerosis, and cardiovascular diseases (Bar-Ya'akov et al. 2019; Caruso et al. 2020). Positive effects were highlighted not only concerning the edible part of the fruit but also the inedible fraction, which currently represents waste from the processing of fruits and has a higher content of bioactive compounds (Mastrogiovanni et al. 2020). The attention of numerous studies is focusing precisely on these wastes, which represent 48% by weight of the whole fruit and are an important source of bioactive substances such as polysaccharides, flavonoids, phenolic acids, and other polyphenols (Romani et al. 2012; Joshi et al. 2019; Passafiume et al. 2019). The biological properties of polyphenols in pomegranate waste materials together with a greater awareness of sustainability and the need to implement a circular economy approach are leading to focus attention on this plant species for the use of its waste and by-products in different sectors. The implementation of multifunctional platforms following a biorefinery approach, integrating different sustainable and green processes aimed at exploiting the whole biomass to obtain different new bio-based products such as chemicals, materials, semifinished products up to biofuels and energy, is currently the most complete application of circular economy concepts from an industrial perspective (Lucarini et al. 2018). In this context, the present study is aimed at optimizing a multifunctional platform for the enhancement and innovation of the pomegranate supply chain. To assess the prefeasibility, two samples were studied obtained from pomegranate waste: a lyophilized aqueous extract from the pericarp (Lyophilized Extract, LE) and the micronized powder obtained by grinding the pericarp after freeze-drying (Micronized Pericarp, MP). The raw material used to prepare the samples was waste fruits because of insufficient size or with characteristics that make them unsuitable for sale as a fresh product or for obtaining juice. The waste fruits were furnished by Supreme Fruit Srl (Cisterna di Latina LT, Italy). LE and MP were chemically characterized for their content in bioactive hydrolysable tannins by HPLC-DAD-

MS analysis; then, their antimicrobial activity was tested on five fungi of agricultural and food interest (*Alternaria* sp., *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *Mucor* sp., *Penicillium digitatum*, and *Pythium ultimum*). These results will allow the assessment of possible applications for waste and by-products from pomegranate processing to obtain, within integrated platforms, innovative semifinished and finished products by recovering active ingredients with functional properties to be used in diversified commodity sectors.

8.2 Materials and Methods

8.2.1 Chemicals

All solvents (HPLC grade) and formic acid (ACS reagent) were purchased from Sigma-Aldrich Chemical Company Inc. (Milwaukee, Wisconsin, USA). Gallic and ellagic acids, of analytical grade, were purchased from Extrasynthèse S.A. (Lyon, Nord-Genay, France). HPLC-grade water was obtained via double-distillation and purification with a Labconco WaterPro PS polishing station (Labconco Corporation, Kansas City, USA). PDA (potato dextrose agar) was purchased from VWR International (Radnor, Pennsylvania, USA).

8.2.2 Samples

The samples under study were obtained from waste fruits furnished by Supreme Fruit Srl (Cisterna di Latina LT, Italy). For micronization, the pomegranate pericarp was cut into small pieces, frozen, freeze-dried, and finely ground with a laboratory horizontal blade mill with a rotation speed of 20,000 rpm (IKA), with short pulses to avoid temperature increases in the material due to friction and impact with the blades. For the extraction, the plant material was placed in a Teflon filter to avoid the release of non-soluble polysaccharides in the extract and stirred in deionized water (6.5% w/v) at 90 °C for 1 h; the material was then left to macerate at room temperature for 12 h. The extract was rinsed to an exact final volume, centrifuged at 5000 rpm for 10 min and analysed. The aqueous extract was then weighed, frozen in Petri dishes, and lyophilized.

8.2.3 HPLC-DAD-ESI-MS Analysis

An HP-1260 liquid chromatograph equipped with a DAD detector and an MSD API-electrospray (Agilent Technologies, Santa Clara, CA) set in negative ionization mode was used. A Luna, C18 250 × 4.60 mm, 5 μm column (Phenomenex, Torrance, CA) operating at 26 °C was used. Eluents: H_2O (pH 3.2 by HCOOH) and CH_3CN. A four-step linear solvent gradient from 100% H_2O up to 100% CH_3CN was performed as previously described (Romani et al. 2012). Mass spectrometer operating conditions: gas temperature 350 °C, flow rate 10.0 L/min, nebulizer pressure 30 psi, quadrupole temperature 30 °C, and capillary voltage 3500 V. Fragmentor 120 eV. Tannins were identified by comparing their retention times, UV–Vis, and mass spectra with those of the commercial standards. Compounds were quantified in HPLC/DAD by using five-point regression curves ($r^2 \geq 0.9998$) in gallic and ellagic acids. Analyses were carried out in triplicate; the results are reported as the mean values with standard deviations ≤5%.

8.2.4 *In Vitro Test*

The test was conducted against five fungi of agricultural and food interest: *Alternaria* sp., *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *Mucor* sp., *Penicillium digitatum*, and *Pythium ultimum* using the poisoned food technique, where the substrate (Potato Dextrose Agar, PDA) is incorporated with the extract to test and the colony diameter is registered, obtaining at the end an inhibitory value expressed as a percentage. For experimental purposes, PDA was prepared following the label instructions and added to the extracts in amounts of 0% (control), 0.5%, 1.0%, and 2.0% w/v. Then, the pH was corrected to 5.6 using 1 M KOH and autoclaved at 121 °C for 21 min. After sterilization, the molten substrate was dispensed in 55 mm Petri dishes. The inoculation was performed by placing a 6 mm mycelium plug obtained from colonies in active growth in the centre of each Petri dish. The test is terminated as soon as the mycelium of at least a colony arrives at the end of the Petri dish. The diameter of each colony was measured, and the inhibitory percentage was calculated using the formula (Cd Td)/Cd*100, where Cd = control diameter and Td = treated diameter.

8.3 Results and Discussion

The samples under study were obtained from waste of pomegranate processing, in particular from fruits of insufficient size or with characteristics that make them unsuitable for sale as a fresh product or for obtaining juice. The pericarp was isolated and used as a raw material to obtain the MP and the LE as described in the "Materials and Methods" section.

8.3.1 HPLC-DAD-MS Characterization of the Tannin Content

For the quali-quantitative chemical characterization of the tannin content, HPLC-DAD-MS analysis was performed on both samples under study and the aqueous extract of the pericarp before lyophilization. The results obtained for the aqueous extract of the pericarp are reported in Table 8.1. The extraction process appears to preserve unaltered a significant portion of α- and β-punicalagin, hydrolysable tannins representative of the *Punica granatum* species. The summed amounts of the respective hydrolysis products, α- and β-punicalin, represent 18% by weight with respect to the quantity of the two non-hydrolysed tannins.

The quali-quantitative characterization of the tannin content in LE and MP is reported in Table 8.2. The total tannin contents are similar for LE and MP, but it must also be considered that MP is the ground vegetal tissue (still containing the fraction of fibre and other insoluble compounds) to be used as such, while LE is totally water soluble. The relative amount of punicalin with respect to α- and β-punicalagin is almost preserved during lyophilization (18% aqueous extract vs 22% LE), whereas MP, which did not undergo hot water extraction, showed a slightly better preservation of punicalagin content (13% total punicalin vs total punicalagin) that is sufficient in both cases.

Table 8.1 HPLC-DAD-MS analysis of the hydrolysable tannins in the aqueous extract of pomegranate pericarp before lyophilization

	mg/mL of extract	mg/g plant material
HHDP glucose	0.012	0.185
Monogalloyl glucose	0.009	0.14
Gallic acid	0.035	0.565
α-punicalin	0.067	1.073
β-punicalin	0.087	1.386
α/β-punicalagin isomer I	0.224	3.582
α/β-punicalagin isomer II	0.082	1.307
α-punicalagin	0.274	4.379
β-punicalagin	0.578	9.248
Galloyl-HHDP glucose	0.008	0.131
Ellagic acid hexoside	0.008	0.133
Vanoleic acid bilactone	0.008	0.13
Granatin B	0.066	1.05
Ellagic acid rhamnoside	0.001	0.016
Ellagic acid penthoside	0.002	0.025
Ellagic acid	0.045	0.722
Total	1.505	24.072

Table 8.2 HPLC-DAD-MS analysis of the hydrolysable tannins in the lyophilized extract (LE) and micronized pericarp (MP)

	Lyophilized extract (LE)	Micronized pericarp (MP)
HHDP glucose	3.936	0.276
Monogalloyl glucose	0.37	0.756
Gallic acid	5.891	0.638
α-punicalin	13.633	7.269
β-punicalin	14.243	9.848
α/β-punicalagin isomer I	38.262	0.975
α/β-punicalagin isomer II	9.874	1.257
bis HHDP-hexoside isomers	0.000	12.909
α-punicalagin	46.771	55.115
β-punicalagin	79.034	72.449
Galloyl-HHDP glucose	2.141	0.528
Ellagic acid hexoside	1.177	1.511
Vanoleic acid bilactone	1.093	0.000
Granatin B	8.102	39.999
Ellagic acid rhamnoside	0.334	0.224
Ellagic acid penthoside	0.501	0.379
Ellagic acid	6.192	4.063
Total	231.554	208.196

Data are expressed in mg of compounds per gram of sample

Table 8.3 Inhibitory value (%) for each pathogen and extract concentration

	Micronized pericarp (MP)			Lyophilized extract (LE)		
	0.5%	1.0%	2.0%	0.5%	1.0%	2.0%
Alternaria sp.	17.02	36.17	44.68	13.48	31.91	59.57
Fusarium oxysporum f. sp. *radicis-lycopersici*	30.34	47.57	55.06	46.07	59.55	66.29
Mucor sp.	58.00	62.67	68.00	54.00	68.00	74.00
Penicillium digitatum	58.96	83.58	97.76	78.36	93.28	97.76
Pythium ultimum	20.00	63.33	70.00	36.00	88.00	100.00

8.3.2 *In Vitro Test*

In all cases, an inhibitory effect proportional to the sample dose was observed (Table 8.3), with an average better efficacy for LE than MP.

Regarding the fungi of food interest, the observed inhibition percentage obtained with MP ranged from 58.0% to 68.0% against *Mucor* sp. and from 58.9% to 97.7% against *Penicillium digitatum*, while the inhibition caused by LE varied from 54.0% to 74.0% against *Mucor* sp. and from 78.3% and 97.7% against *Penicillium digitatum*. The two samples were on average slightly less effective against fungi of agricultural interest. MP caused an inhibition from 17.0% to 44.6% against *Alternaria* sp., from 30.3% to 55.0% against *Fusarium oxysporum* f. sp. *radicis-lycopersici*, and from 20.0% to 70.0% against *Pythium ultimum*. The inhibition observed with LE ranged from 13.4% to 59.0% against *Alternaria* sp., from 46.0% to 66.2% against *Fusarium oxysporum* f. sp. *radicis-lycopersici*, and from 36.0% to 100% with *Pythium ultimum*.

8.4 Conclusions and Future Perspectives

These results highlight the possibility of exploiting the waste from processing pomegranate in an efficient way to obtain new semifinished and finished products rich in bioactive natural compounds with antimicrobial activity for food and green agriculture, following circular economy and sustainability principles. From a future perspective, the two described processes will be upscaled and integrated into industrial platforms and bio-refineries aimed not only at obtaining the primary products but also at transforming the pomegranate waste material into a new and renewable resource with high added value, useful for applications in diversified commodity sectors.

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Chapter 9
Carbon, Water, and Energy Footprint: A Sustainability Assessment for Fruit and Vegetable Losses in Italy

Giuliana Vinci, Roberto Ruggieri, Marco Ruggeri, and Simone Vieri

Abstract According to the Boston Consulting Group (BCG), by 2050, food losses and waste (FLW) could reach 2.1 billion tons, up +40% from the estimates by the FAO in 2011. Therefore, reducing FLW becomes important, not only because of the social and economic impacts they cause but also because when food is lost or wasted, many resources used in its production are also wasted, and large amounts of greenhouse gas emissions (GHGs) are also emitted. Therefore, linking the resource depletion and emissions generated to the production of food that will be lost or wasted could help frame the problem's extent. In this study, therefore, an assessment of the environmental impacts related to fruit and vegetable losses in Italy was carried out through the carbon and water footprint and cumulative energy demand to link, based on available data and databases, resource depletion (water and energy) as well as GHGs to the production of food that was lost in Italy between 2019 and 2020, especially taking fruit and vegetable losses as a reference. The results show that horticultural losses decreased between 2019 and 2020, which reduced the CF by −24% and the WF and CED by −40%. This could save and avoid significant amounts of emissions, water, and energy and could thus fit into the context of achieving some national and international goals, such as the European Green Deal, SDGs, and Directive 2000/60/EC.

Keywords Carbon footprint · Water footprint · Cumulative energy demand · Italy · Food losses · Sustainability

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9.1 Introduction

The agri-food sector annually causes approximately 16.5 billion tons of greenhouse gases (GHGs), including 400 million tons of CO_2 eq in Europe (EEA 2021), corresponding to 31% of total anthropogenic emissions, as well as the depletion of significant amounts of natural resources (Tubiello et al. 2022). Agri-food production has a great impact on the environment, whether food is consumed or not, and in the context of competition for limited natural resources, FLW is a particularly sensitive issue, as well as a threat to the livelihood of future generations. The management of FLW is taken up in the Agenda 2030, especially in subgoal 12.3, but to date, in reality, very little progress has been made, and even risks are going in the opposite direction, so much so that according to the BCG (2018), by 2050, FLW could reach 2.1 billion tons, up +40% from FAO's 2011 estimates (Gustavsson et al. 2011). Reducing FLW becomes important, not only because of the social and economic impacts (BCG 2018) that it causes but also because when food is lost or wasted, many resources used in its production are also wasted (FAO 2013). Linking resource depletion and the emissions generated to the production of food that will be lost or wasted could help frame the scope of the problem. Therefore, an assessment of environmental impacts related to food losses in Italy was carried out, and CF (IPCC 2006), WF (Mekkonnen and Hoekstra 2011), and CED (VDI 1997) were used. Based on the available data and databases, the goal was to link resource depletion (water and energy) and GHG emissions to the production of food lost in Italy between 2019 and 2020, specifically taking fruit and vegetable losses as a reference, based on Italian horticultural production (ISTAT 2021) for both 2019 and 2020.

9.2 Material and Methods

9.2.1 Methods

For the impact assessments, CF was chosen because it allows the investigation of GHGs generated by horticultural losses, while WF and CED link these losses to the depletion of the most used resources for their production. In particular, CF expresses in kg CO_2 eq the direct and indirect GHGs caused by a product or process (IPCC 2006), and it was calculated as Forster and Artaxo (2007) (Eq. 9.1).

$$CF = \sum (G.G._i \times k_i) \tag{9.1}$$

where $G.G._i$ is the amount of GHGs produced and k_i is the CO_2 eq coefficient for that gas. WF was calculated following the framework of Mekonnen and Hoekstra (2011) as the sum of the blue (WF_{blue}), green (WF_{green}), and grey (WF_{grey}) water footprints of the *i*-th agri-food product (Eq. 9.2).

$$WF = \sum \left(WF_{i,\text{blue}} + WF_{i,\text{green}} + WF_{i,\text{grey}} \right) \tag{9.2}$$

where WF_{blue} is the freshwater withdrawal from a reservoir that does not return directly to where it was withdrawn, WF_{green} is the amount of rainwater used by a crop to evapotranspire, and WF_{grey} is the volume of water needed to dilute pollutants generated during the production cycle below certain legal and toxicological limits. Finally, CED is the direct and indirect energy used during the entire life cycle of a product (VDI 1997), and it was calculated based on the methodology proposed by Frischknecht and Jungbluth (2004).

9.2.2 *Materials*

It is good to clarify the distinction made by ISTAT in fruit and vegetable production between total and harvested production. The first is the "totality of the product present on the plant in the hanging fruit state at the time when normal harvesting operations have begun", while the second is the "quantity of a product removed from the place of production regardless of its use." Thus, food losses can be understood as the difference between total production and harvested production. As shown in Table 9.1, in 2020, vegetable losses were approximately 843 thousand tons, while in 2019, they were approximately 865 thousand tons. In fruit production, in 2020 in Italy, the losses were 436 thousand tons compared to 2019 when the losses were 485 thousand. Therefore, considering total fruit and vegetables, food losses in 2019 were approximately 1.35 million tons, while in 2020, they were approximately 1.27 million tons, with a reduction of 72,315 tons (−5%) (although food production increased), probably due to the lockdown, which led to a greater need for food and a greater focus on agricultural losses. Then, the first point that can be made is that, assuming the average consumption of 160 kg/year of fruits and vegetables in Italy, avoiding 72,315 tons of fruit and vegetable losses could have fed 451,000 more people.

In all three assessments, fruit and vegetable production lost in 2020 (1.35 million tons of fruit and vegetables) and 2019 (1.28 million tons) were considered functional units. The two situations were then compared, and CF, WF, and CED were conducted from cradle to farmgate, i.e. considering the production process from seed purchase to ripening, excluding harvesting of the finished product. All fruit and

Table 9.1 Fruit and vegetable production in Italy, 2019–2020 (million tons)

	2019			2020		
	Production	Harvest	Losses	Production	Harvest	Losses
Vegetables	30.6	29.7	0.865	31.4	30.5	0.843
Fruits	13.0	12.5	0.485	13.1	12.6	0.435
Total	43.6	42.3	1.35	44.5	43.2	1.27

Source: Authors' elaboration from ISTAT (2021) vegetable products (and their related production processes) that contribute to agricultural losses in Italy were considered inputs, and the total amount of fruit and vegetable losses, as well as emissions from production processes, were considered outputs. Due to data availability, rice, artichokes, eggplants, figs, prickly pears, and beans were not considered, while since there is still no specific database for Italian fruit and vegetable production, a database to be released in 2023 (Notarnicola et al. 2021), the average production of a given type of food at the global level was considered in the study by using international databases (Agribalyse).

9.3 Results and Discussions

The results show that food losses in 2019 generated a CF of 3.16×10^8 kg CO_2 eq compared with the CF in 2020, which was 2.55×10^8 kg CO_2 eq, with a savings of -6.10×10^7 kg CO_2 eq (−24%) (Fig. 9.1a). This reduction could be attributable to less wastage of inputs (fuels, nitrogen fertilizers, pesticides, and irrigation water). Above all, the mechanization of fields is a significant source of climate-changing emissions due to the extraction of primary energy sources (oil and carbon) for diesel fuel production and combustion during the agricultural phase. Fertilizers, on the other hand, being synthetic products, generate direct impacts related to their production processes and indirect impacts related to their use, since the nitrogen in them, as is well-known, tends to dissipate, either into the water in the form of nitrates or into the atmosphere as N_2O.

Finally, as far as lower water consumption is concerned, irrigation processes, being highly energy intensive, have a high environmental impact due to the electricity production process, which in the case of the Italian mix remains mainly composed of fossil sources (GSE 2020). The CF results show the importance of reducing horticultural losses, as the potential savings in terms of greenhouse gas emissions could be particularly significant, especially considering that the average annual temperature in Italy has already increased by +1.1 °C over the past 30 years (1981–2010) compared to 1971–2000 (ISPRA 2013), in addition to the fact that

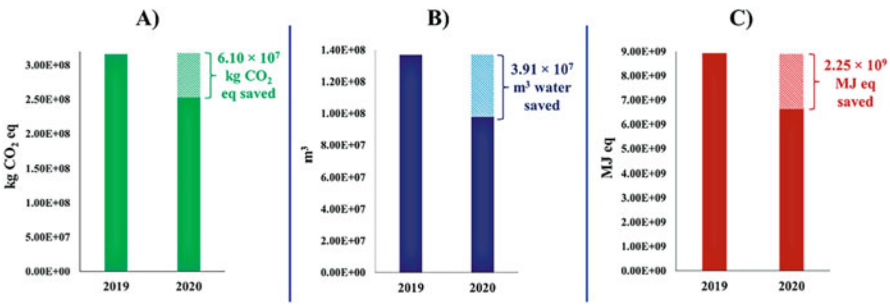

Fig. 9.1 CF (**a**), WF (**b**), and CED (**c**) of fruit and vegetable losses in Italy (2019 and 2020)

climate variations could further exacerbate this situation, with predictive studies (Michetti et al. 2022) showing that in Italy between 2021 and 2050, there could be a further increase of +2 °C compared to 1981–2010 and + 5 °C by 2100, with even worse scenarios, such as higher rainfall intensity, tropical nights (temperatures never below 20 °C), prolonged droughts, and sea level rise (6 cm for the Adriatic and 8 cm for the Tyrrhenian). Therefore, in the context of the pursuit of climate neutrality, also given the dialogue on the zero-emission measure approved by the European Parliament, a reduction in horticultural leakage could help to cut even more of a share of climate-altering emissions that could be avoidable. The CF results are also confirmed in the reduction of WF. Analysis of the results shows that horticultural losses in 2019 generated a WF of 1.37×10^8 $m^{3,}$ while in 2020, the WF was 9.79×10^7 m^3 (-3.91×10^7 m^3 of water, or −40%) (Fig. 9.1b). Water scarcity is a particularly acute problem, especially in the Mediterranean region (which suffers from the highest level of water stress globally) and in Italy, which ranks first in Europe in terms of water withdrawals for drinking (9 billion m^3/year) (ISTAT 2018) and is ranked among European countries with medium to high water stress (Luo et al. 2015). Induced water savings, in turn, could be particularly useful for Italy, especially in view of achieving the goals set by the Water Framework Directive (2000/60/EC) and those set by Agenda 2030, particularly subgoals 6.4.1 (Water Stress) and 6.4.2. (Water Efficiency). Finally, regarding CED, the study results show how a reduction in horticultural losses could induce a “saving” of 2.25×10^9 MJ eq (−40%), from 8.94×10^9 (2019) to 6.69×10^9 (2020) (Fig. 9.1c). The reduction in CED expresses, even more, the importance of energy source management, even considering the current period, characterized by the energy crisis following the war in Ukraine and inflated electricity prices that should push countries even more to accelerate the green transition. However, in the EU, energy production from coal increased by +18% in 2021, for the first time in a decade, and in the next 20 years, Russia will most likely continue to export to Europe through the Nord Stream pipeline. Instead, research and investment will have to go in the opposite direction through the creation of plants that provide high-density renewable energy, which cannot be obtained 100% from renewables. Investment in renewables is therefore necessary because high gas prices and inflated hydrocarbon prices make alternative sources cheap in the long run and because the need for energy security increases the urgency of addressing climate change.

9.3.1 Estimation of a Social Cost: CF and WF

To gain an even better understanding of the extent of horticultural losses in Italy, it might be possible to quantify a possible social cost associated with them. The basic idea is to give CO_2 emissions and consumed water a market value that reflects the price they cost society, based on the shadow price theory (the price of a good in the absence of a market but determined based on the impacts on society of that good or the basis of its scarcity). Regarding CF, recently, the European Bank for

Table 9.2 Per capita social cost of fruit and vegetable losses (CF and WF)

	2019	2020
Carbon footprint		
Ton CO_2 eq	316,000	255,000
Shadow price CO_2	40–80€/ton	
Estimated social cost	12.6–25.2 mln €	10.2–20.4 mln €
Estimated per capita social cost	0.21–0.42 €	0.17–0.34 €
Water footprint		
mln m^3 water	137	97.9
Shadow price water (€/m^3)	5.17 € for m^3 water	
Estimated social cost	708.2 mln €	506.1 mln €
Estimated per capita social cost	11.80 €	8.44 €

Reconstruction and Development (EBRD) has theorized a model whereby it suggests that the price of carbon should be set at 40–80€/ton for 2020 and 50–100€ for 2030 (EBRD 2018). Thus, considering the losses to 2020 and the above shadow prices, if a price were to be applied to the emissions caused by horticultural losses, they would lead to a social cost of between 10.2 and 20.4€ million, with a per capita social cost of between 0.17 and 0.34€ (Table 9.2).

Regarding water, the shadow price was calculated based on the study by Ligthart and van Harmelen (2019) and is approximately €5.17/m^3. Taking 2020 losses and considering the shadow price of water, they could have induced a social cost of €506 million, € 8.44 per capita (−29% compared to 2019).

9.4 Conclusions

Although with some limitations, this study shows, through potential quantification, how a reduction in fruit and vegetable losses could “save” and avoid significant amounts of emissions, water, and energy, which (in the last two cases) could be directed elsewhere and could thus fit into a context of achieving some national and international goals (European Green Deal, SDGs, Directive 2000/60/EC). However, such reductions could also be of considerable help in relation to the current global commodity crisis induced by the situation between Russia and Ukraine, from whose crisis a ripple effect related to price volatility and rising fuel costs could be generated, which would make the production of other commodities and other goods more difficult. The study thus shows the apparent unsustainability of some of the food losses in Italy and is within a line of research related to the quantification of FWL emissions and resource wastage that has yet to be explored. In anticipation of the release of the new ILCIDAF database, future studies could focus on new quantification of agri-food losses, no longer on average productions but on more accurate data, as well as extending the study to a wider part of the supply chain, to understand the problem more thoroughly, not confining it only to fruit and vegetable losses.

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Chapter 10
Green Technologies and LCA for the Analysis of Bioactive Compounds in Wheat Husk: An Integrated Study for Sustainability Assessment

Sabrina Antonia Prencipe, Lucia Maddaloni, Luca Masiello, and Giuliana Vinci

Abstract Wheat is the third most cultivated cereal in the world and is one of the most important cereals for production in the food industry. The FAO has estimated that its production worldwide is approximately 760 million tons, of which Europe produces approximately 33%. Wheat husk, which is the external leathery part of the grain, is one of the main by-products of the wheat supply chain. This low-cost by-product is unstudied and underutilized, although it is generated in abundance in wheat production (approximately 17–20% of grain yield). Therefore, it is important to extract residues of high nutritional value (e.g. polyphenols), thus valorizing agri-food by-products. For this purpose, the study will examine the possibility of recovering bioactive compounds (BCs) (e.g. polyphenols) from wheat by-products using green technologies (such as ultrasound-assisted extraction, natural deep eutectic solvents or NADES, water, etc.), which have been proposed to be *greener* replacements for conventional solvents (e.g. methanol, n-hexane, ethyl acetate). In particular, NADES will be applied for the extraction of BCs, as they are natural solvents compatible with food, pharmaceuticals, and cosmetics. Furthermore, the application of the life cycle assessment (LCA) methodology would allow a sustainability assessment for the recovery of bioactive components compared to wheat by-products.

Keywords Green solvents · NADES · Bioactive compounds · LCA · Environmental sustainability

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10.1 Introduction

The agri-food industry generates significant amounts of by-products that can be a serious environmental problem. Wheat is the most common type of cereal, and its global production reached 770 million tons in 2017, of which 150 million tons were harvested in Europe, thus representing 33% of the total production. (FAO 2018). During the milling process, wheat undergoes a series of treatments aimed at separating the outer fractions of the seed from the endosperm intended for processing and transformation into cereal-based products. Wheat husks are generated as waste material and represent approximately 20% of the total processing output weight, thus corresponding to 30 million tons of wheat husks produced in the European Union (Đorđević and Antov 2016). Therefore, the valorization of agricultural by-products through the extraction and recovery of molecules with high nutritional value (e.g. polyphenols, antioxidants, carotenoids, etc.), as a new resource to be reused in other production processes, could represent an alternative to incineration or compost (FAO 2017). Bioactive compounds (BCs) are studied for their biological properties, which can provide multiple health benefits (anti-inflammatory, hypoglycemic, antimicrobial, antiviral, cholesterol-lowering, etc.

For the chemical analyses of food matrices, the use of conventional organic solvents (e.g. methanol, ethyl acetate, hexane, etc.) is widely used as an efficient extraction solvent for BCs. These solvents are often discarded because of their toxicity and poor biodegradability. Therefore, the use of innovative green solvents, such as deep eutectic solvents (DES) and natural eutectic solvents (NADES), could be a greener alternative. DESs are homogeneous liquids formed from at least one hydrogen bond acceptor (HBA) and one hydrogen bond donor (HBD), and when combined in a certain molar ratio, their melting points are lower than the melting points of the individual components in the mixture (Manuela et al. 2020). When DES are formed from natural eutectic compounds from plant metabolites or their derivatives (amino acids, organic acids, sugars, or choline derivatives), they are called NADES. NADESs are easily biodegradable, and due to their natural composition, the extract obtained from NADESs can be used directly in food, pharmaceuticals, and cosmetics without the need to remove the solvent, thus avoiding costly downstream processing and purification (Cao and Su 2021). In this study, the extraction of polyphenols and antioxidants from wheat husk was investigated by using different NADES. The extraction efficiency of BCs was compared with conventional solvent (ethanol in aqueous solution) and water and was achieved by means of UV–Vis spectrophotometric analysis. Furthermore, the application of the life cycle assessment (LCA) methodology would allow a sustainability assessment for the recovery of bioactive components in comparison with wheat by-products.

10.2 Material and Methods

10.2.1 Natural Deep Eutectic Solvents (NADES) Synthesis

NADES synthesis was performed according to the heating and stirring method (Florindo et al. 2014). Specific molar ratios between the hydrogen bond acceptor (HBA) [betaine (Bet) and choline chloride (ChCl), Sigma-Aldrich, Milan, Italy] and hydrogen bond donor (HBD) [fructose (Fru) and glucose (Glu), Sigma-Aldrich Saint Louis, MO, USA] were synthesized as indicated in Table 10.1. All of the solvents were diluted with 30% water.

10.2.2 Extraction of Polyphenols from the Wheat Husk

NADES and hydroalcoholic-based extraction [(EtOH: H_2O (80:20, v/v)] in wheat husk was performed according to Manuela et al. 2020, with some modifications. Solid–liquid ratios of 0.5 g (±0.01 g) of homogenized wheat husk per 10 mL of NADES, ethanol in aqueous solution (80:20), and aqueous solution were used for the extraction of polyphenols. Extraction was carried out in a Bandelin Sonorex RK100H ultrasonic and thermostatic bath at constant temperature (T = 70 °C) for 40 min. The samples were then centrifuged at 2900× g for 10 min at T = 25 °C. The supernatant was collected in a 10-mL amber flask and stored at T = 4 °C until the day of analysis. All analyses were conducted in triplicate.

10.2.3 Spectrophotometric Analysis for Bioactive Compound Determination

10.2.3.1 Total Phenolic Content by Folin-Ciocalteu Assay

The total phenolic content (TPC) was determined by UV–Vis spectrophotometric analysis according to the Folin-Ciocâlteu method (Preti et al. 2017). The absorbance was measured at $\lambda = 750$ nm in 1-cm path length cuvettes against the blank solution. The total content of phenols was expressed as milligrams of gallic acid equivalent

Table 10.1 NADES components, molar ratios, and water content

Name	Component 1 (HBA)	Component 2 (HBD)	Molar ratio	Water content (%)
NADES1	ChCl	Glu	1:1	30
NADES2	ChCl	Fru	1:1	30
NADES3	Bet	Glu	1:1	30
NADES4	Bet	Fru	1:1	30

(GAE) per g of wheat husk. The results were obtained through a calibration curve ranging from 10 to 100 mg/L ($R^2 = 0.9997$).

10.2.3.2 Total Flavonoid Content (TFC) by Aluminium Chloride Assay

The TFC was determined with the aluminium chloride method, as reported by Zargar et al. (2018). The absorbance was measured at $\lambda = 510$ nm using a UV–Vis spectrophotometer (Jenway, Stone, UK). The results were expressed as mg of rutin equivalents (RE) per g of wheat husk samples ($R^2 = 0.9959$).

10.2.3.3 Antioxidant Activity by ABTS Radical Scavenging Assay

The Trolox equivalent antioxidant capacity (TEAC) of the wheat husk extracts was estimated by the ABTS radical scavenging assay according to Omono et al. (2015) with some modifications. The decolorization of ABTS was expressed as μM Trolox equivalent (TE) per g of wheat husk, obtained by a calibration curve ranging from 0.5 μM TE to 200 μM TE ($R^2 = 0.9963$).

10.2.4 Life Cycle Assessment

The study evaluated the sustainability assessment of wheat by-products, which account for 17–20% of the total production, through the application of the life cycle assessment methodology (ISO 14040, 2006a; ISO 14044, 2006b).

10.2.4.1 Goal and Scope Definition

This study was conducted to compare the environmental impacts of wheat production with wheat by-products for the recovery of bioactive compounds. The system considered the phases from land preparation to harvesting the raw cereal (from cradle to farmgate). The functional unit considered was the cultivation of one hectare (ha) of wheat.

10.2.4.2 Life Cycle Inventory (LCI)

LCI data for wheat cultivation are shown in Table 10.2.

Table 10.2 LCI data for wheat cultivation

Inputs	Unit	Value
Diesel	kg	161.8
Lubricating oil	kg	0.8
Water	kg	900
Mineral superphosphate (19% P_2O_5)	kg	57
Ammonium nitrate (26% N)	kg	78
Urea (46% N)	kg	92
PP (sacks)	kg	7.1
Paper (container)	kg	3.1
Seed	kg	200
Herbicide	kg	0.044
Insecticide	kg	0.378
Outputs		
Wheat	kg	154.300
Wheat by-products	kg	34.800

Table 10.3 Bioactive compounds in different wheat husk extracts

Wheat husk extracts	TPC (mg GAE/g)	TFC (mg RE/g)	ABTS (μmol TE/g)
EtOH:H_2O	1.60 ± 0.06	4.71 ± 0.05	4.92 ± 0.04
H_2O	2.44 ± 0.26	2.86 ± 0.03	5.32 ± 0.12
Bet/Glu	2.68 ± 0.05	4.86 ± 0.19	4.75 ± 0.09
Bet/Fru	3.42 ± 0.28	6.59 ± 0.23	4.76 ± 0.07
ChCl/Glu	1.54 ± 0.13	3.38 ± 0.02	5.17 ± 0.11
ChCl/Fru	1.46 ± 0.14	6.15 ± 0.05	4.51 ± 0.08

Data are expressed as mg/g of sample ± standard deviation (SD); TPC: Total Phenolic Content; GAE: Gallic Acid Equivalents; TFC: Total Flavonoid Content; RE: Rutin Equivalent; TE: Trolox Equivalent

10.2.4.3 Life Cycle Impact Assessment (LCIA)

This phase was aimed at evaluating the contribution of the wheat by-products in terms of individual impact categories by using SimaPro 9.2.2. software. The ReCiPe 2016 Midpoint (H) V1.05 method was used for the impact calculations.

10.3 Results and Discussion

10.3.1 Bioactive Compound Determination in Wheat Husk

Table 10.3 shows the quantitative results for colorimetric assays for the determination of bioactive compounds in wheat husk.

The results showed variability among spectrophotometric assays depending on the composition of the extracting solvent, thus indicating the importance of the selection of suitable NADES. For TPC and TFC, NADES 4 was the best solvent (3.42 ± 0.28 mg GAE/g; 6.59 ± 0.23 mg RE/g), thus showing an extraction efficiency approximately 50% higher than that of conventional extraction (1.60 ± 0.06 mg GAE/g; 4.71 ± 0.05 mg RE/g). This could probably be related to the physicochemical characteristics of NADES, indicating that intermolecular interactions between NADES constituents and phenolic compounds and flavonoids play an important role in solubility (Dai et al. 2013). Our results are in agreement with the study by Cherif et al. (2020), thus highlighting a 45% more efficient extraction by NADES than conventional solvents. Antioxidant activity was tested by ABTS, which is an in vitro antiradical assay that is soluble in both aqueous and organic solvents and can be used to determine both the hydrophilic and lipophilic antioxidant capacity of extracts.

10.3.2 LCIA Results

The application of the LCA methodology allowed the study of wheat production and its waste, the wheat husk, highlighting the stages with the greatest impact. The results of the assessment are shown in Table 10.4.

The results showed that wheat production impacts 15 out of 18 categories. In particular, it greatly impacts the environmental macrocategory, considering high values for global warming (3.29 × 10–1 kg CO_2 eq), ozone formation in terrestrial

Table 10.4 LCIA of wheat production and wheat by-products

Impact categories	Unit	Wheat production	Wheat by-products
Global warming	kg CO_2 eq	3.29×10^{-1}	1.05×10^{-1}
Stratospheric ozone depletion	kg CFC_{11} eq	6.10×10^{-6}	9.91×10^{-7}
Ionizing radiation	kBq Co_{-60} eq	5.29×10^{-3}	6.98×10^{-3}
Ozone formation, human health	kg NOx eq	2.10×10^{-3}	4.34×10^{-4}
Fine particulate matter formation	kg $PM_{2.5}$ eq	8.82×10^{-4}	2.54×10^{-4}
Ozone formation	kg NOx eq	2.11×10^{-3}	4.37×10^{-4}
Terrestrial acidification	kg SO2 eq	4.64×10^{-3}	8.83×10^{-4}
Freshwater eutrophication	kg P eq	1.63×10^{-4}	5.05×10^{-5}
Marine eutrophication	kg N eq	1.97×10^{-3}	3.27×10^{-4}
Terrestrial ecotoxicity	kg 1.4-DCB	2.19×10^{-1}	1.14×10^{-1}
Freshwater ecotoxicity	kg 1.4-DCB	1.15×10^{-2}	3.88×10^{-3}
Marine ecotoxicity	kg 1.4-DCB	4.64×10^{-3}	3.80×10^{-3}
Human carcinogenic toxicity	kg 1.4-DCB	2.02×10^{-3}	2.56×10^{-3}
Human noncarcinogenic toxicity	kg 1.4-DCB	5.26×10^{-1}	1.39×10^{-1}
Land use	m^2a crop eq	1.80	3.11×10^{-1}
Mineral resource scarcity	kg Cu eq	2.75×10^{-4}	4.17×10^{-4}
Fossil resource scarcity	kg oil eq	5.94×10^{-2}	2.25×10^{-2}
Water consumption	m^3	1.02×10^{-2}	2.04×10^{-3}

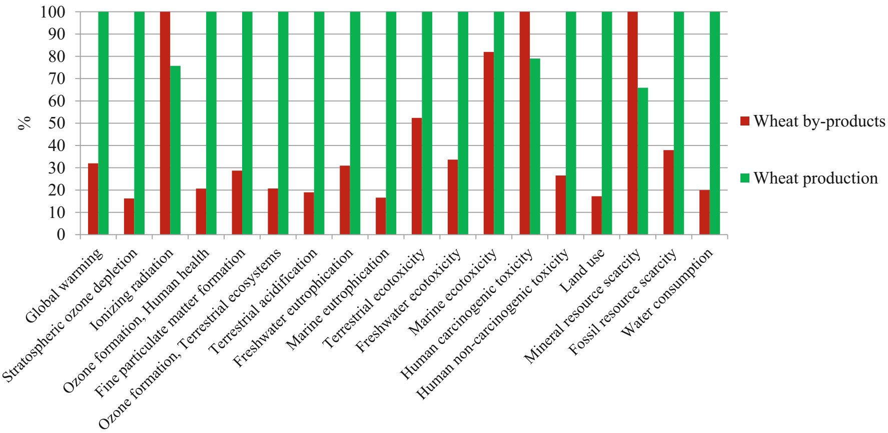

Fig. 10.1 Characterized results of wheat production concerning wheat by-products

ecosystems (2.11 × 10–3 kg NOx eq), terrestrial acidification (4.64 × 10–3 kg SO_2 eq), freshwater eutrophication (1.15 × 10–2 kg P eq), and marine eutrophication (1.97 × 10–3 kg N eq). All of these values of grain production were 70% higher than the results of grain by-products, as shown in Fig. 10.1, where the results were characterized and expressed as a relative impact, where the scenario with the highest value in the impact category is set as the reference value (100) and the other is calculated accordingly. Furthermore, after demonstrating how wheat by-products have less impact than wheat itself by extracting polyphenols using NADES, these wastes could be valorized by incorporating these theoretically edible extracts into foods.

This possibility would also generate a gain from an economic point of view, considering a yield of 2.2% polyphenols from the wheat husk matrix, that phenolic acid is the polyphenol most present in wheat (Shahidi and Ambigaipalan 2015) and that its cost in pure form is 169€ per 0.1 g (Sigma-Aldrich, Milan, Italy).

10.4 Conclusions

This study showed that new natural deep eutectic solvents (NADESs) can be an exceptionally effective means of recovering polyphenolic antioxidants from the by-products of wheat processing, particularly husks. Furthermore, through the application of the LCA methodology, it was possible to assess the sustainability of the recovery of bioactive components from wheat by-products. Our study demonstrates that the use of husks can be useful in mitigating several environmental impacts, including the potential for global warming. Moreover, thanks to its polyphenol content and its extraction by means of green and naturally based solvents such as NADES, it is possible to use them for the formulation of functional foods, also generating a profit in circular economic optics.

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Chapter 11
Modelling Leather Industry Waste from the Circular Economy Perspective: An In-Depth Review

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Abstract The tanning industry is not only a significant economic sector in Italy but also a source of high environmental impacts. Many studies have underlined the issues of each phase of the leather production cycle, looking for eco-friendlier solutions. This research was encouraged by the Sustainable Development Goals set by the 2030 Agenda, in particular goals 12 and 13, which promote responsible consumption and production and the fight against climate change, respectively. In support of these goals, the application of circular economy (CE) practices allows both a reduction of the environmental impact and economic savings. The tanning industry indeed produces a huge amount of liquid and solid waste, and the CE model allows both the prevention and recovery of such waste. This paper provides a review of the potential applications of the CE to the tanning sector through the design of eco-sustainable products and the reuse of waste as secondary raw materials within the same or other production processes. The use of biological, chemical, and thermal techniques allows for a high degree of reducing waste production and recycling of secondary materials with a significant decrease in environmental pollution.

Keywords Circular economy · Leather waste · Environmental impact

11.1 Introduction

Currently, corporate sustainability is a requirement for maintaining an industrial economy that achieves a sustainable competitive advantage. The latter has changed its configuration, and it consists of not only an economic but also a social and, above all, environmental component. The economic strategy adopted by the market, indeed, is no longer based on the linear model centred on the exploitation of

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resources until they are exhausted, on mass consumption and on the accumulation of waste. The current and sustainable model proposed is the circular economy model, which mainly provides for the reuse of waste as secondary raw materials.

Tanned leather is characterized by high-level manufacturing and a process handed down over time and is known throughout the world for its value. Hence, the tanning sector has significant economic importance, representing a strategic segment for the manufacturing sector in Europe, which accounts for 30% of global turnover. Furthermore, the finished leather chain generates a value creation boost of 125 billion euros in turnover for downstream producers. In Italy, the value of production amounts to 3.5 billion euros with volumes of 97 million m^2 of finished leathers. It must be stressed that a certain amount of waste directly proportional to the volumes of production has been generated, with an average of 2.63 kg per m^2 of finished leather. Leather manufacturing could be defined as one of the oldest examples of a circular economy, as well as being a natural and biodegradable material (SER 2020). However, to produce finished leather, the raw material requires a series of processes presenting multiple critical environmental issues. Therefore, the benefits of recycling the waste leather derived from animals destined for slaughter are outweighed by the polluting effects caused by its production process.

Specifically, the various processing stages of the production cycle that transform 1 ton of raw leather into tanned leather generate an average of 15–50 m^3 of wastewater, a range of 450–730 kg of solid waste and 500 kg of sludge derived from wastewater treatment plants (Hu et al. 2011). Particular attention should be given to the chemicals present in wastewater and sludge since 1 ton of raw hides includes approximately 240 kg of COD, 100 kg of BOD, 150 kg of suspended solids, 170 kg of sodium chloride, 80 kg of sulphate, 10 kg of sulfide, and 5 kg of chromate (Tasca and Puccini 2019). Overall, European cow tanneries generate approximately 4105 tons of sludge per year and approximately the same amount of other solid residues (Tasca and Puccini 2019). Many researchers have studied the stages of the leather production cycle to identify the most environmentally impactful stages.

This study provides a depth review of the clean technology innovations for the sustainability of the production tanning process aimed both at reducing the use of necessary resources and the quantity of waste produced, notwithstanding improving the quality. Furthermore, the review investigated research concerning technologies aiming to solve the issue of the recycling of waste produced by the tanning industry.

11.2 Methodology

First, we highlighted the inputs and outputs most required and characterized by the greatest environmental impact. Based on this assumption, we gathered scientific literature concerning the best preventive techniques and tools capable of reducing the environmental impact, in addition to solutions to recover production waste by redesigning it from a circular economy perspective.

Multiple publications were selected from different databases: ResearchGate, Scopus, Springer, and ISI Web of Knowledge were mainly used. The keywords used for the bibliographic research were "leather production" retrieving 36,677 results, reduced to 16,613 results using "sustainable leather"; the other words that guided the research were "leather waste" obtaining 21,166 results reduced to 7786 by adding the word "recycling". Among all the results obtained, we selected 15 articles that collected the techniques and applications of the circular economy, starting from the tanning sector, in different sectors.

11.3 Production Inputs and Outputs

The tanning production cycle includes various operations starting from drying or salting, followed by soaking necessary to rehydrate the leather and remove the salt, calcination useful for the removal of hair and meat residues, and preparation of the leather for the reception of tanning substances. Next, deliming removes the lime previously used, while pickling reduces the pH of the leather, and bating allows for separation.

The fibres of the leather and the degreasing removes the natural fat, up to the tanning. This operation assumes a predominant role in the process giving to the leather the conditions of resistance and stability of the material through the use of tanning agents such as chromium or vegetable tanning agents. Post-tanning and finishing operations make the material complete with its organoleptic and aesthetic properties and, therefore, free from defects (Covington 2009).

As shown in Fig. 11.1, a per-phase analysis of the inputs and the outputs generated allows us to identify which resources are most consumed and how much and what waste is produced. The inputs with the highest utilization rate are water and energy. Particularly, considering the system boundary from raw leather (1 ton) to finished leather (200 kg), the inputs are the following: 21.4 m^3 of water, 2.313,2 MJ of thermal energy, and 294.92 kWh of electric energy (Notarnicola et al. 2011). It must be noted that the leather tanning phase consumes approximately 90% of the total energy (Navarro et al. 2020). Among the production outputs, chromium is the chemical substance that is most polluting. Specifically, chromium(VI) oxidized by chromium(III) in tanning is carcinogenic, allergenic, and mutagenic (Wang et al. 2017). This substance is present in wastewater, sludge, chrome-tanned leather shavings, and chrome leather trims, generating harm to the environment and human health. A significant problem for tanning companies but also for leather product manufacturing companies is the amount of shavings and scraps that accumulate and contain chemicals. In particular, 1 ton of raw hides generates 225 kg of shavings and 150 kg of trimming (Hu et al. 2011). This overview of the most relevant inputs and outputs makes it possible to identify the critical process points of the product process.

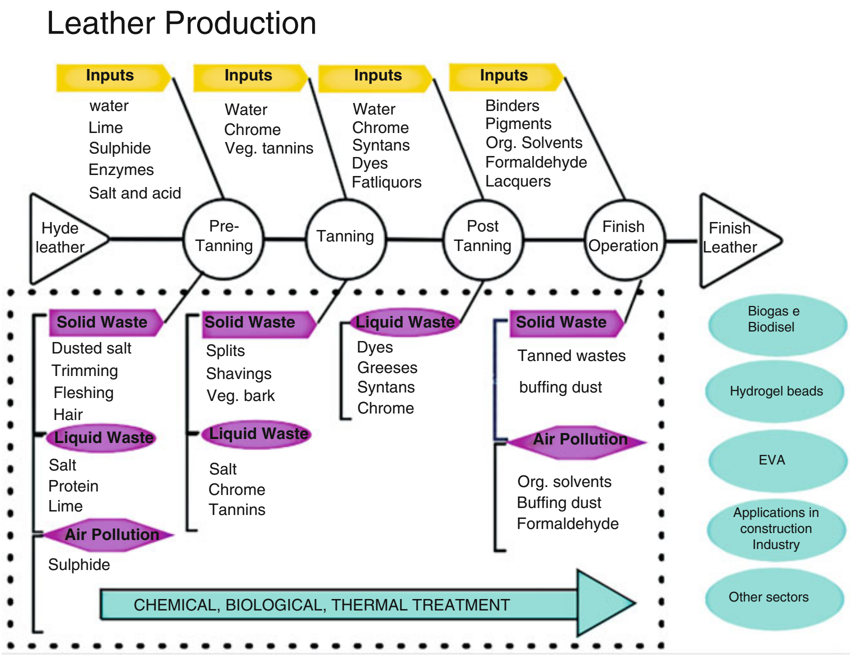

Fig. 11.1 Circular economy's applications in the leather sector

11.4 Clean Technologies

There are several technologies applied to the production process to reduce the environmental impact. The most numerous are dedicated to the change, reduction, and/or recycling of the most amounting and impactful inputs and outputs, such as water and chromium.

China et al. (2020) propose improvement techniques in the tanning phase. They provide for the recycling of exhausted chromium liquids through the direct recycling method, which is more immediate and economical than the indirect method. The authors also investigated tanning technologies with high chromium exhaustion that make use of auxiliaries or other solvents in addition to water to improve the absorption of chromium and total replacement of chromium salts using alternative tanning agents. Although China et al. (2020) proposed a method that leads to a reduction in the amount of polluting wastewater, Sathish et al. (2019) studied a process that would allow the complete replacement of the use of water in leather processing using a supercritical fluid as a solvent, eliminating not only the environmental impact of water waste but also the costs associated with the treatment of wastewater. The same advantages are obtained with the use of switchable solvents, also benefiting from energy savings.

Kanagaraj et al. (2020) included vegetable tanning among sustainable tanning systems, highlighting, however, the critical issues linked to the use of 20–40% vegetable tannin, which generates considerable quantities of organic loads, sludge, and unpleasant odours. Krishnamoorthy et al. (2012) propose a solution with the use of green chemistry that develops an ecological tanning system based on optically active unnatural d-amino acids (d-AA) with aldehyde (Ald) as a chrome-free tanning. This method proves to be more effective since it reduces the environmental impact of completely nontoxic wastewater without burdens concerning the disposal of solid and liquid waste.

The preventive technologies implemented upstream of the production process are not sufficient to solve the environmental issues of the sector. Specifically, there are multiple applications with a view to the circular economy capable of transforming by-products into secondary raw materials for the same tanning sector or other industrial sectors. Through chemical transformations, they are used in the energy, infrastructural, and construction fields. Ding et al. (2022) provide a circular economy application with chromed leather scraps in the building field, specifically obtaining hydrogel beads for the preparation of light gypsum; this composition has a lower mechanical resistance and thermal conductibility. This last feature offers opportunities to produce materials useful for thermal and acoustic insulation. Indeed, Marconi et al. (2020) used leather scraps for the preparation of thermal insulation panels. However, the use of this waste provides for an increase in the aluminium thickness present in the panel, which is responsible for 60% of the environmental impact of the frame.

Battig et al. (2021) also exploited the potential of wet white skin waste as a functional adjuvant and replacement in flame-retardant (EVA) polymeric composites, improving their mechanical properties with respect to tensile strength and Young's modulus and fire-fighting performance. An interesting sector of application of tanning waste is biofuels. These could be used as a source of energy needed during the production process. Priebe et al. 2016 proposed the production of biogas or methane fractions through the anaerobic treatment of solid waste, obtaining lower energy consumption and disposal costs, while Keskin et al. (2020) studied the production of biodiesel using waste fat, obtaining a yield of 86.8%; however, on the output parameters of a diesel engine, there was no reduction in NOx emissions but only in the fumes.

11.5 Conclusions

The review carried out investigated the current multiple technologies aiming to improve the environmental impact of the tanning sector, although most of them require huge investments for companies to adapt the disposal and purification plants. The recovery of leather scraps as raw materials for other sectors, however, allows economic savings on disposal costs as well as encourages circular economy models. Although the fields of applications are numerous and heterogeneous, there is a lack of industrial symbiosis districts between the tanning industries and the companies that use leather waste. The building of such clusters would further reduce costs for all businesses with a significantly lower environmental impact.

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Chapter 12
Application of the MFA Methodology for the Analysis of Paper and Cardboard Waste in Italy and a Focus on Waste Management in Apulia

Vincenzo Campobasso, Teodoro Gallucci, and Giovanni Lagioia

Abstract The raw materials crisis has put a strain on the paper market, leading to a real supply race forcing recycled paper suppliers to decrease their production capacity. In recent years, the paper recovery market has undergone significant changes: just think how wastepaper from the recycling cycle in Italy had a cost of zero euros in February 2020, at the Milan Chamber of Commerce, compared to 68 euros in February 2022. These figures drive home the importance of rethinking production cycles from the perspective of the circular economy. In this study, the authors have studied the paper value chain to analyse the sustainability of the paper sector in Italy with a focus on the Apulian region using the Material Flow Analysis (MFA) tool to identify critical points in the regional system. The authors' goal is to identify critical aspects of the current system as a starting point for future improvement scenarios aimed at greater circularity while responding to the logistical and economic needs of the sector.

Keywords Wastepaper · Waste management · MFA · Paper recycling · Paper mills

12.1 Introduction

The guiding principle of the EU Waste Framework Directive (EU Directive 2008/98/EC) places a hierarchy in waste management outlining prevention and recycling actions with a minimum threshold of 50% waste recovery through separate collection. In contrast, landfill represents the least sustainable management of MSW (municipal solid waste); in contrast, it has been the most widely used option in Europe and the most widely used in the world. The idea that maximizing waste

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collection leads to increased levels of recycling is often misleading. This is because there is no market for secondary materials; hence, the supply and demand for recycled materials are unbalanced, and recycled materials continue to be present in the market despite the lack of supply. The importance of investing both in upgrading the old recycling plants and in the construction of recycling facilities as an alternative to landfills or to promote operative actions, such as a tax credit for recyclers and tax breaks for those who purchase recycled materials, should be emphasized. Concerning waste recycling, the current scenario is divided into established supply chains (glass, paper, metal, wood, plastic) and still embryonic supply chains (electronic waste, aggregates, organic fraction, photovoltaic panels and so on), for which there is enormous potential for development. In this study, the authors have studied the paper value chain to analyse the sustainability of the paper sector in Italy with a focus on the Apulian region using the Material Flow Analysis (MFA) tool to identify critical points in the regional system. The rising costs of wastepaper and the absence in the Apulian territory of a paper mill, which therefore avoids an internal circularity of waste, have been the main reasons that led the authors to examine cardboard waste.

12.2 The Main Literature Review Analysed for the Case Study

The MFA tool is a methodology that provides useful information on direct flows to disposal and/or recovery that represent potential sources of secondary materials. For this reason, literature is often used to understand the life cycle to monitor wastes in and between the processes in the system. In waste management, there are different examples of research studies. Stanisavljevic et al. (2015) evaluated different solid waste management scenarios at the regional scale, whereas Deshpande et al. (2020) showed the importance of adopting MFA in the fish industry to support both industry and policymakers in realizing improvements. Villalba (2020) developed a mass balance table to calculate and examine indicators for waste subcircuits; Hsu et al. (2021) analysed inefficiency and potential leakage to natural systems of the plastic sector in EU 28, and Amicarelli et al. (2021) tested MFA to verify the reliability in sustainability assessments of the meat industry in Italy, whereas Caldeira et al. (2021) assessed food waste through a combination of MFA and statistical information.

12.3 Material and Methods

12.3.1 Material Flow Analysis

The MFA is based on the mass balancing principle, and it is the central methodology of industrial ecology. The MFA is a tool that measures incoming and outgoing materials while examining and measuring the flows of each material in the entire process. The application of MFA has recently increased in waste management, becoming a tool to support decisions at the policy and administrative levels. According to Brunner and Rechberger (2004), the "MFA is a systematic assessment of material flows and stocks within a system defined in space and time". In the current case study, the authors applied a top-down approach, collecting data through national reports, databases, and a specific interview with local managers operating in the sector of paper and cardboard waste recycling in Italy with a focus on Apulia. To evaluate the performance of collection, sorting, and recycling of recovered paper, the following indicators were defined: recovery rate (RR), recovery utilization rate (RUR), recovery import rate (RIR), and recovery export rate (RER).

As underlined in the literature, there are different performance indicators, and the authors have chosen two material cycle indicators: the "Direct material input" (DMI), which measures the direct and actual input of materials into a well-defined national economy as the sum of domestic extraction plus physical imports, and the "Material use efficiency" (MUE), which represents an appropriate value for quantifying the recovery of by-products (Hashimoto and Moriguchi 2003). In addition, the "Total material input productivity" indicator was calculated to assess eco-efficiency.

Table 12.1 describes the methods of calculating the selected indicators.

12.3.2 *Paper Recycling in Italy and Comparison with Apulia*

All data come from official national reports of 2019, and the year is taken as a reference for the study. In 2019, the value of the paper industry's turnover in Italy was 7.26 billion euros, down 6 percent from 2018. Paper production requires fibrous materials, such as virgin fibre and pulp, and nonfibrous materials, such as minerals and starches, as inputs. Paper recycling is a classic example of the circular economy both because of the features of the finished product, which is easily recyclable and biodegradable in the environment, and because fibres are currently fed back into the production cycle approximately 3.6 times. In Italy in 2019, there was a raw material consumption of 10,085,000 t to produce 8.901 million tonnes of paper, where roughly more than 50% is represented by secondary material (Assocarta 2020). In

Table 12.1 The methods of calculating wastepaper performance indicators

Recovery rate (RR)	$\frac{\text{waste paper selective collected}}{\text{PB products consumed}} \times 100$
Recovered utilization rate (RUR)	$\frac{\text{recovered paper consumed}}{\text{PB products consumed}} \times 100$
Recovered import rate (RIR)	$\frac{\text{recovered paper imported}}{\text{recovered paper produced}} \times 100$
Recovered export rate (RER)	$\frac{\text{recovered paper exported}}{\text{recovered paper produced}} \times 100$
Material use efficiency (MUE)	$\frac{\Sigma \text{ material consumed} - \Sigma \text{ material disposed of}}{\Sigma \text{ material consumed}}$
Direct material input (DMI)	Domestic extraction + physical imports
Total material input productivity (TMIP)	$\frac{\text{Industrial output value}}{\text{DMI}}$

Source: Based on Sevigné-Itoiz et al. (2014) and Amicarelli et al. (2021)

2019, the paper collection for recycling was 6.564 million tonnes; the import of paper for recycling was 0.311 million tonnes, and the export was 1.815 million tonnes, leading to paper recycling of 5.060 million tonnes (Fig. 12.1).

The Apulian separate wastepaper collection is 198,750 t, which represents 10% of the total municipal waste (ISPRA 2022). Of the 198,750 pieces of wastepaper, 95% is sent to the selection platform and successively transferred to different paper mills outside the region. Figure 12.2 depicts the cycle paper collection phase in Apulia in 2019. Wastepaper represents 43% of the total waste produced in Apulia.

12.4 Discussion and Conclusions

The authors compared the results obtained in Italy with the results of Sevigné-Itoiz et al. (2014) for some performance indicators (Table 12.2).

The comparison between the Spanish and Italy paper collection system highlights that Italy has a higher RR compared with Spain, and this is representative of a high grade of circularity of the paper in Italy. From the comparison, it emerges that the recovered utilization rate shows a value of 73.74%, which is lower than the value of the Spanish system equal to 78.5%; the reason for these data is attributable to the use of virgin fibre for the production of paper. Hence, the RIR and RER values show that Italy has a significant paper collection phase and, unlike Spain, a smaller phase of importing wastepaper.

Regarding the TMIP and MUE indicators, since there is no research at the European level that has computed the values of these indicators, the authors calculated them in 2014 (Assocarta 2015) and 2019 in Italy and successively compared the results (see Table 12.3).

The results showed a general improvement in TMIP in 2019, passing from 691.81 € to 686 €. The MUE in 2014 was not possible to compute since there are only aggregated data that cannot allow calculation.

It was difficult to calculate the RR, RER, RIR, and RUR performance indicators in Apulia because some initial data were missing. Mainly, the calculation of RR, RER, RIR, and RUR was not possible because data on paper production and consumption in Apulia are not available. The main problem is due to the absence of some regionally broken-down data that do not allow some allocations.

The same critical issue was found for the calculation of the MUE and TMIP because of the lack of data for calculating *the regional paper DMI*.

It is therefore important to have disaggregated data at the regional level to be able to evaluate and make regional estimates on consumption.

As Fig. 12.2 shows, most of the wastepaper collected in Apulia is sent outside the region, which leads to the contradiction that the increase in the collection phase does not correspond to a regional circularity of the paper sector. For example, in 2001, the Apulia region collected a total of 48,930 t of paper, whereas in 2019, it collected

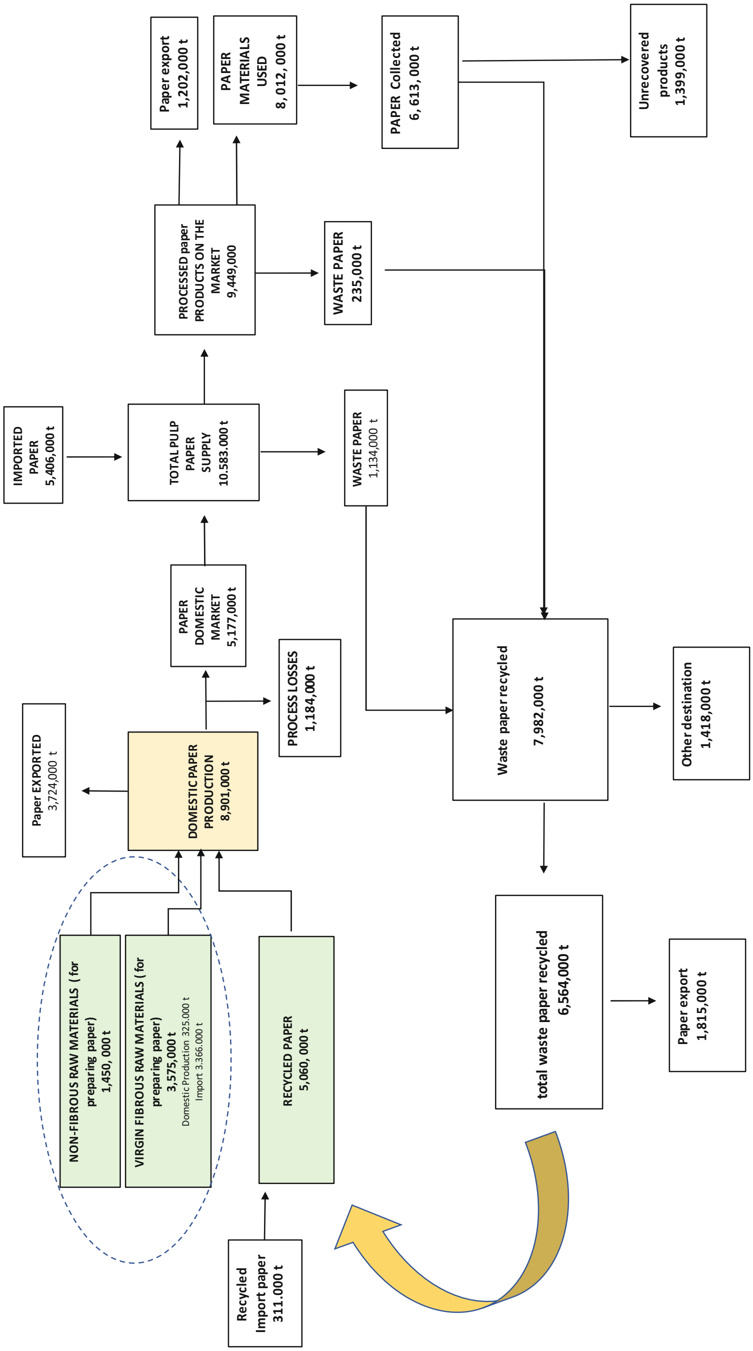

Fig. 12.1 Italy's paper recycling collection phase

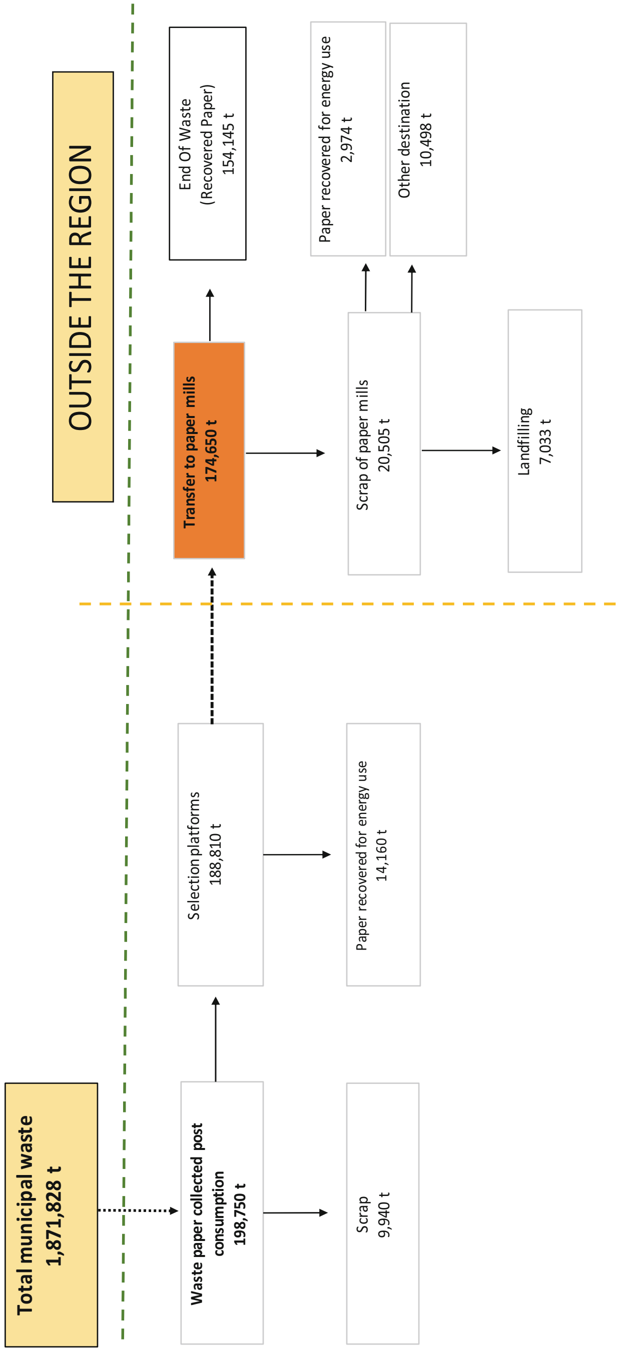

Fig. 12.2 Apulia paper recycling collection phase

Table 12.2 Comparison of environmental performance indicators on wastepaper collection between Italy and Spain

RR	RUR	RIR	RER
Italy			
82.54%	73.74%	4.73%	27.65%
Spain			
69.1%	78.5%	28.6%	19.4%

Notes: *RR* recovery rate, *RUR* recovered utilization rate, *RIR* recovered import rate, *RER* recovered export rate

Table 12.3 Comparison of MUE DMI and DMIP at the domestic level

Indicators	2014	2019
TMIP	691.81 €	686 €
MUE	Missing data	82.5%

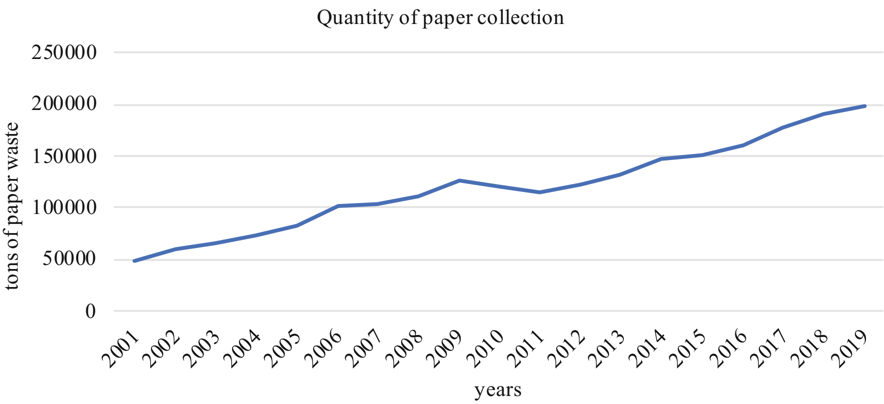

Fig. 12.3 Tonnes of paper waste collected in Apulia from 2001 to 2019

198,750 t, with a total increase of 406.2% (Fig. 12.3). The increase in the collection phase has not provided any environmental benefit in the region, considering the increase in the environmental aspects due to transport outside the region and the development of some business circular models.

Future projections to 2025 indicate an amount of recycled paper waste of 220,000 t, bringing the recycling rate to 98% from the current 95%. Considering future projections, the presence of a paper mill in Apulia is necessary. The construction of a paper mill will create an internal circularity system while simultaneously reducing the environmental impacts due to road transport that are unavoidable today.

This work stands as a basis for future research aimed at assessing the impacts of the Apulian waste collection system using the LCA methodology by subsequently imagining improved scenarios of a paper mill, supplementing the current work with surveys aimed at quantifying regional paper consumption to fill the current lack of data necessary for a national comparison.

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Chapter 13
Material Flow Analysis and Life Cycle Assessment of Waste Electrical and Electronic Equipment in a Regional Circular Economy Scenario

Patrizia Ghisellini, Renato Passaro, and Sergio Ulgiati

Abstract This study analyses the waste electrical and electronic equipment (WEEE) management system of the Campania region, assessing the input and output material flows to and from the system and the environmental impacts of the recovery of the materials and components of WEEE after their first-step separation in a treatment plant located outside the region. The LCA midpoint and endpoint preliminary results demonstrate the environmental impacts of the collection and treatment of the R1 and R2 WEEE categories. The comparison of the environmental impacts for the recovered materials with the highest share (e.g. iron in R1 and mixed iron and steel in R2) shows that the recovery of secondary materials from WEEE generates lower environmental impacts than the production of the primary materials. This study confirms the importance of evaluating the environmental impacts of the European WEEE management system to better understand the social and just implications of the circular economy model.

Keywords Material flow analysis · Life cycle assessment · Waste electrical and electronic equipment · Circular economy · Recycling

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13.1 Introduction

The traceability of products at the end of life is a critical factor for key EU product value chains and waste streams, such as waste electrical and electronic equipment (WEEE), due to the lack of comprehensive data about their treatment and their related environmental and social impacts (Berežni et al. 2021; Ghisellini et al. 2019; European Union 2017; Umair et al. 2015). Furthermore, WEEE as a waste stream is a very heterogeneous category of products and materials, including hazardous ones. Since 2002, the EU has adopted two important directives[1] to regulate and improve WEEE management. In Italy, Ministerial Decree 185/2007 transposed the first WEEE directive identifying the main actors and functions of the WEEE management system over five WEEE categories:

– R1: Refrigerators and air conditioning systems.
– R2: Large household appliances.
– R3: TV sets and displays.
– R4: Small household appliances, consumer electronics, office automation, computer appliances, lighting devices.
– R5: Light sources (excluding incandescent lamps).

The WEEE directive aims to introduce circular economy (CE) principles in the sector by preventing WEEE generation, promoting a more efficient use of resources/products by means of their reuse or recovery into secondary raw materials and improving the environmental performance of all stakeholders involved in the WEEE life cycle (European Union 2017).

This study proposes a joint application of material flow analysis (MFA) and life cycle assessment (LCA) to evaluate the following:

– The life cycle of the legal WEEE management system of the Campania Region (as a case study useful to other regions, of course).
– The environmental impacts from the collection and treatment of WEEE.
– Opportunities for improving the environmental performance of the regional WEEE management system.

13.2 Review of the Literature

The international literature shows a number of interesting cases that assess the environmental performance of regional or national WEEE management systems via LCA and MFA. Fiore et al. (2019) and Biganzoli et al. (2015) applied both MFA and LCA to assess the mass balance of the treatment and recovery stages for each of the five WEEE (or three WEEE categories in the case of Fiore et al. 2019) categories as

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012L0019-20180704

well as the environmental performances of the investigated WEEE regional/metropolitan systems from collection to recycling/disposal of the recovered materials and components. Beyond the Italian context, a recent paper applies both LCA and MFA to study WEEE management in the UK, whereas De Souza et al. (2016) use LCA for the analysis of the sustainability of WEEE management options in the Metropolitan Region of Rio De Janeiro. Finally, Angouria-Tsorochidou et al. (2018) applied MFA to map the life cycle stages of WEEE in Denmark and integrated this method with an economic analysis to evaluate the benefits of reuse rather than recycling. They found that a management system based on reuse is economically viable and has the potential to provide environmental and social benefits.

13.3 Material and Methods

This section provides a brief introduction to the LCA method that is adopted in the present study jointly with the MFA. The system under investigation is the regional WEEE management system of the Campania region for the five categories of collected WEEE in 2020. As applied by the previous literature (Biganzoli et al. 2015), each of the five categories of WEEE has been analysed separately as well as jointly. The present study shows the preliminary results of the recovery processes for categories R1 and R2 of WEEE and considers the treatment process performed in the first treatment plants involving the dismantling of the WEEE, the separation of the main components (such as cables, compressors, motors, capacitors, etc.), and the recovery of the materials. The study aims to provide results for all the other WEEE categories (R3, R4 and R5) in the Campania region and elsewhere. Additional processing stages also showing the separation of all the abovementioned components into their constituent materials (iron, steel, copper, plastic, precious materials, etc.) will be investigated. The results will be presented later.

13.3.1 Material Flow Analysis

This method quantifies the patterns by which materials entering a system (e.g. industrial) are used, reused, and lost in the form of waste in a given time (Graedel 2019). Therefore, MFA is a key method in industrial ecology frameworks, such as LCA, as it contributes to achieving the goal of providing information about the environmental impacts of resource use and the related flows of products and waste (Duchin and Levine 2008) to promote better management and planning. The MFA considers data about the physical and socioeconomic flows of an investigated system, such as biotic or renewable, abiotic or nonrenewable raw materials, water, air, earth consumption, solid waste, emissions, and stocks. These different types of flows in the MFA can also be retrieved in the LCA approach (e.g. in the impact assessment method ReCiPe midpoint and endpoint 2016) by means of the breakdown of impact

Table 13.1 Material and energy inventory data for 1 ton of R1 WEEE collected in the Campania Region and treated in Balvano and Sessano del Molise treatment plants

	Flows	Data sources	Amount	Unit
Input	WEEE collected and treated		1	ton
	Transport from regional collection points to treatment plants	Transport, freight, lorry 3.5–7.5 metric ton (Ecoinvent 3.8)	133.5	ton*km
	Electricity, medium voltage—IT	Ecoinvent 3.8 and Biganzoli et al. (2015)	100	kWh/ton
	Landfilling of residual waste and polyurethane from WEEE	Ecoinvent 3.8 (waste treatment and disposal)	186.5	kg/ton
Output	Recovered aluminium		4.8	kg/ton
	Recovered cables		2.3	kg/ton
	Recovered compressors		140	kg/ton
	Recovered electronic boards		0.90	kg/ton
	Recovered glass		10.60	kg/ton
	Recovered wood		1.20	kg/ton
	Recovered plastic		160.30	kg/ton
	Recovered oil		2.90	kg/ton
	Recovered gas		5.30	kg/ton
	Recovered lamps		0.20	kg/ton
	Recovered capacitors		0.20	kg/ton
	Recovered copper		0.40	kg/ton
	Polyurethane, to landfill		166.00	kg/ton
	Residual waste, to landfill		20.50	kg/ton

Sources: Elaboration of the authors

categories such as "fossil depletion", "metal depletion", and "land use", which are generally included (with some differences) in the "abiotic material indicator" of MFA; "species biodiversity loss", generally included in the MFA "biotic material indicator"; "water use" accounted for in both approaches; and finally "global warming potential" and "acidification potential", among others, very close to the "air use" and several emission indicators of the MFA approach. Due to lack of space, in this study, we limit our examples to LCA indicators, being well aware of the partial integration and overlapping of the two approaches, as shown in Tables 13.1 and 13.2.

13.3.2 Life Cycle Assessment

The LCA method is performed taking into account the standard ISO 14040:2006/Amd 1:2020.[2] LCA is performed via four main stages: goal and scope, inventory analysis, impact assessment, and interpretation.

[2]ISO 14040:2006/Amd 1:2020, available online at: https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:amd:1:v1:en. Last accessed: 15/09/2022.

Table 13.2 Material and energy inventory data for 1 ton of collected WEEE R2 category in the Campania Region and treated in the plants of Balvano and Sessano del Molise

	Flow	Data sources	Amount	Unit
Input	WEEE collected and treated		1	ton
	Transport from regional collection points to treatment plants	Transport, freight, lorry 3.5–7.5 metric ton (Ecoinvent 3.8)	133.5	ton*km
	Electricity, medium voltage – IT	Ecoinvent 3.8 and Biganzoli et al. (2015)	66	kWh/ton
Output	Recovered steel and iron		648.10	kg/ton
	Recovered concrete		274.00	kg/ton
	Recovered motors		70.00	kg/ton
	Recovered cables		5.00	kg/ton
	Recovered capacitors		1.20	kg/ton
	Recovered electronic boards		1.70	kg/ton

Sources: Elaboration of the authors

13.3.2.1 Goal and Scope

The main goals of this LCA study are the evaluation of the environmental impacts associated with the collection of the five categories of WEEE of the Campania region and their recovery, namely:

- Collection of WEEE in the five provinces of the Campania Region and their transport outside the Region towards the first treatment plants located in Balvano (Potenza) and Sessano del Molise (Isernia);
- Recovery of WEEE after the first treatment plants. These two plants treat approximately 75% of the total WEEE of the Campania Region. Due to the lack of data about the residual 25%, we assumed that they had been treated in similar plants.

The considered functional unit is 1 ton of collected and recovered WEEE.

13.3.2.2 Life Cycle Inventory

The main steps in this stage include material flow data collection and the adoption of allocation procedures in the case of multifunctional processes (de Bruijn et al. 2002). The input and output inventories are quantified according to the selected functional unit (1 ton collected WEEE to be treated).

The data collected in this study are both primary and secondary data. The first one regards the annual flows of WEEE collected in the five provinces of the Campania Region as well as the data about the material input and output flows in the treatment plants, while the secondary data regards the transport stage of the collected WEEE from each province of Campania to the treatment plants of Balvano and Sessano del Molise based on Ecoinvent, while the electricity consumption in these plants is estimated from Biganzoli et al. (2015). Tables 13.1 and 13.2 show the primary and secondary data of the collection and treatment stages for the R1 and R2 WEEE categories. Both tables also show the mass balance for each of the two categories of WEEE and all the materials/components recovered from the treatment of 1 ton of WEEE. The environmental allocation was performed according to the economic value of the materials and components. Most of the prices have been collected from Borsino dei Rifiuti.[3]

13.3.2.3 Life Cycle Impact Assessment

This stage consists of the processing of the inventory data, which translates into specific impact categories through characterization methods, highlighting the potential contribution that the system provides to each environmental aspect considered. The impact assessment method adopted is ReCiPe Midpoint and Endpoint 2016 (Huijbregts et al. 2017).

13.4 Results and Discussion

The preliminary results only refer to the R1 and R2 categories. The midpoint results (e.g. for the climate change impact category) per functional unit (1 ton) of the recovery of all R1 materials and components generate 32.97 kg CO_2 eq./ton, while, e.g. the recovery of iron, after dismantling the WEEE in the R1 category, contributes 21.41 kg CO_2 eq./ton. The endpoint results per functional unit for the R1 category show that collection and recovery contribute to the depletion of ecosystems by 3.97E-07 species-yr, to resource depletion by 7.17 US$ and damages to human health by 4.86E-05 DALY (disability-adjusted life years).

The midpoint results per functional unit (1 ton) for the R2 category of WEEE show that the recovery of steel and iron after dismantling the WEEE has the highest share in the total climate change impact category (110.01 kg CO_2 eq./ton), contributing 86.33 kg CO_2 eq./ton. The endpoint results per functional unit show that the total impacts of R2 treatment contribute to the depletion of ecosystems by 1.04E+06 species-yr, to resource depletion by 6.40E+00 US$ and to damage to human health by 2.10E-04 DALY (disability-adjusted life years).

We also compared the environmental impacts of the main recovered materials in the WEEE R1 and R2 categories, e.g. "iron" and "mixed iron and steel", respectively, with the primary materials from mining and industrial processing. In the R1 category, the amount of iron recovered per ton of treated WEEE is 484.40 kg, whereas the amount of mixed "steel and iron" in the R2 category is 648.10 kg per functional unit. The environmental impacts of the production of primary iron (per 1 kg) generate 0.18 kg CO_2 eq., while the production of secondary iron from the R1

[3] https://www.borsinorifiuti.com/2020/prezzirifiuti.php

category of WEEE only generates 0.04 kg CO_2 eq. The production of 1 kg of “mixed steel and iron” with similar percentage composition contributes to climate change by 2.44 kg CO_2 eq., while the recovery of “mixed iron and steel” from WEEE R2 contributes a lower 0.13 kg CO_2 eq. Similar results can also be found for the other impact categories. We expect that other WEEE recovered materials (copper, aluminium, glass, concrete, etc.) may show the same impact behaviour, and work is in progress to finalize these calculations.

13.5 Conclusions and Future Perspectives

This study was aimed at evaluating the environmental impacts of the WEEE management system of the Campania region in the stages of collection and treatment. The LCA, integrated with MFA, confirms its importance in evaluating the implementation of the European model of WEEE management from collection to first treatment. The preliminary results of this study show that the recovery of a wide range of materials and components from WEEE is beneficial for the environment. The analysis will be further advanced towards the evaluation of the environmental impacts of the other WEEE categories (R3, R4, R5) and the comparison of the impacts of the most representative recovered materials with the same materials produced by virgin sources. From this perspective, LCA/MFA can also be considered a useful integrated tool for improving the understanding of policy makers about the environmental impacts of the legal WEEE system and cycle as well as on the social and just implications.

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Chapter 14
Closing the Cycle by Reusing Treated Wastewater: The Role of Prato in the European Debate on the Circular Economy

Leonardo Borsacchi, Alessandro Brogi, Donatella Fibbi, and Patrizia Pinelli

Abstract Circular economy policies in the management of water, especially at the urban level, are relevant to overcome water scarcity issues and to accelerate the transition to more sustainable practices. To stimulate the transition to a circular economy, in 2015, the European Commission adopted a "Circular Economy Package", which includes priorities for legislative revision. More recently, by launching the European Green Deal, the European Commission aimed to boost the efficient use of resources by moving to a circular economy and stopping climate change. Water issues were included in the European debate, involving cities in processes of legislative revision. At the European level, the Urban Agenda for the EU was established with the aim of favouring the discussion on the circular economy at the city level. The Municipality of Prato represented Italy in the EU partnership on circular economy. Prato is one of the largest Italian industrial districts and one of the most important textile production centres in the world. The local centralized water treatment plant also plays one role as the best circular practice within the textile district. This paper describes the role of the Municipality of Prato at the European level in the process of legislative revision in terms of wastewater reuse.

Keywords Circular economy · Cities · Water · Wastewater · Urban agriculture

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14.1 Introduction

The circular economy enables the development of a brand-new paradigm, where the model overcomes the concept of an economy that closes the loop with waste (Ellen Macartur Foundation 2015). Today, both the reasons for sustainability and the environmental impact suggest a radical switch to the circular paradigm, with positive conditions leading to a full exploitation of the great potential of this new approach (Ghisellini et al. 2016). To stimulate the transition to a circular economy, in 2015, the European Commission adopted a "Circular Economy Package" (CEP), which includes revised legislative proposals. CEP consists of an action plan with concrete actions and measures covering from production and consumption to waste management and the potential market and reuse of secondary raw materials (European Commission 2015). These actions aimed at both promoting closing the loop in the products' life cycle and bringing benefits for both the environment and the economy. During the Dutch presidency of the European Union in 2016, EU Ministers responsible for territorial cohesion and/or urban matters adopted the so-called Pact of Amsterdam (PA). PA strived to involve urban authorities in achieving better regulation, better funding and better knowledge, considering the cities as drivers of innovation. To ensure that these facts are acknowledged and reflected by EU legislation, funding and knowledge sharing, the so-called Urban Agenda for the EU (UAEU) was established. Among the UAEU, the EU Partnership on Circular Economy (EUPCE) operated from 2016 to 2020. In fact, cities play an essential role in the development of a circular economy, acting as enablers of potential measures by which they can influence both consumers and businesses (Kirchherr et al. 2017). Moreover, overall governance, enabling businesses, public procurement, consumption and resource management are the themes that would all have a bearing upon the development of circular economy concepts within cities. EUPCE consisted of six urban authorities, namely, the City of Oslo, the Hague, Prato (as Italian representative), Porto, Kaunas and Flanders region. Additionally, member states (i.e. Finland, Poland, Slovenia and Greece) and the European Commission (in particular DG Regio, DG ENV, DG Clima, DG RTD, DG Grow) were involved. Within the partnership, the Municipality of Prato (MoP) led the debates regarding wastewater reuse.

Prato is one of the largest Italian industrial districts and one of the most important textile and clothing production centres in the world. Since the postwar period, textile waste management has represented one of the main drivers for textile district development: recovery and recycling of natural fibres from rags and used clothes were the basis for Prato's yarn and textile industry. Prato has always been a model of innovation in this sector, having historically based its industrial fortune on the reuse of waste from the textile process and on the reuse of second-hand clothing from all over the world. The local centralized water treatment plant also plays one role within the textile district. Created in 1981, GIDA was founded to manage wastewater and sewage treatment plants, as well as the industrial aqueduct network. The core of the centralized treatment system is the Baciacavallo treatment plant. Weekdays, the plant can treat up to 130,000 m^3/d, breaking down to 100,000 kg of COD per day and 4500 kg of surfactants per day. It consists of stages for equalization, primary sedimentation, biological oxidation, sedimentation, flocculation and a final refinement with ozone to remove colour and surface residues. The sludge line consists of gravity thickening, mechanical dewatering by centrifugation and sludge incineration. The MoP, together with GIDA, and the scientific partner ARCO took a step forwards to outline a future vision of a sustainable city where water management is circular.

This study aims to describe the role of Prato (as member of the Urban Agenda partnership on Circular Economy) in addressing the recent EU legislation revision process on the reuse of treated wastewater. In particular, the proposal for Regulation of the European Parliament and of the Council on minimum requirements for water reuse was discussed in 2018 and approved in 2019.

14.2 Materials and Methods

The paper is the result of the involvement of the authors within the EUPCE. Among the methods used for the results achieved the following: (a) desk-based analysis of reports and publications on CE and about main European legislation on water, (b) conduction of semi-structured interviews with local representative stakeholders and (c) participation at all debates and meetings within the EUPCE. These methods have allowed diversifying the sources of information to obtain a comprehensive and consistent picture of existent and potential water reuse issues. Furthermore, this paper focuses on the legislative revision called "Regulation of the European Parliament and of the Council on minimum requirements for water reuse". Finally, the minimum requirements proposed have been compared with the current results of the analysis on the treated water exiting the GIDA treatment plant.

14.3 Results and Discussion

Despite legislative restrictions, reclaimed water could potentially be used under specific safety procedures for several purposes (i.e. street cleaning, irrigation of parks and gardens, etc.). It should be noted that with the term "urban wastewater", European legislation defined domestic wastewater as the mixture of domestic wastewater with industrial wastewater and/or run-off rainwater. Although water reuse encounters numerous barriers in the EU, this practice is commonly used in extra-European countries (i.e. Israel, Australia and Singapore). In Europe, wastewater from industrial production activities has more regulatory limitations than urban wastewater. Moreover, as an awareness constraint, reused water is considered less attractive than freshwater (European Commission 2018a, b). Both southern member states, such as Spain, Italy, Greece, Malta and Cyprus, and northern member states, such as Belgium, Germany and the UK, already have in place initiatives regarding water reuse for irrigation, industrial uses and aquifer recharge. Cyprus and Malta already reuse more than 90% and 60% of their wastewater, respectively, while Greece, Italy and Spain reuse between 5 and 12% of their effluents, clearly indicating a huge potential for further uptake (European Commission 2018a, b). In Italy, the level of stringency of the existing water reuse standards has been reported to be an obstacle to further uptake solutions due to administrative burden and associated costs for local authorities (European Commission 2006).

The need to address the problem at the EU level (and to overcome differences at the member state level) was acknowledged in 2012 in the Commission Communication named "A Blueprint to Safeguard Europe's Water Resources" (European Commission 2012). In 2016, the European Parliament encouraged the Commission to draw up a legislative framework on water reuse (European Commission 2018a, b).

Within the EUPCE, MoP (leading the action on water reuse) proposed the use of treated industrial and civil waters (e.g. urban wastewater) at the urban level for irrigation purposes (e.g. urban green-gardens, green areas, peri-urban agriculture). That action idea has come along with the announcement of the EU Commission about the issue of a proposal for "Regulation of the European Parliament and of the Council on minimum requirements for water reuse". For this reason, together with other municipalities involved in the EUPCE, the MoP decided to start a debate over the new proposal, contributing to the general discussion about requirements and future applications.

According to the Commission's proposal, reclamation plant operators should ensure that reclaimed water destined for a specific use (e.g. crop irrigation) complies with specific quality requirements. The proposed limits distinguished among (i) food crops consumed raw (so-called class A), (ii) food crops where the edible part is not in direct contact with water or processed food (class B), (iii) food crops where the edible part is not in direct contact with water or processed food and drip irrigation only (class C) and (iv) use of reclaimed water in crops for industrial or energy purposes (class D). To avoid unequal barriers, the proposal went in the direction that no member state could ban imports of food products irrigated with reclaimed water in another member state. Member state competent authorities were set to be responsible for enforcing the permit and carrying out inspections as necessary.

To evaluate if the minimum requirement expressed in the EU proposal were realistic, within the EUPCE, MoP, GIDA and ARCO compared the requirements with the results of treated wastewater exiting from the GIDA plant. It should be noted that GIDA treats urban wastewater as a mix of domestic wastewater with industrial wastewater (coming from textile industries of Prato district), meeting the requirements of Italian legislation. The considered analyses are the official ones carried out by GIDA (through the internal accredited laboratory as well as by an external accredited laboratory) from 2014 to 2017 considering E. coli, BOD5, total suspended solids (TSS) and turbidity. Table 14.1 shows the average of the results of the analyses, in correspondence with the minimum requirements established by the proposal as well as the limits required by the Italian DM 185/2003 on "Legislation about use of reclaimed water".

Table 14.1 Averages of the analyses' results

Parameter accounted	Quality class A (limits)	Quality class B (limits)	Quality class C (limits)	Quality class D (limits)	Italian law DM 185/2003 (limits)	GIDA (average of analyses)
E. coli (cfu/100 ml)	≤ 10	≤ 100	≤ 1000	≤ 10,000	100	2.48
BOD5 (mg/l)	≤ 10	According to council directive 91/271/EEC			20	< 5
TSS (mg/l)	≤ 10	According to council directive 91/271/EEC			10	1.14
Turbidity (NTU)	≤ 5	–	–	–	–	0.8

According to these comparisons, both with the average and with absolute values, water exiting from GIDA meets the limits indicated in the proposal.

Moreover, the proposal, along with laying down minimum requirements for water quality, provided indication about the conduction of specific risk management tasks for the safe use of reclaimed water. In fact, the reclamation plant operator could set the risk management plan.

EUPEC issued a position paper to address the proposal and its feasibility. After having validated the proposed quality limits, some remarks were issued about the responsibility of food business operators that use reclaimed water within their production (i.e. crop irrigation or water as food ingredient). Further indications for food operators in fact are considered crucial to push them to take into specific account the hazards linked to the use of reclaimed water (to further add eventually control points and analyses in the HACCP plan). It should be noted that if the reclamation plant operator knows the destination of treated water, it could be easier for him to set the treatments according to the requirements. In fact, collaboration among reclaimed plant operators and food operators could create positive industrial symbiosis. At the city level, this kind of collaboration can advance social relationships among the involved local actors, including surrounding neighbourhoods.

14.4 Conclusions

This paper aims to outline the role of the MoP within the EUPCE and to describe the recent evolution of EU legislation on the reuse of treated wastewater. The European Parliament voted on the new regulation in 2019, and it is expected to be effective at the member state level from June 2023. Along with the harmonized minimum water quality requirements for the safe reuse of treated urban wastewaters in agricultural irrigation, the regulation took into account suggestions from public consultation and position papers (including the one proposed by EUPEC). In the regulation, risk management is considered relevant to assessing and addressing potential additional health risks and possible environmental risks. The new rules are to be situated in the context of the new Circular Economy Action Plan adopted in 2020, which includes the implementation of the new Regulation amongst Europe's priorities for the circular economy.

Further development of this work will be to understand, at the city level and among agricultural operators, the degree of acceptance of this regulation, together with the perception of citizens and consumers. Indeed, in light of the recent critical water scarcity in Italy, due to the unusually high temperatures, the application of this regulation could represent a valid solution.

Disclaimer The views expressed herein are those of the authors and therefore do not necessarily reflect the official opinion of the European Commission.

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Part III
Circular Economy and Sustainability Issues in Several Sectors: Energy

Chapter 15
Natural Gas Supply in Italy: Analysis and Perspectives

Anna Tacente, Bruno Notarnicola, Giuseppe Tassielli, and Pietro A. Renzulli

Abstract The work analyses Italy's current strategies for gas supply to guarantee the energy security of the national market and its potential capacity for diversification. In the first part, having examined the Italian situation relative to domestic production and the quantity of imported gas, the work focuses on the countries from which Italy imports natural gas through pipelines: Russia, Algeria, Azerbaijan, Libya, Norway and Holland, and LNG through LNG carriers, also analysing the reserves, production and infrastructures present there. In the second part, in light of the current situation characterized by strong instability, the prospects of diversification of natural gas supply routes in the Mediterranean context are analysed. The exploitation of natural gas reserves in the eastern Mediterranean area and the development of regasifiers to accommodate LNG can make a valuable contribution to the diversification of energy supplies.

Keywords Energy · Security · Supply · Diversification

15.1 Introduction

The conflict in Ukraine has highlighted Italy's strong energy dependence on foreign countries and, in particular, on Russia; this has made clear the need to diversify natural gas supply sources and increase domestic production and regasification capacity. National production of natural gas is insufficient to cover national needs: Italy extracted 3.4 billion m^3 of natural gas in 2021, against consumption of 76.1 billion m^3, an increase of 7.2% compared to 2020. In 2021, Italy imported 72.7 billion m^3 equal to 95% of its gas requirements (Mise 2022a). On the basis of

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the data collected, it is intended to identify a possible strategy to diversify energy supplies in the coming years.

15.2 Materials and Methods

The work is based on the analysis and selection of the main documents, plans and statistical data taken from the official websites of the Italian government, the main operators in the energy sector and the companies that manage gas transportation at an international level. A further source is the sector's economic newspapers.[1]

15.3 Results and Discussions

Italy extracted (in 2021) 3.4 billion m^3 of natural gas from 1298 active wells (Table 15.1).[2]

The drilling of wells for gas extraction, which had reached its peak in Italy in the early 1990s (128 wells and up to 20 billion m^3 of natural gas), decreased in the following years to an average of approximately 30 wells per year, partly due to the limits imposed by the PITESAI plan for concessions on new wells. The largest proven and unexploited gas reserves are in the northern Adriatic. Other deposits are found in the Sicilian Channel, the Ionian Sea and the sea northwest of Sardinia. There are approximately 350 billion m^3 of natural gas in the Italian subsoil, which includes already confirmed or only potential reserves. Proven reserves are in the range of 70–90 billion m^3. According to the most recent PITESAI estimates, by upgrading the nonoperating wells and improving the operating ones, a natural gas production of 10 billion m^3 per year could be achieved. The largest number of productive wells is in Emilia-Romagna (187), Tuscany (45), Sicily (44) and Molise

Table 15.1 Distinction of active wells in Italy

Active wells	Gas
Dispensing production wells	514
Nondispensing production wells	752
Other active wells (monitoring, reinjection, other use)	32
Total	1298

Source: Authors' elaboration from Pitesai (2021)

[1] The Italian natural gas sector has not been subjected to extensive research; one of the first attempt to provide an overview of the sector, Bianco, V. (2018), Overview of the Italian natural gas sector, International Journal of Energy Sector Management Vol. 12, n. 1, 2018 pp. 151–168.

[2] PITESAI (Italian acronym), Sustainable Energy Transition Plan for Eligible Areas. Producing well means a productive well that is currently extracting hydrocarbons from the reservoir.

(15). The number of wells per region does not correspond to the quantity of gas extracted, as seen from the comparison in the table below (Table 15.2).

15.3.1 Natural Gas Exporting Countries to Italy

In 2021, Italy imported 72,728 million m^3 of gas from the countries shown in Table 15.3. The gas is fed into the network at the nine entry points, at the six interconnection points with methane pipelines and the three interconnection points with LNG regasification terminals.

Table 15.2 National gas production 2021 broken down by regions and sea areas

Natural gas production *year* 2021			
Region	*scm*	*Region*	*scm*
Basilicata	1,191,551,798	Lombardia	8,986,570
Sicilia	162,390,302	Piemonte	6,974,260
Emilia-Romagna	129,079,536	Marche	5,478,960
Molise	57,411,581	Calabria	5,157,142
Puglia	49,350,503	Toscana	3,175,178
Abruzzo	930,175	Veneto	924,443
		Total Land	1,629,782,032
Sea			
Zone A			1,021,804,820
Zone B			558,115,379
Zone C			3,710,669
Zone D			285,269,672
		Total sea	1,868,900,540
		Total land+sea	3,498,682,572

Source: The table was elaborated by the authors based upon Mite (2022b)

Table 15.3 Italian imports of natural gas by country of origin in the year 2021

Country	Imported volume (million m^3)	Percentage (%)
Russian Federation	28,988	39.86
Algeria	22,584	31.06
Azerbaijan	7214	9.91
Qatar	6877	9.46
Libya	3231	4.45
Norway	1937	2.67
Netherland	312	0.42
Others	1585	2.17
Total	72,728	100

Source: Mite (2022a)

15.3.2 Main Natural Gas Imports Pipelines

Until 2021, Italy imported 28,988 million m^3 from the Russian Federation via the 4451 km long Urengoy-Uzhhorod pipeline, with an effective capacity of 28 billion m^3 per year (Offshore Technology 2021), which starts from the Urengoy field in Siberia and connects to the 380 km long Tag (Trans Austria Gas) to reach Italy via the Tarvisio plant.

Algerian gas, currently at 22,584 million m^3, arrives in Italy via the Transmed pipeline, approximately 2000 km long, which crosses Tunisia and arrives at the Mazara del Vallo plant, Sicily (Mise 2022b). The transport system from Algeria to Italy consists of the Enrico Mattei gas pipeline (GEM) section in Algerian territory, the section in Tunisian territory, TTPC (Transtunisino) and the "sea-line" section in the Strait of Sicily (Tansmed 2022).

The TAP (Adriatic Pipeline) gas pipeline, in operation since 2020, brought 7214 million cubic metres of natural gas to Italy in 2021. With a capacity of approximately 10 billion m^3 of gas per year, the TAP allows gas extracted in Azerbaijan from the Shah Deniz field in the Caspian Sea (which has an annual capacity of approximately 25 billion m^3 standard) (Snam 2022a, b) to reach Puglia via Turkey, Greece and Albania. The 878 km long TAP (773 onshore and 105 offshore) arrives at the pipeline receiving terminal in Melendugno (Lecce), connecting the extraction area in Azerbaijan through the SCP (South Caucasus Pipeline) for 692 km and the TANAP (Trans Anatolian Pipeline) for approximately 1800 km.

Libyan natural gas of 3.231 million m^3 comes from the offshore Bahr Essalam and Wafa fields in the southwestern part of Libya, compressed by the Mellitah Power Plant and fed into the 520 km long GreenStream via the Mediterranean Sea to the Gela gas reception terminal in Sicily.

From Northern Europe, 1937 million m^3 arrive from Norway and 312 million m^3 from the Netherlands (Mise 2022b) through the 293 km long Transitgas with a capacity of approximately 18 billion m^3 per year (Transitgas 2022) connected to the national network at Passo Gries in Piedmont, as well as with the Trans Europa Naturgas Pipeline at Wallbach (in northern Switzerland) and the Rodersdorf network (at the French border).

15.3.3 Importing Through LNG. The Regasifiers

There are three regasification centres in Italy: Panigaglia and Livorno, on the Tyrrhenian Sea, and Rovigo, on the Adriatic Sea. The largest plant is Adriatic LNG, an offshore plant off the coast of Porto Viro (Rovigo) that connects to the network at Cavarzere; in 2021, it regasified 7.3 billion m^3, and it has a regasification capacity of 8 billion m^3 per year.[3]

A total of 6877 million m^3 of natural gas per year arrives in Italy from the "North Field" in Qatar. Liquefied gas (LNG) transported by ship arrives at the Adriatic LNG terminal in Rovigo with an annual capacity of 8 billion m^3.

Approximately 12 miles off the coast between Livorno and Pisa, in the Tyrrhenian Sea, there is the "FSRU Toscana", which in 2021 regasified 1.4 billion m^3. It has an annual capacity of 3.75 billion m^3 and a gross storage capacity of approximately 137,100 m^3 of LNG. The third active regasifier is located near Panigaglia, an onshore facility with a maximum annual regasification capacity of 3.5 billion m^3 of natural gas (Snam, 2021): in 2021, it regasified 1.07 billion m^3.

15.3.4 Prospects for Greater Diversification

To ensure a greater diversification of natural gas supply sources and reduce the strong dependence on Russia, the Italian government has recently planned gas for an additional 25 billion m^3 for 2024–2025 to be imported in various forms even from geographically distant countries.

15.3.4.1 Domestic Production and Regasification Capacity Increase

An increase in domestic gas production may come from existing or active wells by 2023 without the opening of new gas fields but only by reducing the environmental and bureaucratic constraints imposed by PITESAI; a significant increase in production may only occur in the following years. Approximately 1.4 billion m^3 per year may come from the Cassiopea and Argo fields in the Sicilian Channel, fully operational by the first half of 2024 (Eni, 2022a).

The optimization and expansion of the total annual capacity of the three existing regasification terminals, today 15.25 billion m^3, are closely related to the possibility of importing additional quantities of gas. In December 2020, the Adriatic LNG Terminal S.R.L. (ALNG) submitted a request for authorization to increase the current maximum regasification capacity from 8 billion m^3 to 9 billion m^3 for the offshore terminal in Porto Levante Rovigo (Mise 2022a). The purchase of FSRU (floating units) can provide a quick alternative to storage and regasification terminals. In May 2022, a contract was signed for the LNG carrier "Golar Arctic" sale from Golar to Snam, which will be installed within 2 years in Portovesme, Sardinia, after being converted into a storage and regasification unit with a capacity up to

[3] On the topic, for a more complete infrastructural and regulatory analysis of the LNG sector in Europe. see Dorigoni, S. and Portatadino, S. (2008), LNG development across Europe: infrastructural and regulatory analysis, Energy Policy, Vol. 36 No. 9, pp. 3366–3373.

140,000 m^3. In June 2022, Snam purchased the Golar Tundra, a storage and regasification vessel (FSRU) with a continuous regasification capacity of 5 billion m^3 per year, which will be located in the central north and will start operations in spring 2023 (Snam 2022c).

15.3.4.2 Increased Imports Through Pipelines

Additional volumes will increasingly arrive from the second half of 2022 by 2 billion m^3 up to 25 billion m^3 in 2025. The immediate goal is to replace the 50 percent of Russian gas supplies by 2023. The energy cooperation agreement of 11 April 2022 between Italy and Algeria will make it possible to use the transport capacities of the Transmed-Mattei pipeline and supply Italy with 3 billion m^3 more gas as early as 2022, plus another 6 in 2023 to reach 9 billion m^3 per year in 2024 (Eni 2022b, c). An additional 2 billion m^3 is also expected from Azerbaijan through TAP (Dominelli 2022). The uncertainty of the current political situation in Libya leads to the conclusion that an increase in supply to Italy is difficult today.

15.3.4.3 Increased Imports Through LNG

The possible increase in LNG supply from Congo, Angola, Egypt, Qatar, Mozambique, Nigeria and Indonesia is estimated to be approximately 1.5 billion m^3 in the second half of 2022, rising to 12.8 billion m^3 in 2025.

The agreement signed in April 2022 with Angola and Congo foresees a gas supplies increase in exports towards Italy, respectively of 1 billion m^3 and more than 4.6 billion m^3 per year (Eni 2022c).

The April 2022 framework agreement between ENI and Egypt, together with that for the restart of the Damietta liquefaction plant, is aimed at maximizing the production and export of Egyptian gas to Europe and Italy of 3 billion m^3 in 2022.

Qatar has pledged to supply Italy with 2 billion m^3 by exploiting the remaining capacity of the Transmed pipeline (Il Sole24ore 2022). Other states, such as Mozambique, Nigeria, and Indonesia, areas where extraction activities have increased considerably, could supply a further 2.2 billion m^3 of gas within the next 3 years (Euractiv.it 2022).

15.4 Conclusions

The above analysis showed that it is possible to increase alternative supplies by 2025 through various strategies: through southern gas pipelines by 25.2 billion m^3, as shown in Table 15.4.

In the current critical framework, it is necessary to plan adequate gas supply strategies that require, first, an expansion of the competitiveness of the specific

Table 15.4 Additional imports from southern countries 2022–2025

Alternative sources of supply to Russian gas 2022–2025 in billion m^3	
Italian production	1.4
Algeria	9.0
Azerbaijan	2.0
Congo	4.6
Angola	1.0
Egitto	3.0
Qatar	2.0
Mozambico, Nigeria, Indonesia	2.2
Total	25.2

market, as well as the strengthening of the infrastructure of transport and distribution networks, storage facilities and LNG terminals; a strategy also combined with community choices for the further development of renewable energies and energy efficiency.

The expansion of regasification capacity could make Italy an important hub in the Mediterranean Sea for gas transport. The answers to such a complex scenario cannot be of an emergency nature but imply a comprehensive EU supply strategy with long-term objectives that go beyond the current crisis.

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Chapter 16
The Agro-Photovoltaic Sector as a Possible Implementation Tool in the Sicilian Energy Transition

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Abstract The energy transition represents a crucial topic for achieving the objectives of the 2030 Agenda, which aims to promote sustainable development and is strongly incentivized by numerous European and national interventions, like the Recovery and Resilience Plan and several others. The goal of this research is to highlight the great potential of the photovoltaic sector, showing how its versatility and adaptability constitute an important strength compared to other renewable sources. In particular, the paper investigates the process of integration between photovoltaics and agriculture that is occurring in the Sicily region, giving rise to agro-photovoltaics. After presenting the strategies proposed by the Environmental Energy Plan of the Sicily Region to address the green revolution and the energy transition of the island, the paper shows the main features of this system and some projects for the construction of agricultural parks and agro-photovoltaic plants. Furthermore, despite the current social debate that creates friction between the various stakeholders regarding the exploitation of the soil, the integration between the two sectors could trigger a virtuous circle that puts agricultural and livestock farms as the main beneficiaries of the economic and environmental advantages derived from agro-photovoltaics and drives the island towards an effective energy transition.

Keywords Energy transition · Agro-photovoltaic sector · Circular economy · Sustainability

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16.1 Introduction

Among the various typologies of renewable energy sources, a primary role could be reserved for the photovoltaic sector since, due to its technical characteristics and potential for integration with other technologies or activities, it is able to guide the energy transition. The goal of the present study is to analyse the photovoltaic sector, tracing its main dynamics, with particular reference to the related legislation in Sicily. One of the starting points is the National Recovery and Resilience Plan (NRRP), the document that each member state must prepare to have access to next-generation UE funds (Peters et al. 2020), a tool introduced by the European Union for postpandemic COVID-19 recovery (Assessorato dell'energia Regione Sicilia 2019b). The plan was created following the guidelines issued by the European Commission and is divided into three princes: digitalization and innovation, ecological transition and social inclusion (Assessorato dell'energia Regione Sicilia 2019a). European countries should achieve very ambitious objectives by 2030 and 2050 (International Energy Agency 2021). They aim for a progressive and complete decarbonization of the system ("net-zero") and strengthening the adoption of circular economy solutions to protect nature and biodiversity and guarantee a fair, healthy and respectful food system. The mission is based on four parts:

- M2.C1. Circular Economy and Sustainable Agriculture.
- M2.C2. Renewable Energy, Hydrogen and Sustainable Mobility.
- M2.C3. Energy Efficiency and Redevelopment of Buildings.
- M2.C4. Protection of the Territory and Water Resource.

It is evident that the role of renewable energy sources is central to the implementation of each individual component (Decreto Legislativon.199, 8/11/2021). Photovoltaic and solar energy are large investments in both fields C1 and C2. Italy is among the countries of the European Union with the highest direct consumption of energy in food production (third, after France and Germany). Total energy costs represent over 20% of the variable costs for farms, with higher percentages for some productive subsectors (Confagricoltura 2021). The proposed intervention aims at modernization of the agricultural, zoo-technical and agro-industrial sectors, using buildings' roofs for the production of renewable energy, thus increasing the sustainability, resilience, green transition and energy efficiency of the sector and contributing to the welfare of animals (Dupraz et al. 2021). As part of Mission C_2, with the aim of increasing the share of renewable energy and in line with the European and national objectives (Regolamento UE n.2221, 23/12/2020), 1.1 billion euro has been allocated for agro-vault development. Note that the agricultural sector is responsible for 10% of greenhouse gas emissions in Europe. With this initiative, the topics of sustainable agricultural production and energy production by renewable sources are addressed in a coordinated manner with the aim of spreading agro-vault systems of medium and large size. The investment amount aims to make the agricultural sector more competitive, reduce energy supply costs and simultaneously improve climatic-environmental performance. The installation of an agro-photovoltaic plant with a production capacity of 1.04 GW would produce approximately 1300 GWh per year, with a reduction in greenhouse gas emissions of approximately 0.8 million tons of CO_2 (Elamri et al. 2018). Since 2014, Sicily has been characterized by a conspicuous slowdown relating to the installation of new plants as a consequence of the exhaustion of the incentive availability derived from the 5th energy account. Solar photovoltaics, in line with the national trend, are certainly the most common technology. In fact, 100% of the municipalities of the Sicilian Region have at least one. Its power, equal to 1238 mw, is able to produce enough electricity to satisfy the needs of approximately 620,000 families (Table 16.1). In fact, 21 municipalities have invested in photovoltaic energy in public building structures in recent years (Pagano et al. 2021). In the next section, the main regulatory items are exposed. In Sections 16.2 and 16.3, the key technical features of the agro-photovoltaic system and its environmental and economic interactions will be briefly described. The major environmental, agronomic and economic effects of the installation of this kind of system will be analysed in Sect. 16.4, with particular regard to Sicily (Regolamento UE n. 2221, 23 dicembre 2020). Section 16.5 contains some concluding remarks on the strengths and weakness of the APV as a leading role of the energy transition (Matarazzo et al. 2018).

16.2 Review of the Regulatory

Looking at the regulatory context of the photovoltaic sector, the institution in charge is the Italian Electrotechnical Committee (CEI 85-25: 2008). The CEI is an association of private law, without profit, responsible for the national technical standard in electrical engineering, electronics and telecommunications (Matarazzo 2018).

The main rules that apply to the sector are the following:

CEI EN 61215: Photovoltaic Siliconian photovoltaic modules for terrestrial applications. Qualification of the project and homologation of the type (CEI 85-25: 2008).

CEI EN 61646: Photovoltaic movie modules for terrestrial uses. Project qualification and type approval (CEI EN 61646: 2012; CEI EN 62446-1: 2016).

CEI EN IEC 61730-1: Qualification for the safety of photovoltaic modules. Security prescriptions CEI EN IEC61730-2: Qualification for the safety of photovoltaic modules. Prescriptions for tests (CEI EN IEC 61730-2: 2018).

CEI EN 62108 concentration photovoltaic modules and systems. Qualification of the project and type approval (CEI EN IEC 61853-3: 2018) CEI 0-16: Reference technical rule for the connection of active and passive users to the networks at and Mt of the distribution companies of electricity (CEI 0-16: 2019);

CEI 0-21: Reference technical rule for the connection of active and passive users to the BT networks of the electricity distribution companies (CEI EN IEC 61853-4: 2019).

Table 16.1 Sicilian photovoltaic solar systems per province

Sicily	SICILY	2016 n	2016 MW	2017 n	2017 MW	Number %	Power %
Agrigento	AGRIGENTO	5471	204.2	5759	207.9	5.3%	1.8%
Caltanissetta	CALTANISSETTA	3426	91.4	3589	92.7	4.8%	1.3%
Catania	CATANIA	8860	214.7	9387	220	5.9%	2.5%
Enna	ENNA	1992	72	2104	73.2	5.6%	1.7%
Messina	MESSINA	5082	61.3	5456	63.8	7.4%	4.1%
Palermo	PALERMO	6271	168	6757	172	7.7%	2.4%
Ragusa	RAGUSA	5104	206.4	5367	209.1	5.2%	1.3%
Siracusa	SIRACUSA	5581	194.9	5884	198	5.4%	1.6%
Trapani	TRAPANI	5186	137.6	5493	139.9	5.9%	1.7%
Total	TOTAL	46,973	1350.5	49,796	1376.6	6%	1.9%

Source: National Recovery and Resilience Plan (NRRP)

On February 7, 2012, in the regulatory context of Presidential Decree 1 August 2011, the circular of the Ministry of the Interior was published – Department of Fire Brigade regarding the installation of photovoltaic systems. Although photovoltaic systems do not fall within the activities subject to fire prevention controls, the installation could result in fire risks for the occurrence of interference with the combustion product ventilation system or for the propagation of flames inside or all outside of the buildings. To avoid this, the photovoltaic system must be installed on incombustible coverage and elements. The location of the modules and electrical pipes must always allow the correct operation and maintenance of any smoke and heat evacuators present, as well as consider the existence of possible fire-conveying routes (Scuderi et al. 2022). The photovoltaic system must also be equipped with an emergency command device.

16.3 Materials and Methods

In recent years, there has been an international debate concerning the lack of natural resources and their sustainable use. Among these is the soil, a resource of fundamental importance that increasingly disputes various activities that require massive exploitation, such as those typical of the primary sector, but is also essential for the development of energy from renewable sources (Agostini et al. 2021). In this context, agrivoltaic technology is inserted a new and promising technology capable of guaranteeing the integration and synergy of agriculture and the production of renewable energy from photovoltaic systems. Starting from the analysis of the regulatory context, the lack of a structured and well-defined rule can be deduced (Regolamento UE n.1999). The design phase of an agrivoltaic system is much more complex and articulated, which requires the multidisciplinary skills of experts who can evaluate the environmental impacts of photovoltaic structures on crops and land. Although the diffusion is still quite limited, there are multiple studies that have been highlighting the massive benefits for several years now that an installation of this kind can guarantee, in terms of yield, quality and quantity of crops. The beneficial effect is also evident in terms of reducing CO2 emissions, saving water and fighting desertification (Del Borghi et al. 2022). Designing an agrivoltaic system requires transversal skills ranging from engineering to agronomy and economy to new technologies. For this reason, the presence of a multidisciplinary team to evaluate and develop technical and agronomic solutions to find an efficient compromise about the coexistence between photovoltaic and agriculture (agro-photovoltaic—APV) is needed, reflecting, for example, on the structure, height and distance between panel modules and on the percentage of expected shading in relation to the height of the sun in the various months of the year (Marraou et al. 2013). The fundamental prerequisite for the construction of any APV system is a detailed description of the site that includes the features of the soil (agricultural, industrial, abandoned quarries, landfills), the surface and the type of plant cover, the slope, the type of exposure to solar rays, the presence of institutional constraints and so on. In this regard, it is essential that the ground is not affected by urban, environmental and landscape constraints. The installation of photovoltaic panels on agricultural land changes the cultivation methods mainly for two reasons: reduction of direct radiation available to crops and limitations to the movement of agricultural machines for the footprint of the support structures (Dinesh and Pearce 2016). The total or partial coverage of a crop with photovoltaic panels determines a modification of the direct radiation available to crops and, to a lesser extent, the other microclimatic conditions. A species sown with a high cultivation density will be most affected by obstacles due to the structure compared to a species characterized by low crop density, arranged in rows, which frequently benefits from support structures for itself or for irrigation systems (localized irrigation, antibrin irrigation) or protection. Therefore, the choice of possible species to be cultivated below photovoltaic covers is linked to numerous physiological aspects of the plant and agronomic features relating to the cultivation techniques. It should also be considered that appropriate regulation of the slope of the panels during the cultivation season could guarantee the coexistence of solar panels and agricultural crops (Zingale et al. 2022). Photovoltaic coverage could also protect crops from adverse climatic phenomena (hail, frost, strong rains) and, in periods of greater radiation, can also reduce the occurrence of water stress by reducing the evapotranspiration of crops (Solar Power Europe 2020).

16.4 Results and Discussions

In regions with more favourable conditions for extensive breeding and pasture, agrivoltaic integration can encourage production and self-supply and side lines of the main forage activity, allowing an increase in livestock, making it more appropriate for corporate skills and therefore for the best enhancement of grazing surfaces (Amaducci et al. 2020). The key point is the search for a balance between the profitability of photovoltaic plants and agricultural production and economic management. In this regard, it should also be noted that the concession of land in use for APV provides an interesting supplementary source of income for farmers. From the first information acquired directly by some farmers, the fee offered to them to take advantage of the surface rights of the land ranges between 2000 and 4000 euro per hectare, depending on the position, exposure to the sun and extension of the soil. The government, through the funds allocated by the NRRP, aims to make the agricultural sector more competitive, reducing the energy supply costs (today estimated to over 20% of the variable costs of companies and with even higher levels for some herbivorous and grain sectors) and at the same time improving climatic-environmental performance (Caruso et al. 2021). Due to its position at low latitudes, climatic characteristics and territorial availability, Sicily is one of the Italian regions where the greatest agrivoltaic investments are concentrated. In particular, in most of the Sicilian districts, there is a strong commitment to building plants of various sizes and powers. Specifically, two plants were installed in the province of Agrigento for a power of 79 MW, eight plants in the province of Catania for a total power of

153 MW, a plant in the province of Caltanissetta for a power of 185 MW, flour plants in the province of Enna for a capacity of 128 MW, nine plants in the province of Palermo for a capacity of 723 MW, two plants in the province of Ragusa for a capacity of 63 MW and five plants in the province of Syracuse for a capacity of 252 MW. There is also a plant that falls territorially in the provinces of Palermo, Agrigento and Trapani for a power of 71 MW, a plant that falls territorially in the provinces of Palermo and Trapani for a power of 141 MW and a plant that falls within the territory in the provinces of Catania and Enna for a power of 40 MW (DecretoLegislativon.77,31 maggio 2021).

16.5 Conclusions and Future Perspectives

The economic and environmental sustainability of agriculture and its social acceptability will therefore depend on the capacity to build a system of effective rules able to balance the landscape and environmental protection, integrated with agronomic needs and economic profitability. The risks and critical issues also include problems arising from the difficulty, slowness and uncertainty of the authorization process, from the regulatory vacuum that characterizes the legislative context and from a tendency towards obstructionism and social scepticism towards agro-photovoltaic systems. Indeed, many entrepreneurs who intend to invest in the sector are discouraged and prefer to research suitable land in other regions, even if in less favourable climatic conditions. Other weak points to consider are the higher investment and maintenance costs of the APV system compared to a traditional system and the technical and agronomic limits to their installation. Actually, the structures necessary for agrivoltaic installation have a very high cost and require a strong commitment on the part of the farms that have to bear the economic outlay. With this in mind, an incentive system is desirable, both for direct investments and for external interventions. On the one hand, the plant costs can be approximately 30–40% more than a traditional ground-mounted photovoltaic system; on the other hand, the higher power yield of this kind of plant, the agronomic advantages deriving from the shading created by an agrivoltaic system, which allows a substantial reduction in plant transpiration and therefore requires less irrigation water, and the extra income for the conceiving farmer must be included in the global evaluation of the economic convenience. It is also necessary to keep in mind the particular agronomic conditions that limit the construction of such plants. In fact, their installation in orchards with tall trees or requiring frequent and complex cultivation exigencies, such as in citrus groves, is almost technically impossible. On the other hand, it is necessary to take into consideration the main ecological and environmental strengths in terms of sustainability derived from APV. They result in a strong push towards innovation in agricultural environmentally compatible and more competitive processes. Among the most relevant:

- Reduce soil evaporation and recover rainwater.
- Protect crops from extreme weather events by offering shade and weather protection.
- To recover part of the abandoned agricultural land, allowing the achievement of the decarbonisation objectives.
- Reduction of the water requirements of crops.
- Create agro-energy communities to distribute economic benefits to citizens and agro-energy companies in the area.
- Create new jobs and increase agricultural income by combining renewable energy production with agriculture and herding, especially in inland areas of Sicily (Sturiale and Scuderi 2016).

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Chapter 17
Redevelopment of Industrial Brownfields Through Green Hydrogen: Evolution and Criticalities

Maria Rosaria Sessa and Ornella Malandrino

Abstract Human activity continues to have innumerable impacts on the environment and hence on the territory, creating potential environmental and social damage in increasingly vast areas that now affect the entire planet and which, in the long term, may lead to the impoverishment of natural resources and the eco-systemic functions connected with them, with consequent significant economic damage. From this perspective, the redevelopment of industrial brownfields represents an opportunity: *i)* to relaunch the territorial system from the economic point of view, *ii)* to accelerate the transformation of the business community, *iii)* to raise the level of architectural and landscape quality of urban spaces, *iv)* to favour the settlement of highly innovative activities in terms of the specificity of production, and *v)* to reduce the socio-environmental impacts on the surrounding community both now and in the future. In Italy, the current PNRR (National Recovery and Resilience Plan) is also urging the country's regions and autonomous provinces to identify and therefore redevelop their industrial brownfield lands to convert them into centres for the production and distribution of hydrogen from renewable energy sources (green hydrogen). Hydrogen is increasingly being considered an energy vector that can promote environmental protection, social welfare, and the consequent improvement of the economic performance of production organizations. At the same time, in 2019, the European Commission, with the European Green Deal, indicated green hydrogen to achieve climate neutrality by 2050. Therefore, this paper aims to recall the main benefits of green hydrogen and its critical points within the sustainable development of a territory.

Keywords Green hydrogen · Brownfields · European Green Deal · Sustainability · Urban regeneration

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17.1 Introduction

Currently, economic, social, and environmental sustainability is becoming more important in urban and territorial development policies in Europe and internationally. Some important global environmental problems (e.g. climate change and the depletion of natural resources) require following a “decarbonization process” for an energy transition. Energy transition means not only a move away from energy from fossil sources in favour of renewable ones but also an improvement of the energy efficiency related to energy production and an awareness of energy consumption by citizens. This is even more true at the local level, where the sustainability paradigm can support the identification of production and consumption models capable of reconciling economic development and environmental protection in different socio-cultural and institutional contexts (Proto and Supino 2009).

According to the author (Mio 2021), only a few organizations today implement the sustainability paradigm, understood as the creation of long-term value, in particular shared value. The creation of shared value focuses, therefore, on identifying and strengthening the connections between social welfare and positive economic results and presupposes the recognition of the interdependencies between corporate action and the social context of reference. It is from these considerations that reducing the negative environmental impacts of enterprises is a major challenge, both at the international level and at the regional and local levels. The need for reducing atmospheric emissions, which are responsible for climate change, is all the more urgent in densely industrialized areas, which are traditionally located near highly populated urban areas, such as those in Europe (Johnson et al. 2017). The quality of air in rapidly growing economies is also worsening, as industrial clusters bring about both economic growth and environmental impacts (Gereffi and Lee 2016). Issues of environmental resource protection, sustainable processes, and energy choices must be considered when promoting the development of sustainable industrial areas (SIAs) (Zhu et al. 2017). In such a scenario, the activation of new forms of collective action and collaborative economies (in which production and consumption give rise to new systems of exchange), combined with the opportunities offered by digital technologies, are the cornerstones of the energy transition and represent an opportunity for the creation of new green and circular economy models. However, the green growth of industrial areas is still a critical issue for the pursuit of Agenda 2030 (UNF 2019), particularly for how to redevelop industrial brownfield lands into SIA in the context of more complex urban regeneration (Dong et al. 2016; Mattoni et al. 2015). Recently, the European Commission presented the European Green Deal (European Commission 2019), which has been hailed as an opportunity for a low-carbon transition as well as a long-term strategy for SIA in the context of urban regeneration. In particular, sustainable development of urban areas has become the prime challenge in the energy sector, promoting objectives such as (i) energy consumption and carbon footprint reduction, (ii) low-cost and low-carbon electricity supply, (iii) a smart European electricity grid, (iv) alternative fuels and mobile energy sources, (v) innovative knowledge and technologies, (vi) market uptake of energy and ICT innovation, and (vii) robust decision-making and public engagement. Following this perspective, green hydrogen seems to be assuming a key role in the energy transition in the twenty-first century. In this regard, industrial brownfield lands can be converted into centres for the production and distribution of green hydrogen, fostering the spread of SIA and, more generally, urban regeneration spaces according to sustainability principles. Therefore, this work aims to analyse the main potential of green hydrogen as well as its critical points for the redevelopment of industrial brownfield sites.

17.2 The Redevelopment of Industrial Brownfields Through Green Hydrogen

In recent years, interest in industrial area redevelopment, the production systems that reside within them, and the territory in which they are located has been growing. Internationally, SIAs are defined using the concept of eco-industrial parks (EIPs), within which mutually beneficial relationships are established between organizations and their environment through the management of raw materials, by-products, and waste shared (Beltramo et al. 2014). Different terminologies and definitions are used by various organizations around the world to refer to EIPs or relatively similar concepts. At the national level, reference is made to productive areas ecologically equipped (APEAs are the Italian acronym).

In Italy, law No 59 of March 1997 and its implementation Decree No. 11 of March 1998 (known as the Bassanini Decree) indicated in the APEA a possible model for integrating the management of economic development, environmental protection, and social growth of the community, entrusting to the regions and local authorities to identify, within the framework of their territorial planning, industrial areas to redevelopment in SIA. The national legislative decree lays down provisions for urban planning, environmental and energy requirements, and forms of financing. The urban planning indications refer to the identification, by the municipalities, of industrial brownfield lands to convert into SIA within their territory, taking the morphology of the area and the results that can be achieved deriving from economic, urban planning, and landscape surveys. Instead, for the forms of financing, the regions independently establish how to act in terms of incentives and financing. For the environmental and energy aspects, the reference legislation establishes that the sustainable industrial areas model must reach goals of eco-efficiency considering two fundamental elements: the construction of new infrastructures and services, to complement the existing ones, and the organization of production areas, able to bring economic, environmental, and social benefits to enterprises, consumers, citizens, and, generally, the local community, which individually would not be able to achieve. It is precisely in this context that green hydrogen can be included to support the redevelopment of industrial brownfield lands into SIAs, promoting decarbonisation in the energy sector.

17.2.1 Green Hydrogen

Hydrogen is increasingly seen as the driver of change in the energy system internationally. It cannot be considered a novel energy carrier since its discovery as a fuel dates back to 1783, when Antoine Lavoisier together with Laplace reproduced Cavendish's experiment, showing that the combustion of hydrogen generates water vapour (Carpuso et al. 2022). Because of this characteristic, hydrogen can be recognized as a "clean fuel". This means that there is no CO_2 emission when hydrogen is burned to produce either heat or electricity or both of them, aiming to accelerate decarbonization. Hence, hydrogen could replace conventional fossil fuels and reduce their related carbon emissions, pursuing sustainability goals (e.g. Agenda 2030 and European Green Deal). There are several methods of hydrogen generation with different levels of sustainability. The hydrogen produced from renewable sources through electrolysis is called green hydrogen; when it comes from coal gasification with water vapour, it is called brown hydrogen. It is called grey hydrogen if fossil fuels are used and blue hydrogen if production is from fossil fuels, but at the same time, CO_2 produced in the process is sequestered and stored (Koch Blank and Molly 2020). The most widely used system today is the extraction of hydrogen from CH_4 methane by steam reforming, which unfortunately also generates CO_2. In fact, according to the International Energy Agency, approximately 75 million tons of hydrogen consumed per year globally comes from fossil fuels, particularly natural gas, which generates huge amounts of climate-changing emissions (IEA 2020). The European Union currently uses approximately 9.7 million tons of hydrogen per year (Confindustria 2020). Thus, it is clear that this energy carrier is of fundamental importance for future energy systems. It is equally clear that the most economically, environmentally, and socially viable method of hydrogen generation must be identified. With the Green Deal, the European Union identifies green hydrogen as a priority area for achieving carbon neutrality by 2050. Additionally, the "Hydrogen Strategy for a Climate Neutral Europe" sets out a vision of how the European Union can turn clean hydrogen into a viable solution to decarbonize various sectors over time by installing at least 6 GW of renewable hydrogen electrolysers in the EU by 2024 and 40 GW of renewable hydrogen electrolysers by 2030 (European Commission 2020a). Italy has well presented its "National Hydrogen Strategy", which aims to achieve 2 percent hydrogen penetration in final energy demand by 2030 and envisages investments of up to €10 billion between 2020 and 2030 to launch the low-carbon hydrogen economy and achieve the above hydrogen demand penetration target (Mise 2020). To achieve these carbon-neutral goals, the European and national roadmaps must be well structured around a few main pillars (production, storage, transport, distribution, and end uses). This will enable countries to be ready for the coming zero-emission energy demand. In this scenario, it is possible through green hydrogen to respond to two important challenges, contributing to European climate neutrality and supporting the conversion of industrial brownfields into SIAs. In particular, industrial brownfields can be converted into "hydrogen valleys," taking advantage of areas already connected to the electricity grid and well established in the national production context to install, already in the first period of the roadmap, electrolysers powered by over-generation from renewables or dedicated plants, promoting supply and demand that can coexist and local cooperation that could be the basis of the hydrogen economy model (European Commission 2020b).

17.2.2 Benefits and Critical Issues

In Italy, within the framework of the National Recovery and Resilience Plan, Mission 2 “Green Revolution and Ecological Transition”, and Component 2 “Renewable Energy, Hydrogen, Grid, and Sustainable Mobility”, the government is urging regions to launch a selection procedure in their territories to finance investment projects involving the reconversion of industrial brownfield lands in hydrogen production and distribution centres by only renewable energy sources. In particular, the government aims to create ten hydrogen valleys, i.e. sustainable industrial areas with a hydrogen-based economy, promoting the regeneration of urban spaces through the redevelopment of industrial brownfield lands and the pursuit of global sustainability objectives starting from the local territory. Thus, the implementation of hydrogen centres could bring many benefits to businesses, consumers, and citizens who have decided to adopt its schemes in industrial areas to be redeveloped. In fact, green hydrogen (i) does not emit CO_2 or other pollutants, because it is produced from renewable energy sources; (ii) the cost of transport is lower than electricity; (iii) it can be stored for long periods, (iv) it can efficiently decarbonize “hard-to-abate” sectors, such as steel and refining; (v) it can be used in sustainable mobility, through the use of fuel cells; and (vi) it favours “sector coupling”, i.e. integration between the electricity and gas sectors, which allows for greater flexibility and thus lower costs for the energy system as a whole. However, to date, despite these multiple benefits, the focus of policymakers on this issue through the promotion of initiatives (such as the PNRR) risks being general criteria not adequately supported in the implementation phase. Therefore, the success of a future hydrogen economy will require addressing multiple aspects to improve the current state of affairs. In particular, it will be necessary to lower the costs of renewable hydrogen and concentrate efforts in areas where it is the most efficient solution. In addition to hydrogen generation, it is important to consider its entire value chain. While most technologies are already mature at different levels of the hydrogen supply chain, their complexity causes a relatively low energy efficiency due to the numerous processes that are needed to supply hydrogen to final users. The focus is often on generation costs, but evidence shows that both hydrogen transportation and storage represent key challenges in terms of energy losses and required infrastructure (Nousson et al. 2021). The complexity of the supply chain suggests that hydrogen is a valuable carrier that should be used primarily in applications that have few feasible alternatives for decarbonization (Velazquez Abad and Dodds 2020). Less promising, on the other hand, is hydrogen for light transport, from the car down to the bicycle, as electricity is proving to be by far the most competitive and hardly replaceable solution among the green ones. Similarly, it would not seem advantageous in terms of environmental impact to think about using hydrogen for heating buildings, although there are discussions about using the gas network as an infrastructure into which a percentage of hydrogen could be mixed. The most profitable use that can be made of green hydrogen is a combination of green hydrogen and electricity produced from renewable sources. However, to produce green hydrogen in significant quantities, it would have a huge surplus of renewable electricity, in particular photovoltaics, lowering the costs of the technologies and infrastructure for its production and distribution. It is important to define transparent and clear standards and targets for the development of hydrogen pathways and expected impacts, including the technologies that are considered, the system boundaries, either system operation or lifecycle assessments, and the thresholds that are assumed to define low-carbon hydrogen.

17.3 Conclusions

The future energy scenario will need increasingly more energy produced by renewable sources, and green hydrogen will play an important role in this transition. Given the current great and widespread interest in hydrogen, this paper aimed to provide an overview of potential benefits and possible critical issues when considering the redevelopment of industrial brownfield sites into hydrogen production and distribution centres in Italy. Hydrogen valleys can act beyond the energy sector and play a more transformative role at the local level. They are characterized by the participation of a wide range of actors, and local administrations can play a key role in facilitating implementation and future development. These are actions that, in addition to energy savings, promote other initiatives, including sustainable mobility, local employment, educational and dissemination programs, building renovation, and/or urban regeneration projects. The next phase of this research will be to apply learning in a specific local context, quantifying the monetary, environmental, and social benefits of redeveloping an industrial brownfield site in a hydrogen valley to meet the challenges of the sustainability paradigm at the national and international levels.

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Chapter 18
Life Cycle Assessment and Life Cycle Costing of a Unitized Regenerative Fuel Cell Stack: A Preliminary Study

Teresa Maria Gulotta, Roberta Salomone, Giovanni Mondello, Giuseppe Saija, and Francesco Lanuzza

Abstract The unitized regenerative fuel cell (URFC) with a polymeric electrolyte membrane (PEM) is an emerging energy storage system that could play an essential role in decarbonizing Europe. Considering that the sustainability of PEM-URFC devices has not been studied in depth, further analyses are needed. In this context, this paper focuses on the central main component of a PEM-URFC, the stack, by assessing its potential environmental and economic impacts. Thus, using primary and secondary data, the life cycle assessment (LCA) and environmental life cycle costing (ELCC) methods are applied, following a cradle-to-gate approach. The analysis shows that the main hotspots of the stack are linked to the membrane electrode assembled (MEAs), which contribute to approximately 68% of the total cost and more than 76% of all the environmental impact categories. These results are connected to the presence of materials characterized by high or medium critical supplies (e.g. platinum for catalysts, etc.) and high costs due to the early stage of market development. Furthermore, the study highlights the need to have more reliable data on crucial and critical elements used in this type of device and more life cycle thinking studies on URFC to update the current knowledge on hydrogen technologies.

Keywords PEM · Life cycle assessment (LCA) · Environmental life cycle costing (ELCC) · regenerative fuel cell · hydrogen

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18.1 Introduction

To achieve carbon neutrality and to reduce external energy dependencies in Europe by 2050 (European Commission 2019), the unitized regenerative fuel cell (URFC) of type polymeric electrolyte membrane (PEM) seems to be a valid option for improving the power system's stability, given its ability to work both as an electrolyser, to produce hydrogen fuel, and as a fuel cell, to reconvert it into electricity when required (Regmi et al. 2020). Although several studies are available on this device's electrochemical performance and design (Gabbasa et al. 2014), the potential life cycle environmental and economic impacts of the URFC and of the stack, which represents the heart of this technology, have not yet been studied in depth. To reduce this literature gap, this paper aims to provide a preliminary estimation of the environmental and economic impacts of a small stack of a PEM-URFC. The stack is at the early design stage and has been developed in the context of the project "ELETTRORIGENERA" (PO FESR SICILIA 2014–2020 AVVISO 1.1.5—PROGETTO ELETTRORIGENERA N. 08ME2899200216). The potential impacts are estimated by combining the life cycle assessment (LCA) (ISO 2006a, b, 2020a, b) and the environmental life cycle costing (ELCC) (Hunkeler et al. 2008) methods. This analysis allows a global understanding of the contribution of each consumed material and energy and related emissions, as well as environmental externality prices on the PEM-URFC stack's impacts, to identify its main critical hotspots.

18.2 Material and Methods

18.2.1 *Goal and Scope Definition*

The study combines LCA and ELCC methods to (i) evaluate the environmental and economic impacts of a PEM-URFC stack, (ii) identify its main environmental hotspots, and (iii) calculate the contribution of environmental externalities to life cycle costs. The LCA method is applied according to ISO 14040-44:2006 (ISO 2006a, b, 2020a, b) using Simapro software (PRé Sustainability 2022). The ELCC is applied according to Hunkeler et al. (2008), using Simapro to estimate externalities' monetization and an MS-Excel worksheet to manage data. According to Masoni and Zamagni (2011), the functional unit selected is a PEM-URFC stack of 3 and 1 kW of nominal power in electrolyser and fuel cell modes, respectively. A cradle-to-gate approach is applied, accounting for all energy and material flows linked to the manufacturing phase.

18.2.2 Life Cycle Inventory

The inventory data of the stack are modelled by using both primary and secondary data (see Table 18.1). In particular, the primary data provided by the ELETTRORIGENERA project's partners are weight, number, materials composition, and costs of each component (produced and provided by third organizations). The proxy of working processes (e.g. sintering, thermoforming, etc.) and all materials production processes are selected from the Ecoinvent database (Wernet et al. 2016), except for Nafion and Teflon manufacturing processes estimated according to the literature, respectively, from Evangelisti et al. (2017) and Simons and Bauer (2015). Due to missing inventory data, iridium and ruthenium oxide and ertalyte manufacturing are assumed from similar materials (Mori and Štern 2016).

Table 18.1 Number, weight, and price of components included in one URFC stack

Component	N.	Main materials [% on weight]	Total weight [kg]	Price [€][a]
Membrane electrode assembly (MEA)[b]	30	Catalyst-coating membrane (CCM): Membrane (Nafion[c] 3.39%) Electrocatalysts (iridium ruthenium oxide[d] 0.05%, platinum black 0.07%, platinum on carbon 0.05%) Ink preparation (carbon black 0.25%, methanol 0.18%, Nafion[c] 2.03%). Gas diffusion layers: Mesh (titanium 42.13%) Felt (porous titanium 51.92%)	5.72	29,183
Frame[b]	60	Ertalyte[e] (100%)	1.99	9000
Gasket hole[b]	60	Polytetrafluoroethylene[f] (Teflon) (100%)	0.33	16
Bipolar plate[b]	30	Titanium (100%)	1.59	3600
Current collection plate (CCP)	2	Copper (100%)	0.22	150
Gasket final	2	Polytetrafluoroethylene[f] (Teflon) (100%)	0.02	1
Tie rods, spring	20, 300	Iron (100%)	0.71	270
Endplates	2	Aluminium (100%)	3.86	936

[a]Prices comprehensive of materials acquired and manufacturing costs at laboratory scale
[b]Components of the cells
[c]Manufacturing process assumed by Evangelisti et al. (2017)
[d]Manufacturing process assumed as palladium by Mori and Štern (2016)
[e]Manufacturing process assumed as PET
[f]Manufacturing process assumed by Simons and Bauer (2015)

18.2.3 Life Cycle Impact Assessment

For environmental impact calculations, the CML-IA baseline (CML 2016) method is applied to evaluate abiotic depletion potential (ADP), acidification potential (AP), global warming potential (GWP), eutrophication potential (EP), and photochemical oxidation formation (POF).[1] In addition, using the cumulative energy demand (CED) method (Frischknecht et al. 2015), renewable (CEDr) and nonrenewable primary energy (CEDnr) consumption is calculated. The ELCC is calculated as Eq. 18.1 by summarizing two values: (1) the life cycle costs (LCC) of each component and (2) the environmental price (EP).

$$\mathrm{ELCC} = \sum_{i=1}^{\mathrm{components}} (\mathrm{LCC} + \mathrm{EP})_i \tag{18.1}$$

The first is based on primary data provided by the ELETTRORIGENERA project's partners, including materials and manufacturing costs; the latter is calculated by applying the environmental prices method (De Bruyn et al. 2018), which includes the average European prices for the social cost of pollution expressed in Euros per kilogram of pollutant.

18.3 Results and Discussion

The environmental, energy, and economic results are reported in Table 18.2.

Concerning the environmental impacts, during the manufacturing phase, the stack contributes approximately 0.026 kg Sb_{eq} in ADP, 30 kg SO_{2eq} in AP, 619 kg CO_{2eq}

Table 18.2 Environmental, energy, and economic impacts of the PEM-URFC stack

Impact categories		Units	Values
Environmental impacts	ADP	kg Sb_{eq}	2.63E-02
	AP	kg SO_{2eq}	3.00E+01
	GWP	kg CO_{2eq}	6.19E+02
	NP	kg PO_{4eq}^{3-}	3.02E+00
	POF	kg C_2H_{4eq}	1.12E+00
Energy impacts	CEDnr	MJ	8.74E+03
	CEDr	MJ	3.87E+02
	CED	MJ	9.12E+03
Economic impacts	LCC	€	4.22E+04
	EP	€	6.75E+02
	ELCC	€	4.29E+04

[1] These choices were performed according to Masoni and Zamagni (2011), where these impact categories are considered essential in LCA studies of fuel cells and electrolysers.

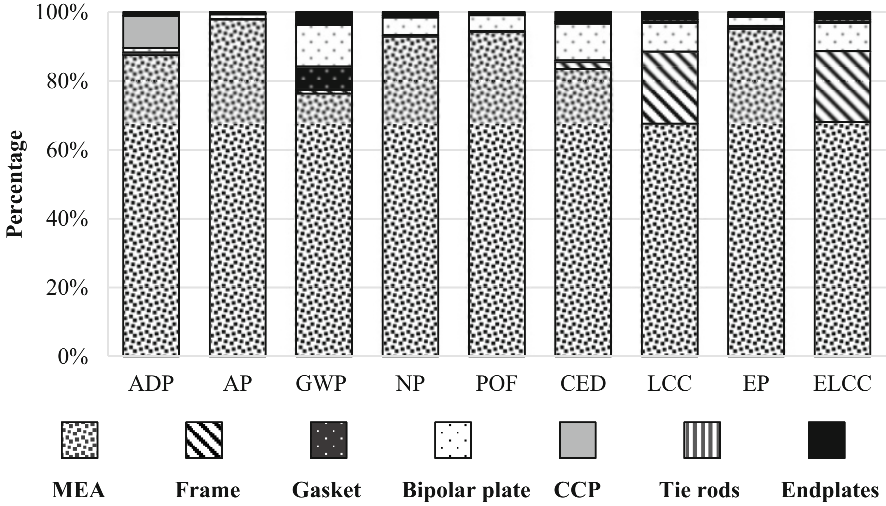

Fig. 18.1 Contribution analysis and hotspot identification for PEM-URFC stack manufacturing

in GWP, 3.02 kg PO^{3-}_{4eq} in NP, and 1.12 kg C_2H_{4eq} in POF. Focusing on CED, the primary energy consumed for component manufacturing is 912 MJ, of which 96% is produced from nonrenewable energy sources. The life cycle costs of stacks increase as one moves from conventional LCC (43,155.98 € per unit) to environmental LCC (43,830.55 € per unit), reflecting the inclusion of "environmental externalities". Considering that the costs of components refer to a device not still commercialized, the LCC is relatively higher than similar mature technologies, and environmental prices contribute to approximately 1.5% of economic impacts globally. Plotting the overall contributions in percentages allows for identifying the main hotspots linked to stack manufacturing for each impact category and visualizing the substantial differences and analogies among them (Fig. 18.1).

The main environmental and energy impact contribution in the manufacturing phase comes from the MEA, responsible for more than 76% (GWP) of all the impacts. These high values are linked to electrocatalysts responsible for more than 88.7% of the impacts of MEA, except for $CED_{r,}$ in which catalysts are responsible for at least 62.39%. The rest of the elements are responsible for 37.61% in CED_r, 11.30% in GWP, and 8.74% in CED_{nr}, while in the other categories, they contribute to less than 2% of MEA impacts. In contrast, the lowest impact of the stack is related to the tie rods contributing less than 0.16% in all environmental categories. Focusing on the economic impacts, it could be observed that the highest manufacturing costs are related to MEAs that contribute 68.05% in LCC and 95.14% in EP, reflecting the environmental emissions linked to the mining of platinum. Although the monetization of impacts increases the global economic impacts by less than 2%, essential differences exist among components, for which it is calculated that the EP increases

LCC from 0.01% in the frames to 18.04% for gaskets. Comparing environmental and economic impacts, Fig. 18.1 shows that while the hotspots are similar for MEA and bipolar plates among the ELCC and GWP and CED scores, differences exist in other components and impact categories. For example, while the frame contributes approximately less than 2% in all impact categories, its cost has a much more significant economic impact (20.54% of ELCC). The contrary is for gaskets: the cost has a minor significant percentage (0.05%) compared to the GWP score (6.72%). The highest discrepancies could be associated with the fact that the technologies are not still commercialized, and the particular shapes required for some components are affected by treatment and machinery prices. However, in this preliminary study, considering that third organizations provide the components, it was impossible to provide an estimation of the influential contributions for each material, energy, and operating cost due to missing data for both LCA and ELCC, especially on crucial and critical elements such as catalysts.

18.4 Conclusions

This paper aimed to evaluate the environmental and economic impacts of a PEM-URFC stack to identify its main hotspots. The LCA and ELCC of a small PEM-URFC stack were carried out to reach the study's scope, and a contribution analysis was conducted to identify critical issues. The life cycle study included primary data on each stack component's weight, materials, and costs. Instead, the working process proxies, material production datasets, and environmental prices are taken from the Ecoinvent database and literature studies. The analysis shows that the highest potential impacts are associated with MEA, which includes catalysts and materials (such as palladium, platinum, titanium, and Nafion) characterized by a high or medium critical supply chain that affects both the economic (LCC) and environmental (LCA) pillars of sustainability. Despite the similarities between LCA and ELCC hotspots, some discrepancies were noticed for frame and gasket components. However, considering that most of the data refer to emerging technology at early stage design and laboratory scale, the sustainability of the device has to be evaluated considering different parameters for both economic and environmental models and market scenarios. In addition, future studies may be focused on evaluating, e.g. the whole life cycle of URFC systems from manufacturing to end-of-life, calculating the uncertainty linked to catalyst production processes and the relative effects on results and estimating the potential benefits of technologies compared with alternative energy storage.

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Part IV
Circular Economy and Sustainability Issues in Several Sectors: Leather and Textile

Chapter 19
A Hypothesis of a Lean Warehouse Design for an Italian Textile and Apparel Company

Paola Geatti and Alberto Vedoa

Abstract Currently, companies experience a very competitive scenario: innovations, changes in consumer behaviour, competitiveness and dynamic markets put firms in a position to rethink and improve their organization and processes to increase efficiency and performance. Companies, in order to adapt to this context, can gain insight from Lean management. In this work, the principles of Lean thinking were applied to the case of an Italian company operating in the textile and apparel sector in designing a new warehouse functional to its business; the actual constraints given by the structure of the building to be used as a warehouse were respected, but the economic aspect, the costs to be incurred and the detailed quantity of goods that the company intended to store inside were not reported (for privacy reasons). Through typical Lean thinking processes and tools, such as value stream mapping, 5S and kaizen, several benefits can be achieved.

Keywords Lean warehouse · Italian company · Textile and apparel sector · Warehouse design · 5S Methodology

19.1 Introduction

Recent trends, such as the proliferation of product range, increasing market volatility, the expansion of e-commerce and the shift of production to the Far East, as well as the increasing speed of operations and shortening lead times, force companies to have smooth and efficient logistics operations to increase competitiveness. In particular, within today's supply chains, a high-performing warehouse (W) plays a key role in cutting logistic costs and ensuring that the order is delivered flawlessly (i.e. correct order in the right quantity, delivered to the exact customer at the exact location, on time) (De Koster et al. 2017; Gu et al. 2007, 2010; Rouwenhorst et al. 2000; van den Berg and Zijm 1999). In recent decades, the growing need to improve

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Table 19.1 Muda and examples of W waste

Muda	Examples of W waste
Transportation	Driving an empty forklift or parking vehicles away from unloading
Inventory	Excess stock reducing storage spaces and creating congestion in W areas
Motion	Uncomfortable items placing, unnecessary movements in searching for equipment left (forklifts, hand pallet trucks, etc.)
Waiting	Employees ready but unable to work due to product or machine unavailability
Overproduction	Holding too much inventory, picking for orders before they being requested
Overprocessing	Multiple barcodes scanning, unnecessary packing, moving products through more than one forklift
Defects	Correcting errors (picking the wrong item or quantity or incorrect shipments)

Source: Personal elaboration from Richards (2014) and Abushaikha et al. (2018)

supply chain performance has been forced to focus on reducing non-value-added activities, according to Lean thinking (LT, one of the most powerful management philosophies in recent history), not only in manufacturing operations but also in warehouse activities, so an increasing number of companies all over the world, in different market areas, adopted the LT philosophy in W management (WM), giving rise to Lean warehousing (LW). In recent years, a large body of literature has extensively documented the implementation of LT in logistics in various manufacturing sectors, but very few have addressed the textile and apparel industry in particular with regard to W (Coronel-Vasquez et al. 2022; Rojas-Tovar et al. 2020; Valchkov and Valchkova 2018). Although the ultimate goal of LT is to reach the so-called "zero stock", companies that can work without the W are rare, so they must be made as lean as possible (Abushaikha et al. 2018; Raghuram and Arjunan 2022). Several Lean tools may be efficaciously used in WM, such as value stream mapping (VSM), 5S methodology and the Kaizen approach (Richards 2014; Seth and Gupta 2005). In particular, the VMS technique allows us to visualize the whole process activities and to identify the waste (Muda in Japanese) according to the Lean principles (Table 19.1) to reduce or eliminate them.

The present study investigates the establishment of an efficient configuration for a new W of an apparel company based on theoretical and practical tools of LT, considering the lack of sector-specific solutions in the literature.

19.2 Materials and Methods

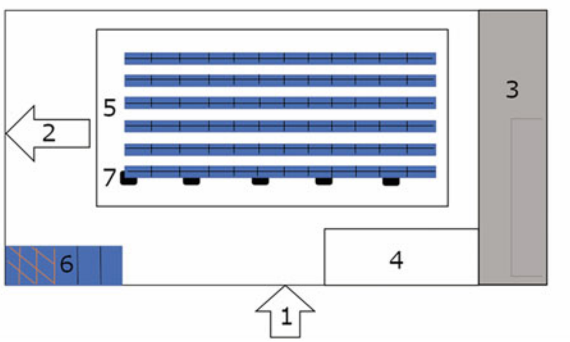
Company X started its activity in Italy in the 1940s as a family business. It was born as a spinning mill, and over time, its core business has been transformed into the production and distribution of three brands (A, B and C) of sportswear. The production process is outsourced to multiple suppliers, and the products are sold in over 50 countries. To date, the company owns two physical Ws (W1 and W2), and a third W (W3) is being set up near the company's headquarters, which will be dedicated exclusively to the C brand. The company's current logistics organization involves nonhomogeneous processes between W1 and W2, both in terms of technologies used and in terms of storage and receipt of goods. Data and information relative to the case study were collected in January–May 2020 by consultation of Company X reports, analysis of the plan of the building that would have housed the W and interviews with the company COO-CFO and his collaborators (variables investigated in the interviews: type of stock keeping units (SKUs), data on the quantity and weight of clothing and accessories of winter/summer seasons, number of transactions per day). Due to agreements with the company, it is not possible to refer to costs to be incurred (or actually incurred by the company) or to the volumes of goods handled. However, some real structural impediments (thus limiting some choices) will be taken into account.

19.3 Results and Discussions

The venue of W3 is that of an existing building used for the storage of another type of goods by another company. The external layout of the building is rectangular with entrance and exit forming the so-called L shape; an entire area identifiable with the short side on the right (from the entrance side) must be used for offices and W staff services, while the entire central part of the building is free for storage of items, taking into account, however, the presence of a row of immovable pillars (Fig. 19.1 and Table 19.2).

The choices to be made regard the arrangement of the shelves, the technology used and the various related areas. Company X uses plastic boxes and cardboard boxes as loading units in its Ws (Table 19.2).

W3 will contain C brand sportswear and accessories, items that vary in weight and volume: their disposition must be managed accordingly. The best solutions to offer to the company in a Lean perspective will be preferred based mainly on three criteria: (1) space used, with reference to both the area available for storage and the



Layout element	Description
1	Goods entrance
2	Shipping
3	Offices
4	Quality control
5	Double-deep racks
6	Pallets
7	Row of pillars

Fig. 19.1 Simplified representation of the internal layout of W3

Table 19.2 Main features outlined for W3

Feature	Details
Layout shape	L-shape
W size (~)	28.6 × 49 m; 1400 m^2
Structural impediments	Pillars in the central area; flooring
Internal layout	One floor approximately 7 m high
Storage area size (~)	15 × 33 m; 495 m^2
Loading unit size	
Small plastic boxes "Double" plastic boxes Cardboard boxes	40 depth × 60 length × 33 height cm 40 depth × 60 length × 65 height cm 60 × 60 × 60 cm
Racking system	
For the storage of plastic boxes	6 double-deep racks with 5 very narrow aisles with 12 bays and 13 or 7 levels (four racks of 13 and two of 7)
For pallets in shipping area	Drive-in LIFO with push back channels
Order-picking	On foot and with mechanically driven upright forklifts
Picking based on	System-managed locations integrated with staff devices
Picking method	Wave picking with arrangement according to the order size
Management control system	WM system and radiofrequency identification
Quality control	Near the entrance area and integrated into the system

available loading units; (2) ease and efficiency of W's various operations (e.g. the ease and time taken for order picking, quality control and goods counting); and (3) adaptability, both in the sense of the ability of this W to adapt to the different future needs of the company and in the sense of being able to offer solutions that can be integrated immediately or in the near future with the other company's Ws. For technical reasons, the only feasible solution in the W considered is that of shelving (not that of hanging garments moving on carousels or manual or automated conveyors) due to the heterogeneity of item sizes and the fact that goods are not only addressed to large retailers or stores but also directly to the end consumer through online purchasing. For reasons of available space and to reduce the time required for movements (in observance of Muda reduction), the optimal solution is double-deep racking, set in shelves consisting of 12 bays, arranged in such a way as to narrow the passage aisles as much as possible. Considering a safety height of approximately 6 m, the shelves will have a maximum of 13 levels by placing only small plastic boxes (33 cm height) and a maximum of 7 levels by placing double boxes (65 cm height). Regarding the third loading unit used in the company (cardboard boxes), given the marginality of its use and thus of the space occupied, being normally used in the stages of shipment on pallets, the optimal solution is to place them in the immediate proximity of the goods exit area. Considering the arrangement established thus far, a drive-in push-back racking system is the right choice, and therefore, the method of withdrawal (for order picking) will follow the LIFO ("last in, first out") mode. The second layout-related decision problem concerns the design part of the internal layout and concerns everything revolving around the placement of equipment, the storage space and the routes to be followed. Even in this case, however, the main issue remains the reduction of "transportation" and "motion". Regarding the orderly arrangement of the SKUs, the chosen methodology is slotting analysis, which requires an initial overview of the types of loads, the load units to be used in the W, how the items will be stored, and the tools that will be used for collection. The articles of the current season (items handled most frequently) must be placed on the nearest shelves, going backwards with the seasons as moving away. The existing W3 flooring will not make it feasible to install copper conducting wires in the floor: it will be necessary to install metal sheets, a sort of "skirting board", at the base of each shelf in direct contact with the flooring so that the driver can channel the vehicle between the aisles of the W. Dealing with the picking methodology, thanks to proper W logistics application programs that allow us to calculate the distance travelled by a picker, and taking into account the sorting problem, the final choice (after having eliminated single-order, zone and batch picking methodologies) falls on wave picking. This implies that the order pickers start collecting each in their respective area and all at the same time, and only after all the pickers have completed their tour does the following wave round begin. In this way, orders can be released at different times in different areas based on the time taken to select orders. However, even here, a subsequent sorting phase is needed, having to combine the partial orders. Basically, W3 should be designed so that at least six vertical forklifts are placed at the end of each aisle on the right side, referring to the goods entrance gate (again thinking of a 6-shelf layout, there are five central aisles plus two external aisles), while the pickup staff should be placed at the beginning of each aisle so that they walk toward the forklifts. In this way, by having all SKUs entered into the WM system and integrated with staff personal digital assistants (PDAs), whenever an order arrives, staff already know the exact shelves and locations from which to draw all the items that make up that specific order. Essentially, therefore, imagine having an order of items perfectly located in the W, so each employee will stand at the beginning of their respective aisle of reference and walk to the end of the aisle collecting all the items. When they reach the end of the aisle, they will leave the items in a designated container and, getting on the respective vertical forklift, they will travel the same route backwards, then leave the items again in a designated container. Thanks to this system, the picker would not have to walk through the entire warehouse individually, nor, as an aisle is reserved for each, would there be hindrances and bottlenecks or worse accidents between an employee on foot and one driving the vehicle. Radiofrequency identification technology contributes to overall visibility by enabling W workers to keep track of both identification and location at the individual item or product lot level and by helping operators avoid two types of Muda, namely, "overproduction" and "inventory". In addition, once the initial setup of the W is done, based on technical and LT considerations, the 5S tool can help in the further organization of the W3 (Table 19.3).

Table 19.3 5S Methodology applied to W3

S	Actions
Seiri (sort, clear out)	Remove obsolete and defective materials, undue and excessive stock, faulty equipment, damaged pallets and packaging waste from the working area Remove impediments in front of the entry and exit areas Eliminate unnecessary equipment, documents, movements Reduce the amount of time needed for material handling Reduce unnecessary vehicle parking Use radiofrequency system to avoid item counting phase Use vacuum for packaging
Seiton (set in order, configure)	Define and label locations and use directional signals Use slotting analysis Place the necessary tools and means near the point of need
Seiso (shine, clean)	Assign specific, daily or periodic tasks to each worker Install boxes at the end of each aisle for the purpose of waste collection Make cleaning tools (brooms and dust pans) easily accessible Employ total productive maintenance Keep the transit areas of vehicles and people clean and neat
Seiketsu (standardize, conform)	Walk through each process with the relevant staff Develop corrective and preventive maintenance actions for tools and equipment and standardize them according to work requirements Create and document new standards and introduce them in each work field Communicate standards with easily readable and understandable documents
Shitsuke (sustain, self-discipline)	Provide regular supervisory discussions between workers and team leaders Educate workers properly; encourage them to accept change Carry out regular checks and audits

19.4 Conclusions

The organization of the new W (W3) of Company X as a Lean W is a first step on the intended road of redesigning the spaces of Company X, which will continue with the complete restructuring of W1 and the subsequent joint configuration of the three Ws. According to previous LW experiences, as also reflected in the literature cited above, several advantages can be obtained with the application of LM to W3: reduced delivery times due to increased flexibility and availability of the product in less time; increased productivity; reduced work in progress and inventory; reduced product costs due to increased efficiency; increased competitiveness, increased focus on customer satisfaction, cleanliness and safety of the workplace; and good working environment and development of staff motivation.

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Chapter 20
Textile Industry Between Past and Future in the "Museo di Merceologia (MuMe)"

Darica Paradiso, Giuliana Vinci, Laura Gobbi, Lucia Maddaloni, and Sabrina Antonia Prencipe

Abstract In Italy, the textile industry represents one of the most important and strategic manufacturing sectors, characterized by new policies related to sustainable transition and digital innovation. The Italian textile industry is also associated with the workmanship, tradition, and ancient knowledge that has characterized Italian history. According to the 2020 ISTISAN report, Italy ranks not only as a country that produces the best fashion in the world but also as the only Western nation that still has production chains that start from raw materials and arrive at finished clothing. Indeed, the Italian textile industry is composed of companies that meet sustainability requirements more than their competitors. This peculiar situation is determined by several factors stemming from historicity, traditions, and existing legislation regarding environmental protection and respect for employees' health. The new Museum of Commodity Science, in Italian "Museo di Merceologia (MuMe)", at Sapienza University of Rome, currently undergoing major renovations, preserves numerous textile artefacts: animal and vegetable fibres, such as cotton, wool, linen, hemp, jute, kapok, silk, byssus, ramie, straw, and so on; man-made fibres such as viscose, rayon, cupro, acetate, etc.; and synthetic fibres, such as nylon, polyester, Kevlar, Lycra, and Gore-Tex. The new museum displays, which will characterize the new MuMe, will provide the public with the tools to understand the mechanisms of the entire production chain that characterizes the textile industry sector but also the possibility of becoming a more aware public, educating it to perform conscious actions on matters of sustainability and reduction of the environmental impact, based on one's own choices. MuMe would act as an educational medium, fielding inclusive hands-on paths and laboratory experiences based both on the weaving of natural fibres with traditional looms and on the design and printing of fabrics through 3D printers. In

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these regards, the MuMe enriches the visit and knowledge of the public through its website with in-depth texts dedicated to both the general public and school students of all levels.

Keywords Commodity sciences museum · MuMe · Textile industry · Fibre · Loom · 3D printer

20.1 Introduction

The textile industry is one of the main manufacturing sectors and is characterized by complex production processes. The textile and clothing sector includes the products of the textile industry (production of textile fibres), the production of clothing, and the preparation of leather goods. The size of the global textile market has been estimated at $ 993.6 billion in 2021 and is expected to grow by 4.0% annually from 2022 to 2030 (Li and Fung Group 2022). In addition, an increase in clothing demand is related to the fashion industry's growth and to the development of e-commerce platforms. In the European economic framework, this sector has a significant market share, with a turnover of approximately 162 billion euros. In the European Union (EU), this sector accounts for 11.9% of world exports, thus highlighting a growth of +6.2% in 2019/2018 (STATISTA 2022). The Italian textile industry is characterized by a clear prevalence of small and very small businesses, many of which are "family-own". The entire production chain is well represented in Italy, although with the increase in competition linked to the production of raw materials in developing countries (DCs), in recent years, there has been a massive delocalization of production processes to countries with a lower labour cost of some production phases (such as spinning and weaving). Furthermore, the Italian textile industry has found itself facing not only the delocalization of the production process but also massive and sudden competition in this sector from third countries, such as China, India, and Bangladesh (ISTISAN 2020). Italy is the third-largest exporter in the world of textile products, which include both fibres and clothes, contributing approximately 25 billion euros to the Italian trade balance (2020) (EUROSTAT 2022). At a European level, Italy is the first producing country, followed by Germany, United Kingdom, France, and Spain. Although the textile industry is widespread in the country, due to historical, social, and economic reasons, the companies are for the most part concentrated in well-defined districts, for example, Prato and Biella for wool, Como for silk, and Varese for cotton. The sector has recently undergone a radical change to maintain its competitiveness by moving towards products with high added value (Uddin 2019). The new Museum of Commodity Science, in Italian "Museo di Merceologia (MuMe)", aims not only to preserve and show the public its collection of textile finds but also to educate the public. In 2022, the Extraordinary General Assembly of ICOM (International Council of Museums) approved the new definition of a museum, which is the result of a long participatory process that involved 126 committees around the world. The definition is as follows: *"A museum is a not-for-profit, permanent institution in the service of society that studies, collects,* *conserves, interprets and exhibits tangible and intangible heritage. Open to the public, accessible and inclusive, museums foster diversity and sustainability. They operate and communicate ethically, professionally and with the participation of communities, offering varied experiences for education, enjoyment, reflection and knowledge sharing"*. Being inside a university, the museum also has the task of promoting cultural projects that connect the lines of research with the public, not only through museum itineraries and laboratory experiences but also through the sharing of knowledge. The new MuMe aims at conveying the knowledge of the traditional and innovative techniques that are the basis of yarn production through museological and museographic itineraries, interactive laboratories, thematic insights, and lines of research accessible through its website.

20.2 Textile Fibres

Textile fibres are fibrous products that, due to their structure, height, strength, and elasticity, have the property of joining, through spinning, into thin, tenacious, and flexible threads that are used in the textile industry for the manufacture of yarns, which, in turn, are transformed into fabrics (by weaving) or jersey. Textiles are divided into natural fibres, which in turn are divided into vegetable and animal fibres, and chemical fibres, which are divided into artificial fibres, i.e. fibres produced starting from polymers of natural origin (e.g. cellulose, viscose, etc.) and synthetic, if produced from synthetic polymers, such as plastics (e.g. nylon, Teflon, etc.) (Fig. 20.1) (Uddin 2019).

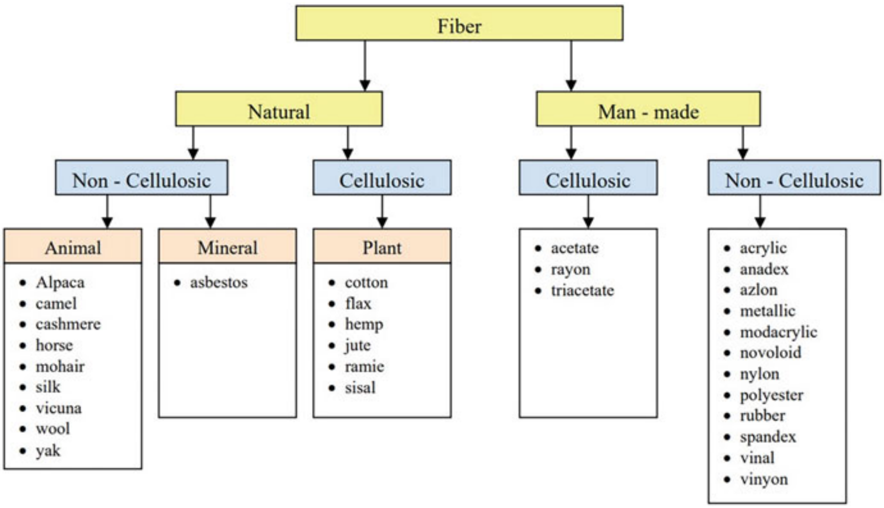

Fig. 20.1 Classification of textile fibres. (Source: Uddin 2019)

Each fibre is characterized by aesthetic properties (geometry, lustre, hand, and so on), chemical (material stability, resistance, and so on), physical-mechanical (hygroscopicity, heat behaviour, electrical behaviour, etc.), and physiological properties (allergenicity, resistance to bacteria/melds, etc.), which make it optimal for a specific use. Globally, cotton is the best-selling and most commonly used natural fibre to produce clothes, which is attributed to its superior properties, such as high resistance to traction and torsion. Cotton accounted for over 39% of the textile sector turnover. Wool-based textiles are the second most commonly used natural fibre (13.3% of the market). Wool is widely used to produce insulation products such as winter clothing, blankets, carpets, and upholstery (Patti et al. 2020).

Natural fibres led the market in 2021 with a maximum revenue share of over 44.5%. This strong growth has been attributed to changing trends in various applications of the fashion and apparel industry. Chemical-based textiles are estimated to account for approximately 60% of textile fibres (Shohabbos 2022). Among the chemical fibres most used in the textile industry, we find synthetic fibres obtained from polyethylene, polypropylene, and polyamides, characterized by high resistance to humidity, acids, and alkalis (Jahandideh et al. 2021; Panda et al. 2021; Hole and Hole 2020).

20.3 Textile Processes

Today, the textile industry includes a significant number and variety of processes that add value to fibre. These processes can range from yarn production to woven production via garment sewing, textile embossing, and composite manufacturing. However, considering textile fibre as the basic unit of any textile product, textile production can be identified as a technical textile. The conventional textile production process has a long history of converting natural fibre into useful products, including textiles, home textiles, and clothing. More recently, into a technical textile using special finishing effects (Fig. 20.2) (Sule 2012; Uddin 2019).

Instead, the production of synthetic and semisynthetic fibres is diversified with the use of monomers, chemical agents, precursors, catalysts, and a variety of auxiliary chemicals that lead to the formation of fibres or yarns (Uddin 2019). Innovation in textile production has introduced a variety of raw materials and production processes that require process control to ensure the quality of the finished product. Monitoring and controlling process parameters can reduce waste, cost, and environmental impact in the textile industry. All processing steps in textile production, from fibre production to the finished fabric, are experiencing improvement in process control and evaluation. It includes the production and processing of textile fibres through the blowing chamber, carding, ironing, and combing; the production of textiles, including knitting, weaving, nonwovens, and subsequent dyeing and finishing; and the production of garments. The global textile industry, in terms of yarn and fabric production, is strongly present and growing. Apparel production is another important area of the textile supply chain. Arguably, clothing is what an

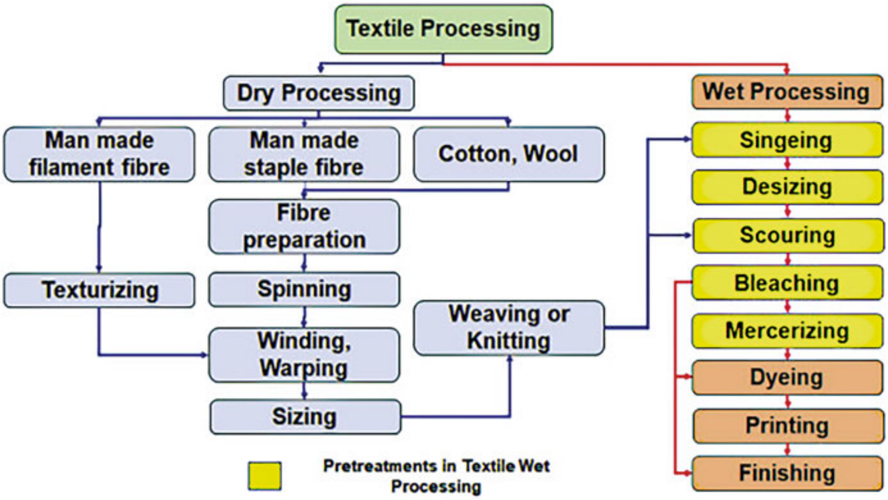

Fig. 20.2 Textile processing. (Sources: Sule 2012 and Uddin 2019)

individual wears for purposes of body coverage, embellishment, or comfort (Aniello 2001; Greta and Lewandowski 2010).

20.4 Museography and Museology

Italy, due to its close links with the textile industry, has numerous museums that collect and conserve textiles and collect data on them. This link between textiles and museums is often interpreted through temporary or semipermanent exhibitions, publications, and website interventions. These interpretations are either presented in isolation or are sometimes embedded in a broader framework including the history of art and design, science and technology, social history and anthropology, local history, and world cultures (e.g. types of textiles and approaches used in the major fashion capitals, such as London, Paris, Milan, or New York, with a long tradition of textile production and consumption, or manufacturing cities, such as Krefeld, Lyon, or Manchester).

Nevertheless, museums dedicated to the history of textiles rarely attract public attention or critical acclaim. Therefore, the italian "Museo di Merceologia" (MuMe), located within the Department of Management, at Sapienza University of Rome intends to draw on the diverse cultural experiences of the participants and the different disciplinary backgrounds they embody (Fig. 20.3).

The complete renovation of the entire museum area has made it possible and will make it possible to improve knowledge about the numerous and very diverse production processes in this industrial sector through the display of textile objects

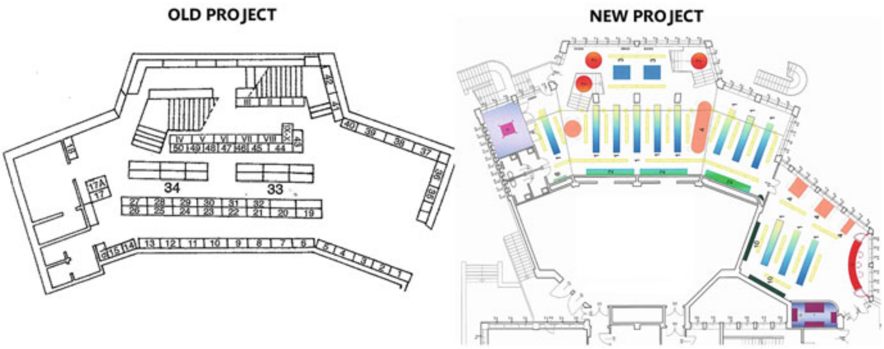

Fig. 20.3 Old and new project of the Museum of Merceology. (Source: Biniecka et al. 2018)

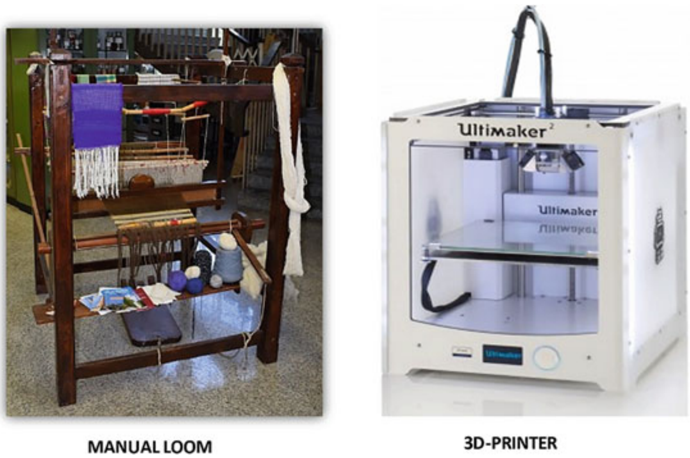

Fig. 20.4 Manual loom and 3D printer of the textile laboratory of the Museum of Merceology (MuMe)

according to the production chain. In addition, thanks to the logistical transformation of the museum, it has been possible to create an area dedicated to interactive textile laboratories, which allow people to get hands-on with past (e.g. loom) and future (3D printer) textile production technologies (Fig. 20.4). The 3D printer ideally replicates the replaced textile mechanical properties, such as tensile strength and strain, flex strength and strain, elasticity, compression strength, and percent swelling (Mondschein et al. 2017). Currently, additive manufacturing in fashion makes it possible to create clothing of extreme complexity, significantly expanding the designer's creative possibilities Additive manufacturing also plays an important role in the museum and museography sector to produce moulds for complex parts and for the direct production of traditional and next-generation materials. For the

MuMe, it could represent not only a simple repository of textile objects but also an opportunity to expand knowledge in the textile sector, thanks to the exchange of knowledge between academic research and the museum.

20.5 Conclusions

The art of weaving tells the story of our civilization, from the rudimentary coverings in use among the Palaeolithic to the refined vintage garments of our times. Knowing, documenting, cataloguing, preserving, and enhancing the techniques of the Italian and world textile industry are just some of the tasks of the *"Museo di Merceologia"* (MuMe). The MuMe can boast some important textile collections ranging from yarns to precious fabric fragments. In these regards, the new MuMe wants to act as an educational medium for the various types of publics. As a university museum, it wants to act as a reference structure between the academic world and citizenship through the new museological and museographic paths that interpret, study, re-elaborate and show the numerous and varied new production chains in the textile sector, characterized by processes that aim to sustainability and the reduction of environmental impact. Therefore, the renewed and innovated MuMe in its exhibitions will be the meeting point of science, history, and knowledge.

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Chapter 21
Production and Consumption Trends in the European Textile Sector and Main Sustainability Challenges

Vera Amicarelli, Maria Pia Spinelli, Christian Bux, and Giovanni Lagioia

Abstract The textile industry is ranked among the top four sectors that use raw materials and water the most, producing a wide variety of items, from apparel to household and technical textiles. In 2015, clothing production, which is responsible for most of the environmental impacts of the textile industry, doubled, with over 100 billion units sold globally. Recent research has estimated that the life cycle of garments does not last even a year due to a linear economic model exasperated by the phenomenon of fast fashion, which involves the launch of collections lasting a few weeks and characterized by very low prices and quality. The European Union will strengthen the competitiveness, sustainability, and resilience of this sector, promoting circular economy actions and more sustainable production processes. Furthermore, Member States will have to guarantee the separate collection of textile waste by 2025. This article aims to trace the current production and consumption trends of the textile sector in Europe and discuss the main challenges to improving its sustainability and circularity. The main results highlight the relevant role of man-made fibres, yarns, and fabrics compared to natural ones. Common European recommendations should be much more incisive to tackle the open loop that characterizes the textile supply chain.

Keywords Textile industry · Textile production · Textile consumption · Sustainability · Life cycle approach

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21.1 Introduction

The textile industry, which includes apparel, household, and technical textile production, is the fourth highest pressure industry after food, housing, and transportation (European Environmental Agency 2019). Globally, it is estimated that the whole clothing industry consumes approx. 80 billion m^3 of water and generates over 1715 million tons (Mt) of CO_2eq, as well as more than 90 Mt. of waste (European Parliament 2019). Each European purchases approx. 26 kg of textiles each year, and the related environmental impacts have been assessed at over 650 kg of CO_2eq per person (European Parliament 2020). It emerges that the textile industry is still more oriented towards the linear economy than towards the circular economy (Luján-Ornelas et al. 2020), and one of the main criticalities is related to the spread of fast fashion, which leads to exaggerated disposal rates and overproduction of useless clothes in short times. In 2015, the production of clothing recorded over 100 billion units sold globally (Ellen MacArthur Foundation 2017), and statistics reveal that more than 30% of clothes are sold at sale prices and approx. 40% remain unsold or do not even reach shops (Danigelis 2017). The European Union has provided guidance to achieve high levels of separate collection of textile waste, encouraging sorting, reuse, and recycling of textile waste. Among others, the Waste Framework Directive requires all European State Members to set up separate collections for textile waste by 2025. Furthermore, the European Union has suggested three strategies to pursue a circular economy in the textile industry: (a) increasing the efficient use of raw materials, (b) enhancing product lifespan, and (c) implementing the smart design of products (Luo et al. 2021). With these premises, the present research aims to trace the current production and consumption trends of the textile sector in Europe to discuss the main challenges in improving its sustainability and circularity.

21.2 Material and Methods

The research focuses on (a) fibre manufacturing and preparation, (b) spinning, and (c) fabric production, including weaving, knitting, or crocheting, and compares the years 2010, 2015, 2019, and 2020. The research boundaries stop at fabrics since Eurostat datasets, on which the data collection relied, do not allow characterising the flows of textile components in the finished products. This means that the volumes obtained according to the following methodology would have been distorted due to the other components constituting the numerous made-up articles that use fibres, yarns, and fabrics. The overall trends of the textiles produced and consumed in the EU-27_{2020} were traced by collecting data on the volumes of fibres, yarns, and fabrics production, export, and import in the decade 2010–2020 from Eurostat *ProdCom* datasets DS-066341 and DS-066342 and *Comext* datasets DS-045409 and DS-056120, that is, reffering to national statistics on production and trade, as already reported in the studies on the accounting of textile flows by the European Commission Joint Research Centre (JRC). The categories chosen for inclusion in the study

Table 21.1 Aggregate categories of fibres, yarns, and fabrics

Aggregated categories of:	Items included in the categories
Fibres	(a) Cotton, (b) wool and other animal hair, (c) silk, (d) synthetic fibres, (e) artificial fibres, (f) other natural fibres
Yarns	(a) Cotton yarns[a], (b) wool and other animal hair yarns, (c) silk yarns, (d) flax yarns, (e) yarns of other natural fibres, (f) man-made yarns[a]
Fabrics	(a) Silk woven fabrics, (b) wool woven fabrics, (c) cotton woven fabrics[a], (d) flax woven fabrics, (e) woven fabrics of other natural fibres, (f) man-made fibres woven fabrics[a], (g) other woven fabrics, (h) knitted or crocheted fabrics

[a]Solely or predominantly

were those corresponding to the following NACE codes within the *ProdCom* list 2020: 13.10 *Preparation and spinning of textile fibres,* 13.20 *Weaving of textiles,* 13.91 *Manufacture of knitted and crocheted fabrics,* and 20.60 *Manufacture of man-made fibres* (Köhler et al. 2021). The choice to exclude nonwoven is given by the fact that the CPA code 13.95.10 in the *ProdCom* list aggregates nonwovens and articles made from nonwovens. As some data on total production by DS-066342 were missing, the gaps were filled with sold production by DS-066341. Although this expedient might lead to nonexhaustive estimation, it helps to get as close as possible to a real approximation of the volumes, which in any case is not fully possible since some information can be rounded to protect the confidential national data. Moreover, DS-066341 and DS-066342 provided data on the production, imports, and exports of fabrics in square meters; therefore, it was deemed necessary to integrate the information and to define the weight of the production using DS-045409 and the *external trade nomenclature reference (HS/CN)* reported in the *ProdCom* list 2020. For the production, the conversion was performed according to the following equation:

$$\text{production } t_{n,y} = \left[\frac{\left(\frac{\text{import } t_{n,y}}{\text{import } km^2_{n,y}} \right) + \left(\frac{\text{export } t_{n,y}}{\text{export } km^2_{n,y}} \right)}{2} \right] \times \text{production } km^2_{n,y} \tag{21.1}$$

Notes: $t =$ tons; $n =$ product code; $y =$ year; $km^2 =$ square kilometres.

When the DS-045409 information on import and export tons was missing and the value for the reference year did not match, the results of the equations referring to the available years were averaged. Then, according to Köhler et al. (2021), the supply (or apparent consumption) was determined as follows:

$$\text{production } t_{n,y} + \text{import } t_{n,y} - \text{export } t_{n,y} \tag{21.2}$$

Notes: $t =$ tons; $n =$ product code; $y =$ year.

Finally, the codes were aggregated into categories to give an idea of the weight size in reference to single fibres, types of yarns, and fabrics (Table 21.1).

21.3 Results and Discussion

In EU-27_{2020}, fibre manufacturing, preparation, spinning, and weaving (i.e. fabric production) are dominated by man-made fibres, which also account for most of the external trade. Figure 21.1 records the main data related to the production, import, export, and supply (i.e. apparent consumption) of European fibres (Fig. 21.1a), yarns (Fig. 21.1b), and fabrics (Fig. 21.1c).

Man-made fibres production is approximately 75% on average in the period considered, but with a slight downwards trend of 13% less in 2020 compared to 2010. Instead, the production of natural fibres has seen an increase of 13% considering the same period, but while the production of cotton, wool and silk is stable over time, not exceeding 5%, 3%, and 0%, respectively, the production of natural fibres such as flax and hemp has grown, taking a market share of man-made fibres. Approximately 50% of exports are represented by man-made fibres and the other 50% by natural fibres, with a large part covered by natural fibres other than cotton, wool, and silk. Synthetic fibres are the most produced and imported (nearly 45% and 70% of fibre production and imports in 2020, respectively), with an annual supply that falls below 1.5 Mt in 2020, after a peak of almost 2 Mt in 2019. It is not surprising that the type of yarn most produced in Europe is that of solely or predominantly man-made fibres, also ranking as the most traded (an average of 70–80% of European production and trade of yarn in the period considered). Regarding cotton yarns and according to the data collected, it seems that the total supply of fibres is not adequate to cover the total national production of yarns. This is due to the fact that data on cotton fibres for uncombed cotton yarns is missing from the databases. In the decade 2010–2020, the supply of artificial and synthetic yarns, which has always been approximately 1.7 Mt, has allowed staying above an annual production of 0.4 Mt of such woven fabrics (approximately 40% of total fabrics production) but dropping in 2020 (over 100 thousand tons less than in 2019). Once again, a large part of the annual supply for the manufacture of finished products is represented by woven fabrics of solely or predominantly man-made yarns (600–700 thousand tons), followed by those solely or predominantly in cotton (300–400 thousand tons). Knitted and crocheted fabrics represent another large slice, but it should be emphasised that in this case, it is not possible to split the data and make a differentiation based on the type of fibre; therefore, overall, woven fabrics represent on average more than 65% of the European production and 70% of the trade. The results highlight the quantity and type of fibres, yarns, and fabrics within the EU, but the measurement of individual mass flows remains difficult due to the lack of data, rounding, and consequent discrepancies. The more difficult it becomes to make such assessments for finished products. In addition, data suggest that the EU is an importer rather than an exporter of textiles, and the production is often even lower than the imported volumes (i.e. fabrics), as shown in Fig. 21.2. Most of these textiles are produced in Asia; indeed, in 2020, the top exporters of textiles worldwide were China (276 billion USD), Vietnam (38.9 billion USD), and Bangladesh (37.3 billion USD) (OEC n.d.). Today, the value chain of textile production is one of the most

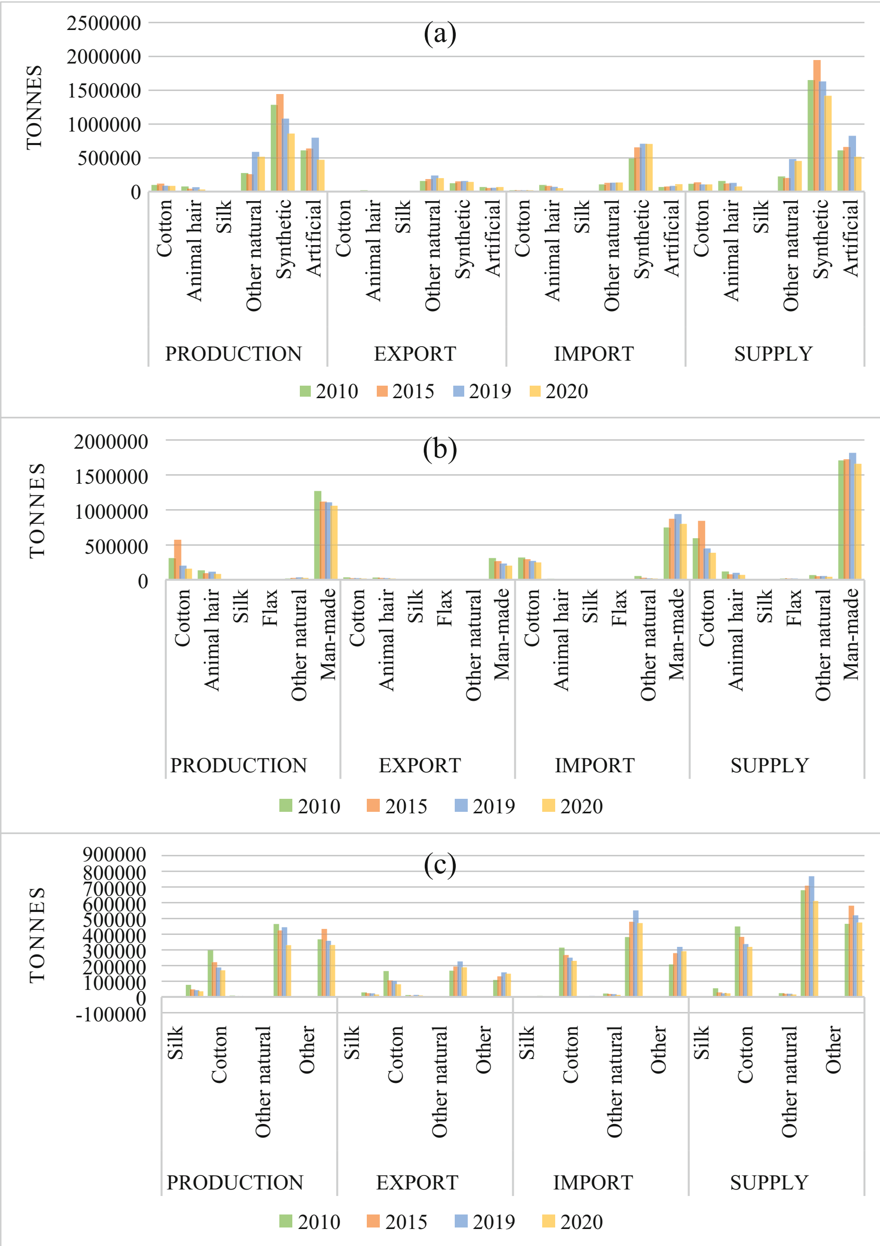

Fig. 21.1 European production, import, export, and supply of fibres (**a**), yarns (**b**), and fabrics (**c**) in 2010, 2015, 2019, 2020

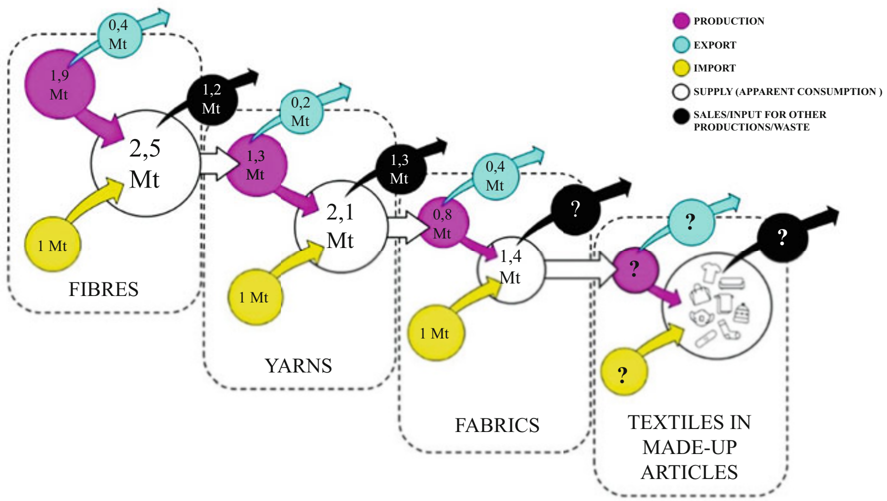

Fig. 21.2 Estimated European textile mass flows in 2020

complex, with companies choosing to outsource manufacturing outside European borders, in cheaper locations with low environmental and social standards and where between 80% and 90% of the environmental impacts actually occur (European Union 2022). This is a key point to stress because European policies cannot be effective if production occurs in places that are not subject to EU legislation.

21.4 Conclusions

The proposed analysis has considered the trends in European production, trade, and supply of fibres, yarns, and fabrics. The results show the predominance of artificial and synthetic fibres, yarns, and fabrics over natural ones. Moreover, trade data highlight the role of the EU as a textile importer from countries with low environmental and social standards. Data availability and existing classification systems mainly affect the possibility of tracing and measuring textile mass flows with a life cycle approach to tackle the open loop that still characterises the textile industry. To boost these results, next to the obligation of textile separate collection by 1 January 2025, the EU should suggest a set of tools to measure textile flows as happened with food waste (e.g. Directive 2008/98/EC on common methodologies and minimum quality requirements for the homogeneous evaluation of food waste quantities and composition). Common European recommendations should be much more incisive to drive the textile industry towards sustainable challenges.

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Chapter 22
The Future of the Italian Tanning Industry Considering the Recent Geopolitical Crisis

Giancarlo Palumbo and Isabella Maria De Clemente

Abstract The war in Ukraine—and its disturbing long-term prospects—risks further exacerbating the historic need for raw materials (raw and semifinished) of Italian tanneries, already plagued by years of competition, sometimes unfair, made up of customs barriers and limitations of various types that have stolen, especially in recent years, a lot of raw materials from the free market. Given the greater availability of raw hides, the tanneries of non-European countries (Asian and South American) could take advantage of this to reduce our competitiveness on international markets. The foreign procurement of raw hides accounts for over 90% of the needs of Italian tanneries, and the conflict area accounts for approximately 3.5% of total purchases from abroad. Ukraine is one of the main suppliers of semifinished leathers, including Russia and Belarus, and the Italian purchase of raw and semifinished leathers is equal to 70% of the total, while the export of Italian finished leathers to these incident countries alone accounts for 1% of the total. The situation is so worrying that the most important Italian association of the tanning industry, the Unione Nazionale Industria Conciaria (UNIC), in accordance with the European trade confederation, proposed asking the European Commission to limit the export of raw hides/European semifinished products outside the EU borders. Faced with such a disturbing scenario, it is clear that the problem of raw leather supply must be addressed at the EU level with management that takes into account the different production capacities of individual member countries, providing for adequate investment and increasingly implementing the principles of circular economy and technological innovation to the leather industry.

Keywords Leather · Raw hides · Circular economy

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22.1 Introduction

Every year around the world, tanneries valorize and enhance approximately eight million tons of raw hides and skins, a waste material from the agri-food supply chain that would otherwise be destined for disposal in landfills or incineration, resulting in the release of approximately five million tons of greenhouse gases. On the other hand, leather, an extraordinary example of valorization and conversion of a putrescible and polluting material, has a much longer use life than its substitutes and a far more favourable degradative fate for the environment. The market for materials proposed as alternatives to leather, whether exclusively synthetic ones such as polymers derived from petrochemicals or those of synthetic biogenic origin such as AppleSkin, Desserto (essentially cellulosic pulp from various plant sources, including waste), more or less added in some cases with prevailing percentages of synthetic components (PVC and PU), is also growing as an effect of ecoVegan propaganda that is not infrequently as uninformed as it is aggressive. It must, in fact, be remembered that no animal is killed to obtain its skin for tanning purposes (apart from the case of the fur industry); in contrast, the tanning industry has, precisely, the merit of valorizing a waste product that would otherwise constitute a serious environmental problem. It is no coincidence that the 2021 UNIC sustainability report includes the proposed use of the ethical claim “we recover our hides and skins from the food chain”, which, in an extremely succinct and effective way, summarizes the origin of a material that is natural, biodegradable, and able to meet the requirements of the circular economy. Moreover, many claims of often ideologized propaganda are punctually refuted by scientific studies, as demonstrated recently (Meyer et al. 2021) by the FILK Freiberg Research Institute, which compared eight new materials by subjecting footwear made with genuine leather uppers and artificial materials to various tests (standardized physical tests in use for leather such as mechanical performance, water absorption, water vapour permeability, etc.). It emerged from the study that the most significant parameters of functional performance are, for genuine leather, superior in many respects to synthetic materials, of which none can simultaneously match the physical-mechanical properties of genuine leather, which is the result of the special, inimitable three-dimensional interwoven structure of collagen fibres that “have no beginning and no end” and is appropriately protected by Legislative Decree No. 68/2020, which defines it as a material of animal origin that has preserved the original intact fibrous structure (Fig. 22.1).

22.2 Historical Evolution of the Italian Tanning Industry

Italy had more than 1300 tanneries at the beginning of the last century (Truffi 1901), concentrated especially in Piedmont, Campania, and Lombardy, with approximately 13,500 workers; it owned, in 1890, 17,500,000 heads of large and small livestock and derived more than 15 million quintals of tanning vegetables (mostly barks and

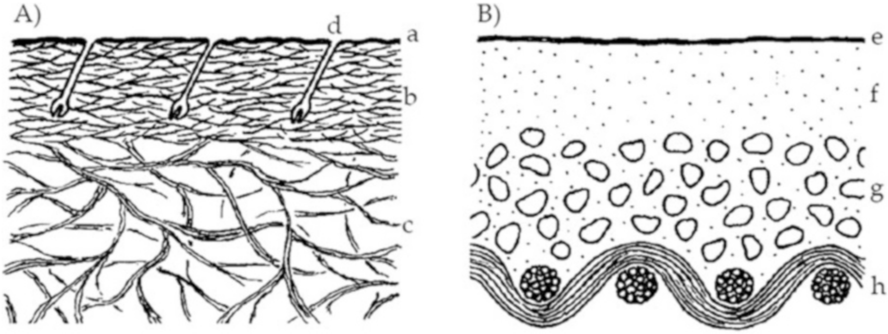

Fig. 22.1 (**a**) Leather cross-section with different densities and angles of interlacing of collagen fibres. (**b**) "Artificial leather" composite of polymer foam, fabric, surface layer of protective/aesthetic coating. (Source: Meyer et al. 2021)

sumac) from its woodland heritage. It processed nearly 60,000 tons of raw hides, approximately two-thirds of which were sourced domestically and the remainder from abroad (mostly from Calcutta, China, the Plata, and the Mediterranean coast of Africa). After more than a century, there are no substantial numerical differences: 1165 companies with more than 17,000 employees, mostly SMEs concentrated today, mainly in the tanning districts of Arzignano (Vicenza), Santa Croce sull'Arno (Pisa), and Solofra (Avellino), which together make 90% of Italian tanned leather production (UNIC 2021). Specifically, in the entire Ateco C15 division – manufacture of leather and similar articles – more than 14 thousand companies were operating in 2019, three-quarters of them micro enterprises (with less than 10 employees), 21.5% with 10 to 49 employees, and only 0.3% with more than 250 employees. Nearly 150 thousand workers in the sector (including footwear) are 40% employed in small enterprises (10 to 49 employees). They are mostly employees (84.2% in 2017), and half are women (Veronico 2021).

Over the years, on the other hand, both production technology has changed profoundly, with finished products that are merceologically highly evolved and varied, as well as the speed of production: just think of the introduction, at the beginning of the twentieth century, of chrome tanning: the patent of the American Dennis, with the "one-bath" chrome tanning is from 1893, and after a slow diffusion, due to some initial difficulties in application, it became established worldwide, so much so that it still constitutes approximately 80% of those in use today. Vegetable tanning, which at the beginning of the last century was practiced with very long and complex procedures with the available tanning vegetables simply chopped up, has also undergone profound innovations in the type of tanning agents. These are now mainly chestnut, quebracho, tara and sumac, as well as a boundless array of evolved "synthetic" auxiliary and substitution tannins, which are traded almost exclusively in the form of concentrated extracts, including vegetable tannin sulphited extracts. Technological innovations have also undergone significant improvements with the introduction of dynamic rather than static tanning processes, which have made vegetable tanning itself possible in a few days rather than in many weeks, as in the case of slow tank tanning. Compared to the past, the localizations and characteristics of raw hides export and supply markets, the result of upheavals (two world wars) and consequent new geopolitical arrangements, have also more or less expanded or shrunk. The UNIC Report 2021 shows that despite the difficult economic situation in the previous year, the Italian tannery, with the high added value of production, maintained its relevant role globally, being the leading European producer of finished leathers, almost exclusively bovine and sheep and goat leathers, the production of which amounted to 97 million square meters (−16.4% over 2019) and 7 thousand tons of sole leather (sole leather, vegetable-based, is traded by weight), with a total value of 3.5 billion euro (−23.1% over 2019), of which more than 70% is generated by exports. Processed hides and skins are destined for the fashion (36% for footwear, 26% for leather goods, and 4% for clothing) and upholstery (furniture 16% and car interiors 16%) sectors. Italy is, by political choices and natural characteristics, a country highly dependent on foreign countries in terms of both energy and raw materials, and even the tanning industry unfortunately does not escape this insufficiency. In fact, it is well-known that the raw material of the tanning industry is a waste product of animal slaughtering and is therefore closely related to meat production. The national livestock population and, in particular, the number of slaughtered animals cannot meet the demand for raw hides and skins of the tanning industry, and this situation is actually not new. In fact, statistics from the late nineteenth century show that the amount of imported raw hides compared to exported ones is largely higher; the same trend, although with different numbers, especially in terms of productivity related to tanning technological evolution, both in tanning processes (fast chrome tanning vs. slow vegetable tanning) and in the level of automation, especially in mechanical operations (fleshing, trimming, etc.), can be seen in more recent statistics, as in the following table (Table 22.1).

The leadership position of the Italian tanning industry, which contributes to 23% of the global value of finished leathers produced worldwide, is the result not only of a recognized superiority of the prestige of Made in Italy but also of a farsighted and

Table 22.1 Historical trend of import/export of raw, tanned, and glove leather in Italy

Year	Raw hides (metric tons)		Tanned hides (metric tons)	
	Import	Export	Import	Export
1876	13,926	2019	1630	771
1896	21,120	8260	2150	850
2017	171,390	49,713	198.075 (semifinished leathers 181,653 + 16,422 finished)	144.366 (semifinished leathers 85,696 + 58,670 finished)
	Pairs of leather gloves			
	Import	**Export**		
1876	14.700	2.626.300		
2017	12.357.166	1.339.747		

Sources: Freely taken from Truffi (1901) and UNIC (2017) courageous strategy of entrepreneurial investments in quality, minimization of environmental impact, and continuous research of more sustainable tanning processes. However, every effort aimed at sustainability is, unfortunately, thwarted by the reduced availability of raw material and the industry of the sector for several decades. Additionally, to avoid the most environmentally burdensome processing steps, tanners prefers to import semifinished products (Wet Blue).

22.3 Current Situation and Future Perspectives

The war in Ukraine, and its disturbing long-term prospects, is likely to further exacerbate the atavic raw material requirements (crude and semi-finished) of Italian tanneries, which have already been plagued by years of competition, sometimes unfair, made up of tariff barriers and limitations of various kinds that have taken, especially in recent years, much raw hides from the free market. Foreign supply of raw material accounts for more than 90% of the needs of Italian tanneries, and the conflict area accounts for approximately 3.5% of total purchases from abroad. Ukraine itself is one of the main suppliers of semifinished leather; including Russia and Belarus, Italian purchases of raw and semifinished leather account for 70% of the total, while exports of Italian finished leather to these countries account for only 1% of the total. The international market for raw hides and skins, especially cattle and sheep and goats, is extremely fluid and complex as well as particularly sensitive to a multiplicity of situations that cannot be easily managed or predicted: industrial, geopolitical, technological, social, and environmental. The series of crises, not only political and commercial, just to mention the most recent ones, which preceded the current one, is worth mentioning as an example:

- 2014, Russian annexation of Crimea with mutual sanctions Russian Federation/European Union
- 2018, US/China trade war with exchange of major tariff sanctions
- 2020, widespread lockdown due to the COVID pandemic

Without coming to any definitive conclusions, there has been an attempt to understand the effects on international trade, which, in essence, seems to have hurt both sides of the dispute but, more importantly, consumers, and this should make people think about the consequences of applying trade sanctions. It has thus gone on to paroxysmally exacerbate a tense situation already present in the leather market, which, moreover, is already struggling due to competition from low-quality, low-priced substitutes. So worrisome is the situation that the Unione Nazionale Industria Conciaria (UNIC), in agreement with the European trade confederation Cotance (Confederation of National Associations of Tanners and Dressers of the European Community), has asked the European Commission to limit the export of European raw/semi-processed hides outside the EU borders to protect the European tanning industry against that of its main non-EU competitors (China, Brazil, Argentina) with greater availability of raw material, which can take advantage of the economic consequences of the war. This is clearly an extreme measure that conflicts with the rules of the free market and is justifiable only in situations of absolute emergency, such as the one we are currently experiencing, which is likely to worsen. Certainly, with the current uncertain geopolitical situation and with the disturbing trend toward bipolarization into blocs, the unavailability of raw material, on the one hand, and the restriction of export markets, on the other, are superimposed on the creeping economic raw hides war that has been going on for many years, not always correctly, with tariff barriers and other non-customs obstacles, has taken considerable quantities of raw and semi-processed hides and skins away from the free market, particularly because of the industrial emancipation policies of emerging or already emerged countries that tend to export less and less raw and more and more finished or semi-processed hides and skins. Among other things, raw hides and skins even if preserved (green salted, dry salted, etc.) do not lend themselves by their nature to excessively long storage periods, thus preventing the possibility of strategic storage, and the same is true for tanned hides and skins. In the face of such a disturbing scenario, there is a clear need to adopt countermeasures projected over the medium and long term, providing, with renewed impetus, adequate investments and increasingly implementing the principles of circular economy and technological innovation to the leather industry. Additionally, because of the geopolitical scenarios on the horizon, coordination first and foremost between UNIC and Italian Tanneries and the European Confederation of National Trade Associations, COTANCE (Confederation of National Associations of Tanners and Dressers of the European Community), will be crucial to propose in the EU an integrated management of the availability of both EU and non-EU accessible raw hides and skins, as well as of energy and water resources, with the Italian tanning leadership not as an antagonistic element but rather as a dragging element of the entire European tanning supply chain: in short, the protection of the Italian tanning industry as the driving force and model of an ever deeper and ever more imperative European integration.

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Chapter 23
Risk Assessment and Life Cycle Approach to Optimize the Sustainability Performance of Leather Products

Anna Mazzi and Melissa Paganin

Abstract The use of chemicals in tanning companies represents a relevant risk for the health and safety (HS) of workers, and risk assessment (RA) is essential for companies to adopt preventive and protective measures to reduce the risks. At the same time, from a market perspective, companies are increasingly interested in demonstrating their sustainability through environmental impact reduction: the life cycle (LC) approach permits the consistent quantification of the environmental footprint of products. Generally, RA and LC are not integrated by companies. The research aims to define an ad hoc methodology that integrates LC and RA for the quantification of HS risks related to processes and products. The methodology is tested in assessing the performances of two leather products realized by an Italian company through identification and evaluation of HS risks associated with LC steps of production. The results demonstrate that the integrated use of RA and LC is effective both to punctually know the HS risks associated with production activities and to compare the performances of different products in terms of the dangerousness of substances and processes used.

Keywords Life cycle approach · Risk assessment · Leather products · Dangerous chemicals · Environmental performance · Health and safety performance

23.1 Introduction

In recent decades, companies have become increasingly interested in reducing the impacts of products with the life cycle approach and preventing accidents through risk management. Life cycle assessment (LCA) and risk assessment (RA) represent the main methodologies to support companies in analysing and evaluating the environmental impacts associated with products and the health and safety risks associated with processes, respectively (Karanikas et al. 2020). The international

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community has defined ad hoc standards to guide organizations in implementing LCA and RA. ISO 14040 defines four steps to conduct an LCA study: goal and scope, life cycle inventory, life cycle impact assessment, and interpretation of results (ISO 2020). To conduct RA, three steps are defined by the ISO 31000 standard: risk identification, risk analysis, and risk evaluation (ISO 2018). Even if LCA and RA refer to different aspects of business management, their integrated use is recommended by standards and scientists to simultaneously reduce the environmental, health, and safety (EHS) risks associated with processes (Mazzi et al. 2017; Toniolo et al. 2019). Three main solutions can be used to integrate LCA with RA (Flemström et al. 2004; Barberio et al. 2010; Mazzi et al. 2013):

(i) RA to support LCA: RA can be used as a subset of LCA to support the inventory or impact assessment step.
(ii) LCA to support RA: Alternatively, LCA can be realized as a subset of RA to support risk identification or analysis.
(iii) Integrated discussion of results: LCA and RA are carried out in an independent way, and their results are compared in the final discussion.

The research aims to design and test an innovative methodology to integrate LCA and RA to evaluate the EHS risks associated with products along LC stages of production.

23.2 Material and Methods

23.2.1 New Methodology to Integrate LCA and RA

In this research, a new methodology is designed in which the integration between LCA and RA is obtained by an integration of each LCA phase and RA step, although the adoption of LCA as the framework and RA as the algorithm. Named "life cycle risk assessment" (LC-RA), the new methodology integrates the steps of LCA and RA in one assessment method, in which RA supports LCA and LCA completes RA, to obtain a complete EHS risk assessment and consequently to improve the EHS performance of processes.

LC-RA methodology includes four steps:

1. The LC-R goal and scope define the expected results of the study, the life cycle stages to be included and the EHS risks being considered.
2. LC-R identification of risks during life cycle stages takes inventory potential EHS risks of raw materials and manufacturing processes.
3. LC-R analysis consists of quantification of the effects of each EHS risk through ad hoc RA eqs.
4. LC-R performance evaluation concludes the analysis through the assignment of the EHS risk index for each LC stage of products.

23.2.2 Case Study

To apply our research, the case study is an Italian tanning company that is a leader in the leather products market. Located in northern Italy, it has four production sites, and 90% of its production is destined to export. The tanning processes recover and transform rotting skin of animals into hygienic, breathable and resistant products. To test the methodology, two products are selected: top-quality leather products, realized by the Italian company and sold to the luxury automotive market, processed with two main important tanning procedures.

Product A is realized with Wet Blues leather, made from chrome tanning processes.
Product B is realized with Wet White leather, made from vegetable tanning processes.

23.2.3 Application of LC-RA Methodology in the Case Study

The LC-RA methodology includes the following key aspects:

- The equivalence of product systems for products A and B is needed to ensure a comparison of the results.
- Chemical risks associated with internal activities in tanning processes must be quantified to permit consistent results.
- Legislative requirements and limits must be considered in EHS risk evaluation through cause-effect analysis.

The goal of the LC-RA study is to compare the LC-R performances of products A and B based on EHS risks associated with internal activities with chemical substances and mixtures. To assure the equivalence in comparison, the functional unit is defined as the production of one square meter of finished product in black colour. Consistent with the goal and functional unit of LC-RA, internal processes using chemicals are considered in the scope of LC-RA. To define the boundaries of LC-R study, operations of manufacturing, transformation, transport, and storage of products are considered. As represented in Fig. 23.1, internal processes are included in the boundaries, while external processes—of suppliers or in outsourcing—are excluded. Moreover, all processes using chemicals are included in the study, while mechanical processes without chemical risks are excluded because they are not relevant to the goal.

To identify and quantify the EHS risks, through an in-depth analysis of processes, the framework represented in Fig. 23.2 is adopted. The risks of each LC phase are derived from the risks of the processes included in the phase. In turn, the risk of each process derives from the risks of activities carried out in processes. The risk index of activity depends on risks associated with substances and mixtures, which in turn depends on the hazard of substances and exposure level. In LC-R identification and analysis, algorithms reported in Table 23.1 are applied to quantify, for each

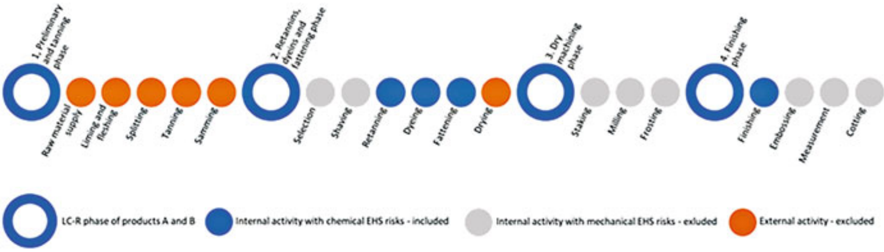

Fig. 23.1 System boundaries of the LC-RA study

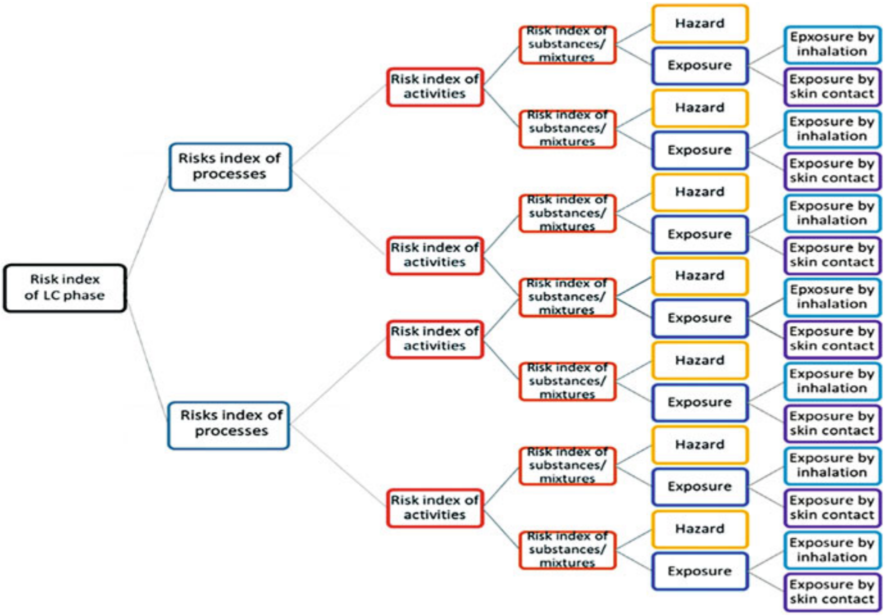

Fig. 23.2 Framework for LC-R identification and analysis in the case study

substance/mixture, hazard, and exposure, and to obtain for each activity and process the final EHS risk index.

In the fourth step, the EHS performance of products is evaluated by using the evaluation matrix in Table 23.2, in which EHS risk index values are distinguished into five categories with related risk evaluation.

Table 23.1 Algorithms adopted to quantify the risk index in the case study

Component of LC-R index	Algorithm
Risk index of LC phase	$R_{\text{LC phase}} = \sum R_{\text{LC processes}}$
Risk index of LC process	$R_{\text{LC process}} = \sum R_{\text{activities}}$
Risk index of activity	$R_{\text{activity}} = \sum R_{\text{substance/mixture}}$
Risk index of sub-stance/mixture	$R_{\text{substance/mixture}} = H \times E$
Hazard index	$H = f_1$ (hazard factors)
Exposure index	$E = \sqrt{E_{\text{inal}}^2 + E_{\text{skin}}^2}$
Exposure index by inhalation	$E_{\text{inal}} = f_2$ (substances factors)
Exposure index by skin contact	$E_{\text{skin}} = f_3$ (substances factors)
f_1 (hazard factors)	Acute toxicity, skin corrosion or irritation, serious eye damage or eye irritation, respiratory or skin sensitization, specific target organ toxicity, dangers for aquatic environment
f_2 (substances factors) f_3 (substances factors)	Chemical-physical characteristics, quantities and concentration in use, conditions and procedures of use, possibility of dispersion, protective measures adopted, exposure time, distance from source

Table 23.2 LC-RA matrix

R = H x E	Risk level	Actions to be implemented
$0.1 \leq R < 15$	Irrelevant risk	No actions
$15 \leq R < 21$	Non negligible risk	Risk treatment can be improved
$21 \leq R < 41$	Medium risk	Adequate measures must be added in medium term
$41 \leq R < 81$	High risk	Urgent reduction measures must be taken
$R \geq 81$	Serious risk	Immediate drastic measures must be taken

23.3 Results

Table 23.3 summarizes the results obtained by LC-R identification and analysis related to products A and B. Activities using dangerous substances are more numerous in the LC of product B than in the LC of product A. Risks associated with activities in the LC of product B are more relevant than those in the LC of product A. Few activities have achieved a medium risk index (orange) in both products A and B, and no activity achieved a high or serious evaluation. In general, product A has better performance since compared to product B, the finishing phase has several dangerous activities.

Table 23.3 Results of LC-RA related to products A and B

		Product A		Product B	
N. activities with substances/mixtures	N. Rsubstances/mixtures quantified	*277*	*100%*	*379*	*100%*
N. activities with "irrelevant risk" (green level)	N. Rsubstances/mixtures < 15	*244*	*88.1%*	*315*	*83.1%*
N. activities with "Non-negligible risk" (yellow level)	N. 15 ≤ Rsubstances/mixtures < 21	*30*	*10.8%*	*39*	*10.3%*
N. activities with "Medium risk" (orange level)	N. 21 ≤ Rsubstances/mixtures < 41	*3*	*1.1%*	*25*	*6.6%*
N. activities with "High risk" & "Serious risk" (red and amaranth levels)	N. Rsubstances/mixtures ≥41	*0*	*0%*	*0*	*0%*

In comparing the number of activities with non-negligible risks (yellow level) and medium risks (orange level), as represented in Fig. 23.3, both in products A and B, most of the non-negligible risks are in finishing, related to the processes "loading in pirovan", "mixing", and "mixture preparation". In terms of medium risks, product B has the worst performance: most medium risks are in phase 2, such as "weighing of chemicals" and "introduction of chemicals into drum".

23.4 Discussions and Conclusions

The research demonstrates the possibility and relevance of integrating LCA and RA through the adoption of LCA as a framework and RA as equations. The LC-RA methodology designed in this research seems able to compare the HS performance of products and their LC stages, highlighting the most critical activities and most dangerous final products. Moreover, the results of the LC-R performance evaluation support the company in reviewing risk treatment measures and improving consciousness of safe behaviour. The adoption of the LC approach in risk evaluation is convenient because it allows us to understand the dangerousness of activities during the processing phases. In turn, RA is useful in the LC perspective to compare the EHS performances of products and motivates both management and workers to increase their commitment to reduce risks. On the other hand, our research suffers two main limitations. First, only chemical risks are quantified in LC-RA, while mechanical processes are not quantified at all. In addition, only internal processes are included in the boundaries, while outsourced processes are excluded. Other research perspectives can be suggested. The LC-RA methodology must be integrated by mechanical risks. Moreover, the boundaries of LC-RA research should be expanded to include external dangerous processes. Future research will also test this

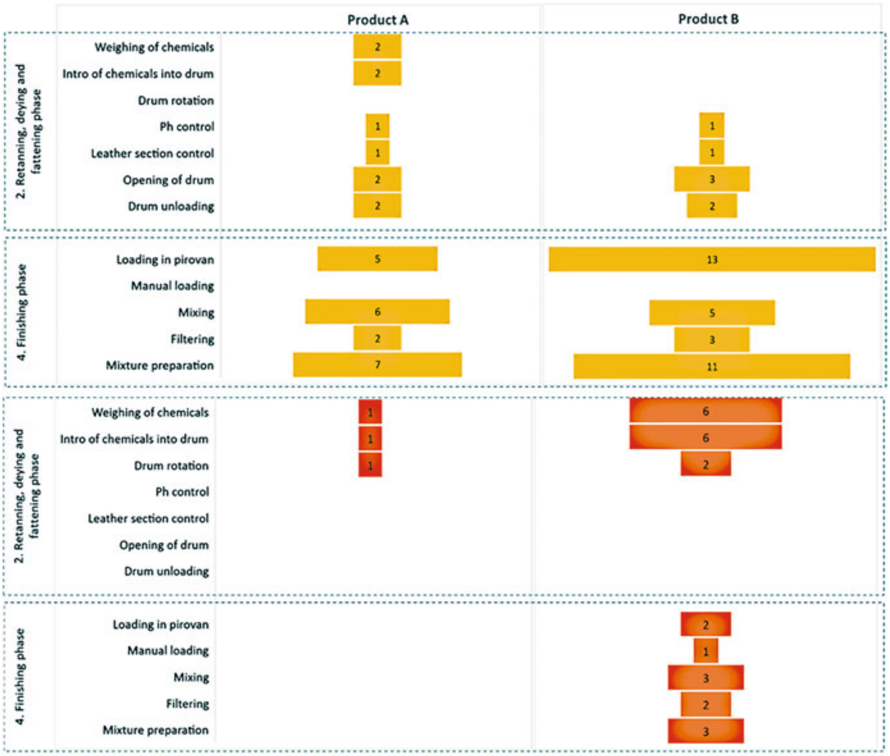

Fig. 23.3 Comparison of LC-RA results: number of activities with non-negligible risk (yellow) and medium risk (orange) per product

methodology in other industrial sectors, with the aim of verifying its validity in more complex products and more dangerous processes.

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Chapter 24
A Combined Economic-Environmental Assessment of an Innovative Chemical Formulation for Waterproofing Applications in the Leather Manufacturing Industry

Enrica Vesce, Rosalia S. Evola, Carlo Ingrao, Annarita Paiano, Giovanni Lagioia, and Riccardo Beltramo

Abstract Industry is proven to be one of the most contributing sectors in terms of soil and water degradation, water and energy consumption, emission of greenhouse gases, and other polluting compounds. Hence, sustainability issues of industrial products are gaining the increasing attention of practitioners, scientists, academia, company owners, policy and decision-makers, and other stakeholders, so much so that those issues are increasingly being placed at the centre of policy agendas and research projects, both on the local and the global scale. In a recent project, attention was focused by the authors of this paper on waterproof agents, with the aim of replacing highly environmentally damaging substances such as perfluoroalkyl substances (PFAs), which, in fact, have been included on the list of persistent organic chemicals by the Stockholm Convention. In this context, the goal of this paper was to analyse the relevant environmental and economic issues associated with an innovative silica-based formulation through application of life cycle assessment (LCA) and life cycle costing (LCC) according to the specialized standards and technical guidelines. This study is conducted in the field of those projects to contribute to enhancing the literature and the knowledge on the important need for implementing sustainable, innovative paths of producing chemical compounds and products for usage in the leather manufacturing industry. Through their study, the authors highlighted that the major environmental and economic hotspots stay in the production of the raw-material requirements for waterproof formulations, which

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demands priority in the identification of the improvement potentials. Doing so can make it possible for the company to understand, already on the lab-scale dimension, where and how innovation solutions can be effective in enhancing the economic and environmental sustainability of its chemical products. This paper also represents the first step towards sustainable material solutions to replace PFAs, thereby favouring greening not only of the chemical industry but also of the leather manufacturing industry.

Keywords LCA · LCC · PFA · Waterproof agents · Leather sector

24.1 Introduction

Raw hides and skins are food-animal slaughtering by-products. The renewability and biologic nature of these raw materials recovered from slaughterhouse wastes make the leather sector part of the avant-garde in the transition towards a circular economic system (UNIC 2020). There are, however, some criticalities about the impact on the environment arising from the leather tanning process that need to be addressed and solved, both regarding resource deployment and the release of liquid, solid, and gaseous emissions. In fact, leather manufacturing – beamhouse, tanning, posttanning, and finishing operations (Black et al. 2013; China et al. 2020) – involves a huge quantity of chemicals, water, and energy, resulting in significant impacts on the aquatic, terrestrial, and atmospheric environments (Dixit et al. 2015; China et al. 2020). Regarding chemicals, Sawalha et al. (2019) observe that tanneries consume approximately 130 types of chemicals, many of which are considered dangerous for the environment and human health (Dixit et al. 2015). Looking at international regulation, Annex XIV of REACH lists 59 substances of very high concern (SVHCs) that must be subject to special authorizations for their manufacture and trade: more than 48% of those substances are involved in the leather manufacturing industry. It is therefore clear that the sustainability of the tannery production system is influenced by the supplying chemical industry (Ingrao et al. 2021a). The choice of chemicals to be applied during tannery operations depends upon the technologies used and the characteristics of the finished leather to be obtained (Ingrao et al. 2021a). Therefore, the role of the specialty chemical industry is fundamental to meet the demands of tanners in terms of environmental sustainability. This contribution is inserted in this context: it develops from the collaboration between the University of Turin and supply chain companies in the leather sector in a project with the aim of developing an innovative waterproof nano-based formulation for finishing applications in substitution for perfluoroalkyl-based formulations. Perfluoroalkyl substances (PFASs) have historically been manufactured since the 1950s for a variety of applications, i.e. firefighting foams, cosmetics, food packaging, coatings for textiles, and leather. Their release into the environment represents, however, a global concern (Wang et al. 2017; Higgins and Field 2017; Xiao 2017), which has also affected northeast Italy, where part of the population has been exposed to contaminated drinking water (Pitter et al. 2020). In fact, PFASs are characterized by high persistence and water solubility, which determine long exposure times and diffusion over long distances; moreover, PFASs are hazardous for living organisms due to their toxicity and bioaccumulative properties (Ahrens and Bundschuh 2014; Wang et al. 2017; Higgins and Field 2017; Xiao 2017). The release of these harmful substances in the environment can occur at every stage of their life cycle (Ahrens and Bundschuh 2014). As illustrative, in the tannery field, it comes to the phases of production and processing (Pitter et al. 2020) into other intermediate or finished chemical products, in the phase of application (e.g. wastewaters of the tanneries), and during the use and disposal of the product in which they were applied (e.g. waterproof leather commodities). To propose a more sustainable alternative to PFASs, an innovative chemical based on nanomaterials was developed. Nanomaterials are considered an emergent keystone technology for more sustainable growth (OECD 2013; EC 2015), and the scientific literature indicates that different types of nanomaterials are currently being investigated as highly promising materials for various applications, including leather treatment (Ingrao et al. 2021a). In this context, the Department of Management research group has carried out a life cycle environmental and economic assessment of innovative nano-based formulations at the pilot plant scale. In the subsequent materials and methods section, the life cycle tools used for assessment are introduced, while in the discussion section, the environmental and economic impacts are separately examined. This contribution, in addition to Ingrao et al. (2021a), enriches the current literature on the evaluation of nanochemicals specifically designed for leather applications and further highlights the importance of conducting a performance assessment at the early stage of industrialization when it is still possible to have a wider margin of improvement.

24.2 Material and Methods

24.2.1 Description of Processes

The system under investigation involves two phases of the leather commodity supply chain: specialized chemical production and tannery operations. In particular, waterproof formulation manufacturing and its application to leather in tanneries were evaluated at the pilot plant level. The principal component of the new formulation is a synthetic silica subjected to chemical surface post-treatment, chosen in the design phase as an alternative to PFAS-based formulation. The surface functionalization allows us to obtain a hydrophobic material to be used to impart water repellence in coatings and plastics. The final waterproof formulation is obtained by mixing silica with other intermediates along different continuous phases using a mixing machine. Then, the formulation is manually mixed with other chemicals during finishing tannery operations. The technology used for chemical mixture application in the finishing phase allows mechanical swabbing of chemicals on leather, ensuring a homogenous dispersion of hydrophobic materials.

24.2.2 Environmental Assessment

The evaluation of this new formulation's environmental sustainability was conducted using the life cycle assessment methodology according to the International Standards 14040 – 14044 (ISO 2006, 2018). Therefore, the analysis was developed by implementing four phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation. The goal of the analysis is the identification of the environmental hot spots along the life cycle of the investigated new product before the industrialization stage with the scope to provide feedback to companies to improve their performance. The first phase also includes the functional unit (FU) definition and system boundary delimitation. The assessment is a cradle-to-gate study: the system includes raw material manufacturing and energy production, transport, waterproof formulation, and other auxiliary manufacturing at the chemical company and their application in tannery (Fig. 24.1). The last two subsystems constitute the foreground system for which the inventory data were directly collected in the field. The FU representative of the system was chosen in agreement with the company technicians and was identified in a 20 ft^2 of waterproof finished leather final output of tannery finishing operations. The second phase consists of the input and output quantitative compilation for every process unit in which the system was divided. The life cycle inventory compilation was conducted by combining primary data directly collected with secondary data extrapolated from the literature and recognized databases. The research team was supported by Scatol8® in energy data collection, which contributed to the increased reliability of the results achieved. In particular, through a sensor network, it was

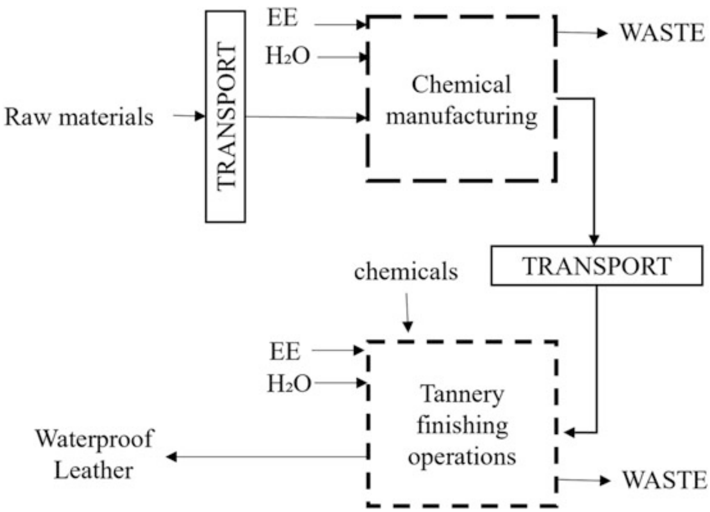

Fig. 24.1 System boundaries considered in the cradle to gate study of production and application of the new chemical formulation

possible to directly detect the real electricity consumption by machinery involved in manufacturing processes (Ingrao et al. 2021b). Subsequently, on the basis of LCI, a life cycle impact assessment was carried out. For this study, the endpoint approach was chosen, and the Impact 2002+ method (Jolliet et al. 2003) was applied.

24.2.3 Economic Assessment

In addition to environmental assessment, life cycle costing (LCC), traditionally considered the economic counterpart of LCA (Klöpffer 2003), was carried out. Currently, the scientific literature includes various contributions on LCC, but despite the importance of these tools for the life cycle sustainability assessment framework (LCSA) (Klöpffer 2003), a unique definition and methodology has not yet been consolidated. For this research, LCA-type LCC assessment (Notarnicola et al. 2009; Schau et al. 2011; Settanni et al. 2011) was considered the most suitable to evaluating physical life cycle products in economic terms and, at the same time, to taking into account the focal company point of view. To align with environmental analysis, the authors refer to the same general framework. Therefore, economic analysis was articulated in the following steps: goal and scope definition, economic life cycle inventory, life cycle cost assessment, and interpretation. The contents of the first phase were coherent with the LCA setting. Goal and scope are translated in economic terms, while the boundaries of the system are restricted only to the foreground system. In the second phase, the identification of economic flows for the feed economic life cycle inventory starting with the physical inventory compiled for LCI (Schau et al. 2011) was carried out. A computational structure for LCC was implemented; in particular, physical input and output flows related to the foreground system are characterized in economic terms and referred to FU through the application of matrix algebra rules. Then, for every process unit included, the costs were assessed. In the interpretation final phase, consideration about value added concept was recalled as reported by Moreau and Weidema (2015) with the aim of supporting the clarification of LCC definition.

24.3 Results and Discussions

The results of the environmental damage calculation conducted according to Impact 2002+ (Jolliet et al. 2003) are shown in Table 24.1. Assessment of environmental impacts associated with the product system investigated reveals that the most impacting phase is represented by the first finishing operation conducted in the tannery. In particular, considering all processes as the upstream phases connected with energy and raw material, the finishing phase impact derives from the production of raw material composing the chemical mixture used. Moreover, the results expressed in terms of damage category showed that the consumption of natural

Table 24.1 LCA and LCC results for every phase associated with the production of the waterproof formulation necessary to obtain 20 ft^2 of waterproof finished leather

	LCA	LCC
Phase	Weighing points (mpt/FU)	Cost outputs (€/FU)
Waterproof formulation	20.48	6.7
1° step finishing	59.05	0.02
2° step finishing	9.01	0.036
3° step finishing	11	0.037
Total	99.54	–

resources, human health, and climate change represent 92.88% of the total damage associated with the manufacturing and application of new formulations. Therefore, it is precisely in the chemical production phase that efforts must be concentrated on identifying more sustainable alternatives, e.g. an appropriate choice of intermediate by a chemical company would determine an increase in the environmental sustainability level associated with the whole leather supply chain. From the economic perspective, research was focused on a cost description to reveal the black box of leather manufacturing. Starting with the economic life cycle inventory, which provides an overview of the activity and resource drivers of the product system analysed, the life cycle cost assessment of 20 ft^2 of waterproof finished leather was implemented. First, the physical inventory was balanced according to a production plan associated with FU. Then, the direct variable costs of materials and energy and the unit cost of outputs were calculated for each process unit composing the physical life cycle of formulation in the chemical plant and in the tannery. The life cycle costing results are represented in aggregate form by the unit cost of output of every phase shown in Table 24.1. These values were obtained through matrix algebra by adding the direct variable costs of the phase with the cost of inputs acquired from other process units. The identification of economic flows through this computational structure at different levels of disaggregation, i.e. for phase and single process units, is very useful for decision support. In fact, these economic values reflecting the physical life cycle of formulation detected during the pilot plant phase provide to the company an adequate basis for definition of the product selling price.

As opposed to LCA, the authors chose not to present an aggregated cost result as the final interpretation of economic sustainability. In fact, the simple sum of the cost along the life cycle phases of innovation would incur double counting, e.g. the cost of waterproof formulation is incorporated into the cost of finishing operations. The focus on value added as the difference between the value of the goods produced and the value of the resources necessary for its generation allows us to avoid economic impact accumulation from a life cycle perspective (Moreau and Weidema 2015). Therefore, the authors agree with the definition provided by Moreau and Weidema (2015), who define the LCC as the sum of the value added along the phases of the product supply chain. For this study, it has only been possible to accurately calculate the value added for the formulation manufacturing phase and, therefore, to reveal only a part of economic value creation.

24.4 Conclusions and Future Perspectives

This contribution is part of a research aimed overall at exploring the feasibility of producing sustainable tanning and finishing products for leather finishing. The need to preserve ecosystems and human health from the hazardous effects of PFAs boosts companies to search for other types of performing resources, as in this case in the field of nanomaterial technologies. In this context, through environmental and economic assessments, the possible impacts of the new waterproof formulation have been identified before its life cycle is active. Therefore, the analysis conducted at the pilot plant level allows us to investigate further margins of sustainability improvement before full industrialization. Based upon the findings of the study, chemical manufacturing emerges as an important environmental hot spot: the results suggest searching for alternative intermediates to combine with less harmful innovation. To investigate the economic aspect of product sustainability, the industrial costs associated with the innovation life cycle were calculated through a computational model from which strategic information on cost structure was extracted to support company cost management. In addition to Ingrao et al. (2021a), the research enriches the knowledge on nanomaterial innovations for leather manufacturing at the first development stages, promoting a multifunctional evaluation through the LCSA framework. Nevertheless, this contribution will be subject to future developments: open questions emerge alongside the assessments, which provides a first response on innovation sustainability. First, comparative studies of products containing PFAs with extensions of the system boundaries to the EoL phase will be conducted to better validate their replacement. Instead, from a methodological point of view, it is necessary to deepen a standardization methodology for LCC and the integration methods of the life cycle tools to provide an overall reliable representation of product sustainability.

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Part V
Circular Economy and Sustainability Issues in Several Sectors: Mobility, Logistics and Transports

Chapter 25
Mobility Environmental Profile in the Framework of a Research Project: The "CRESTING" Case

Ioannis Arzoumanidis, Federico Carboni, Anna Maria Walker, and Andrea Raggi

Abstract Scientific conferences can be significant for knowledge sharing, networking, debates, and the development of new ideas/projects and solutions for scientific research. However, the resource demands of such activities and the environmental impacts connected to them are usually neglected. One of the major environmental aspects in conferences is related to the participants' transport, with life cycle assessment (LCA) being one of the methodologies used to assess them. This study considered the European research project "CRESTING" and the participation of early-stage researchers (ESRs) in conferences/workshops in the countries involved in the project. The analysis assessed the travels made by the ESRs by means of LCA software. The results obtained for one of the impact categories (climate change) were then compared for one of the participants to the ones provided by four travel carbon emission calculation tools to assess their robustness. The results demonstrated that the main contributor to the overall climate change-related impact was air transport (mainly intercontinental). Furthermore, the impact categories of Marine Ecotoxicity and Human Carcinogenic Toxicity were also found to be mostly influenced (due to air transport). Finally, not all simplified tools provided similar results to those calculated by the full LCA software.

Keywords Life cycle assessment · Environmental sustainability · Emission calculation tools · Travel

25.1 Introduction

The importance of scientific conferences is undoubtedly great for knowledge sharing, networking, scientific debates, and the development of new projects, ideas, and solutions for scientific research (Neugebauer et al. 2019). However, what is usually

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neglected is the resource demands of such activities as well as the environmental impacts connected to them (Holden et al. 2017). The importance of sustainability in the events industry was highlighted by the International Organization for Standardization (ISO), which has published ISO 20121:2012 on sustainable event management containing requirements and guidelines (Arroyo-Rodríguez et al. 2014). One of the major sustainability aspects in conferences is the environmental impacts related to the participants travelling to the conference venue and back home, with life cycle assessment (LCA) being one of the methodologies used to identify and assess such impacts (Hischier and Hilty 2002; Neugebauer et al. 2019). For this reason, this study is the first to take into consideration a European research project "CRESTING" (CRESTING 2022), which included the participation of early-stage researchers (ESRs) in conferences worldwide and workshops that took place in the various countries involved in the project and not just a conference as in already existing studies. The analysis focuses on assessing the travel made by the ESRs by means of an LCA implementation, and the results obtained for one of the impact categories (climate change) are subsequently compared (for one of the participants) to those provided by four travel carbon emission calculation tools that can be found on the internet to assess their robustness (Carboni 2021).

25.2 Materials and Methods

CRESTING (CiRcular Economy: SusTainability Implications and GuidING Progress) represents an innovative training network supported by the European Union as part of the Horizon2020 Marie Sklodowska-Curie Actions programme, started on 1 January 2018 and ended on 31 December 2021. In the framework of this project, the movements of the 15 ESRs involved in the project concerned mainly their participation in conferences (52.7%), workshops (22.7%), field research (7.9%), and summer/winter schools (1.8%), mainly up until the COVID-19 pandemic outbreak. Table 25.1 shows the distance travelled per means of transport (38.15% in Europe – mostly in the UK, France and Portugal – and 61.85% elsewhere).

For the LCA/simplified LCA studies, the functional unit (FU) was defined as the mobility of the ESRs of the CRESTING project for project-related purposes (from 21 September 2018 to 28 July 2020), excluding other phases of attending a conference/event, e.g. preparation and execution (please refer to Fig. 25.1). The full LCA

Table 25.1 Distance travelled per means of transport

Means of transport	Travelled distance (km)
Plane	549,962
Train	83,957
Coach	9102
Car	3649
Ferry	1506
TOTAL	648,176

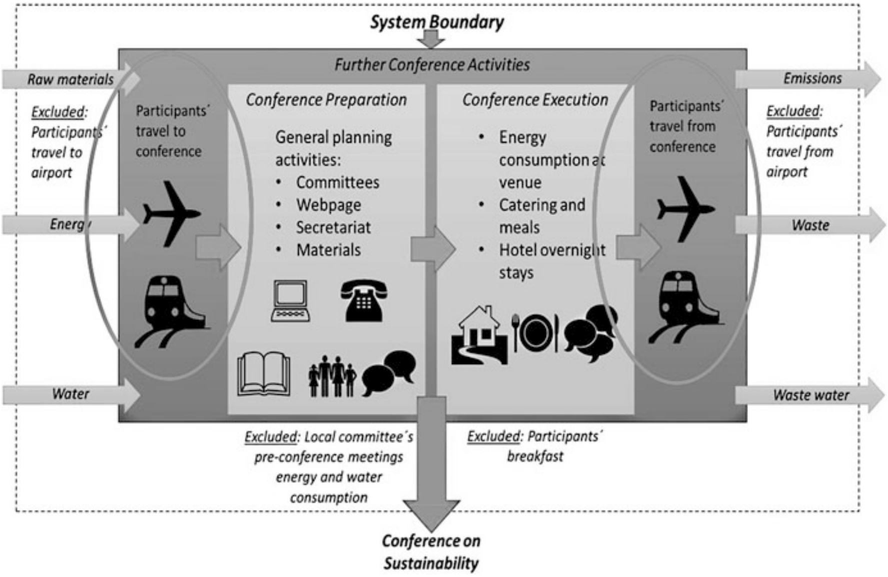

Fig. 25.1 System boundary (indicated in the two circles). (Source: Carboni 2021)

study was carried out by using SimaPro v.9.1.1 software (Pré 2022) and ReCiPe 2016 Midpoint (H) as the Life Cycle Impact Assessment (LCIA) method (Huijbregts et al. 2017). The simplified LCA analysis was carried out for one ESR, as a representative, by means of the following four carbon footprint (CF) calculation tools: CarbonFootprint (2022), MyClimate (2022), EcoPassenger (2022), and ICAO Carbon Emission Calculator (2022). The selected ESR was the one that came closer to the average of parameters, such as time spent travelling, kilometres travelled, countries visited, and type of vehicle used. Finally, it is to be specified that primary data (distance and means of transport) were acquired only regarding the ESRs, not the supervisors, who also joined many of the trips. The associated processes were obtained from Ecoinvent, while attention was given when selecting the most similar one to the means of transport chosen.

25.3 Results and Discussions

With regard to the full LCA implementation, the characterization results of the Life Cycle Impact Assessment (LCIA) phase (Fig. 25.2) demonstrated that for almost all environmental impact categories, air transport had the greatest influence. However, for water consumption, the most impactful was transport by car and transport by train for freshwater eutrophication as well as for land use and mineral resource consumption (although closely followed by air transport in the last two cases).

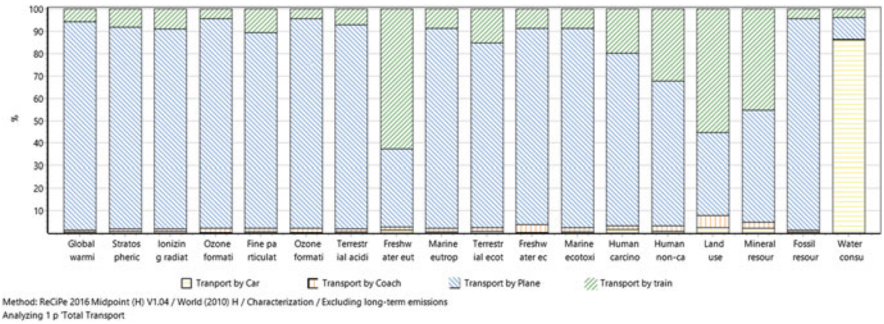

Fig. 25.2 Characterisation results. (Source: SimaPro software)

Table 25.2 Mass of CO_2eq by different calculation tools for the most relevant means of transport

	SimaPro	CarbonFootprint	EcoPassenger	MyClimate	ICAO
Plane intercontinental	1454.56	3700	N/A	2900	791.9
Plane intracontinental	3724.15	3130	5628	4592	2533.9
Train France	0.03	60	28.7	N/A	N/A
Train Germany	0.03	10	10.8	N/A	N/A
Train Austria	163.9	105	48.9	N/A	N/A
Train RoW	0.24	150	27.2	N/A	N/A
Coach	58.04	150	59.4	426	N/A
Car	33.46	30	20.1	63	N/A
TOTAL	6581.67	7295	5823.1	7981	3325.8

In regard to the normalization results, it was found that marine ecotoxicity, followed by human carcinogenic toxicity and terrestrial ecotoxicity, was the most affected impact categories (all of them due to air transport). The carbon footprint/global warming category was not among the most affected categories. However, given the objective of this study, a more detailed analysis showed that for this category, air transport also affected it the most. Regarding the same impact category, the analysis performed with the simplified LCA tools confirmed that plane transport was the most impactful (Table 25.2). A comparison of the emission data to assess the robustness and precision of such tools along with the SimaPro results was also carried out (please refer to Table 25.2). It can be noted that for the CarbonFootprint and MyClimate tools, the value of air transport is somewhat similar (indeed, the former calculated 6830 kg of CO_2 eq emitted, while the latter 7492 kg of CO_2 eq emitted, which are both higher than the SimaPro result, equal to 5178 kg of CO_2 eq emitted). As far as the ICAO tool is concerned, this one shows a much lower value than the previous; indeed, it calculated 3326 kg of CO_2 eq emitted. Finally, for the EcoPassenger tool, it was impossible to compare the results due to the lack of CO_2 data by intercontinental flights within the software. With regard to the emissions of rail transport, in this case, SimaPro calculated 373 kg of CO_2 eq emitted (for a total of 5812 km travelled); CarbonFootprint was the only calculation tool that was possible to compare with, given that it is the only one for which it was possible to calculate all the distances travelled by train (285 kg of CO_2 eq). Furthermore, it was not possible to compare them with the results of EcoPassenger because the emissions related to train transport in China are missing. In regard to coach transport, EcoPassenger was the only simplified tool that provided similar results to those of the full LCA (59.4 and 58.04 kg of CO_2 eq, respectively). Finally, the car transport results were somewhat dissimilar, even though of the same order of magnitude (Table 25.2). To reduce the impact of the most influential option (plane), further research is required with regard to more efficient aircraft, biofuels, and sustainable aviation fuels (e.g. Abrantes et al. 2021). Furthermore, the use of trains should be encouraged, even if that would entail higher transport costs (e.g. Kroes and Savelberg 2019). At the same time, it needs to be acknowledged that the travel time might increase and that current intra-European travel is not yet reliable enough to serve as a complete replacement of planes (ibid.). Finally, the increase in virtual participation in conferences since the COVID-19 pandemic could decrease travelling in the future (Nayak et al. 2022).

25.4 Conclusions and Future Perspectives

This study took into consideration the European research project “CRESTING”, which included the participation of early-stage researchers (ESRs) in conferences worldwide and workshops that took place in the various countries involved in the project. The analysis took into account the travels made by the ESRs (destinations, distances travelled, type of vehicle used, and time spent) and was performed by using an LCA software. The results obtained for one of the impact categories (climate change) were then compared for one of the participants to the ones provided by four travel carbon emission calculation tools that can be found on the internet to assess their robustness. As expected, the results demonstrated that the main contributor to the overall climate change-related impact was air transport, particularly intercontinental journeys. Furthermore, the impact categories of marine ecotoxicity, human carcinogenic toxicity, and terrestrial ecotoxicity were also found to be mostly influenced, once again mainly affected by the huge distances travelled by air. Finally, not all simplified tools provided similar results to those calculated by the full LCA software. This was due to differences in the way these tools performed the calculations and to the fact that they excluded countries from their databases or data for specific means of transport. This study is part of an ongoing project on measuring sustainability in the tourism sector. Future developments may include a scenario analysis for the best alternatives for travelling to events as well as the study of additional simplified LCA tools to assess their robustness. Furthermore, for this study, the international distances travelled by train were attributed to one of the involved countries. For this reason, a sensitivity analysis could be performed between the current modelled scenario and a scenario where the train travel is accounted for in all parts of distances travelled in specific countries.

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Chapter 26
University Students and Mobility. A Sustainability Analysis

Tiziana Crovella, Sara Burdi, Andrea Pontrandolfo, and Annarita Paiano

Abstract This chapter outlines urban mobility as one of the most current challenges to sustainable metropolitan mobility. In this context, university students play a central role in the issue of mobility because commuters reach their campus to attend didactic-training activities. Therefore, constant pressures are generated on the environment in terms of greenhouse gas emissions, particulate matter, consumption of natural resources, and fossil fuels. The methodological path addresses three objectives: first, to map the current university students' mobility; second, to quantify the impacts associated with their mobility in terms of greenhouse gas emissions; and third, to provide more sustainable alternatives to be implemented for the student community by stakeholders. The administration of a questionnaire survey to a sample of students that attending the Campus of Economics in Bari and the elaboration of data through statistical tools allowed the building of a database to address the objectives of the paper and to develop the basis of identification of some more sustainable alternatives for the students' mobility. The outcomes of this analysis aim to stimulate efforts towards priority areas of sustainable transformation and to expand the scientific literature.

Keywords Urban mobility · University students · Emissions · Transport · Sustainable behaviors

26.1 Introduction

Population growth in metropolitan and urban areas provokes critical issues of congestion, environmental pollution, and worsening quality of life. At the European level, the Commission has promoted the Sustainable Urban Mobility

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Plans to address unsustainable mobility policies (Sgarra et al. 2022) and other programs that affect both national and local development. Some of these consist of integrated planning approaches that analyze modes and forms of transport in cities and metropolitan areas (Niglio and Comitale 2015). At the national level, Italy has consolidated transport planning due to excellent regulatory support and the availability of guidelines for stakeholders (Orchi and Valentini 2014). Last, at a local level, Bari, which is the second metropolitan city in Southern Italy after Naples, has adopted a wide range of urban transformation solutions to discourage the massive use of private cars and to increase the achievement of sustainability. It must be emphasized that more than 70% of inhabitants of Bari still use private cars, and only 30% use public transport systems (Niglio and Comitale 2015). For this reason, the pursuit of sustainable mobility is currently one of the greatest environmental challenges that involves the population from global to local levels. In particular, approximately 33% of the population that uses transport on a daily basis consists of students; consequently, this paper analyzed the attitudes of university students towards the environment practising sustainable mobility. In particular, this study stems from the need to comprehend and improve the travel arrangements of students who attend the Bari Economics Campus in the Apulia Region. Furthermore, this analysis presents further insights underlining that the involvement of populations, clusters, and groups (such as students) stimulates the transition towards sustainable mass transport (Balsero et al. 2021; Sultan et al. 2021). In particular, universities are often located inside or close to urban areas that provide different options across multiple transport modes (Fearnley et al. 2018) and therefore present a high impact on the environment. The methodology used in this first research was the survey carried out through the use of a questionnaire online addressed to the students at the University Campus.

26.2 Literature Review

University campuses are considered *"small cities"* characterized by large size, population, and various activities provided, with different direct and indirect impacts on the environment (Alshuwaikhat and Abubakar 2008). For this reason, since the last decade, many universities have been striving to achieve full sustainability (Velazquez et al. 2006) in terms of energy used, waste, water consumed, materials used, infrastructure, and mobility promoted (Bayas Aldaz and Sandoval Hamón 2019). Furthermore, mobility to university campuses is a key factor because it represents a significant part of urban mobility and involves many stakeholders in various capacities (Longo et al. 2015). Additionally, the authors stressed that universities and campuses are institutions that train students and influence government policies at the same time. Shields (2019) highlighted that higher education could influence students' approach to environmental problems and, in particular, to sustainable mobility. In particular, universities train students who directly participate in the transformation process of a sustainable future and transition towards the circular economy (Bayas Aldaz and Sandoval Hamón 2019). In conclusion, the transition to sustainable mobility requires a mental change of people, where the use of private means gives way to different modes of public transport (such as buses, bicycles, car sharing and electric cars), as pointed out by Sgarra et al. (2022). This is the reason why this chapter investigated the sustainable behavior of university students towards mobility.

26.3 Material and Methods

26.3.1 Questionnaire Survey

Considering the models proposed by De Angelis et al. (2021), Ribeiro and Fonseca (2022), and Sgarra et al. (2022), we conducted exploratory empirical research oriented towards *"internal"* stakeholders' choices: we observed a portion of 3000 university students who attended the different courses of the Department of Economics, Management and Business Law in Bari. These observations were conducted through a survey questionnaire submitted to students through a Google Form. In particular, we elaborated 22 questions divided into three sections of the questionnaire: Section 1: General Information; Section 2: Mobility; and Section 3: Preferences and environmental awareness. Notwithstanding, the survey model used is based on Larran and Andrades (2015), a collection of key variables proposed by Eurobarometer (2014), and the questions were focused mainly on sustainable mobility behaviors and actions in the context of university campuses. Moreover, some possible answers have been formulated on the basis of a five-point Likert scale. Furthermore, according to Hair et al. (2014), the statistical sample must be equal to almost 200 respondents.

26.3.2 Estimation of Impacts

With the aim to estimate the impacts generated by university students' mobility, we quantified the emissions generated by a car powered by different fuels or by an alternative power supply on the basis of the distance covered by the students. Considering a typical city car used in Italy by students for urban mobility (Fiat Panda), we elaborated four different scenarios. Particularly, we present the emissions generated by Fiat Panda gasoline powered and 1.2 of displacement; Fiat Panda diesel powered, 1.3 of displacement and Multiject; Fiat Panda mild hybrid powered and 1.2 of displacement; and Fiat Panda liquefied natural gas (LNG) powered and 1.2 of displacement. For these cars, we quantified the emissions considering the different departure locations of economics students, as shown in Table 26.1.

Table 26.1 Estimation impact of students' mobility

Location of departure	% of students per location	Number of students	CO_2 emissions_gasoline/ students (kg)	CO_2 emissions_diesel/ students (kg)	CO_2 emmisions_hydrid/ students (kg)	CO_2 emmisions_LNG/ students (kg)
Bari	69.6	2088	1651.608	1666.224	1300.824	1753.920
BAT	11.6	348	5112.120	5157.360	4026.360	5428.800
Taranto	5.7	171	3284.910	3313.980	2587.230	3488.400
Brindisi	5.1	153	4183.938	4220.964	3295.314	4443.120
Basilicata	5.1	153	2109.258	2127.924	1661.274	2239.920
Foggia	2.1	63	1879.416	1896.048	1480.248	1995.840
Calabria	0.6	18	1448.208	1461.024	1140.624	1537.920
Lecce	0.3	9	309.168	311.904	243.504	328.320

Source: Authors' elaboration on data TerraUp (2022)

26.3.3 Goal and Scope Definition

In this context, the aim of this paper is, first, to analyze the perception and the environmentally sustainable attitudes of the students who attend the Economics Campus of the Aldo Moro University of Bari; second, to provide an estimation of CO_2 emissions generated using a city car to arrive at the Campus of Economics in Bari, powered into different methods (gasoline, diesel, mild hybrid, and LNG) in order to propose environmental enhancements in a further research step.

26.4 Results and Discussion

26.4.1 Outcomes from the Survey

The sample was investigated by submitting a questionnaire survey through a Google form shared among the students by the professors of the department during classroom lessons. Considering 3000 students enrolled in the degree courses of the Department of Economics, Management and Business Law of the University of Bari Aldo Moro, we quantified that the significant sample required 300 answers according to Hair et al. (2014). Particularly, in our case, we have 335 answered questionnaires. Statistically, the values considered in the operation were confidence interval = 5.06, confidence level = 95%, and population = 3000. The results showed that the sample was composed of 60.30% women and 39.70% men, most of whom (67.76%) were between 21 and 24 years of age. Analyzing student mobility preferences, only 27.20% of respondents preferred public transport, while 72.80% preferred private transport, as also highlighted by Cappelletti et al. (2021). These percentages confirm the estimation by Niglio and Comitale (2015), as already mentioned in the Introduction section. Most of the interviewees came from Bari, and the rest were mainly from BAT, Taranto, and Brindisi (Fig. 26.1). Furthermore, only a few units come from neighboring regions, particularly Basilicata and Calabria.

Moreover, 62.7% of students arrive in the city where they attend the course of study, moving from a different municipality/region (this kind of student is named commuter students), 20.6% live in the city where the university is located (this kind of student is named on-site student), and 16.70% live in the city where they attend the study course but reside in another municipality/province/region (this kind of student is named off-site). The sample has an almost equally distributed willingness to pay for their mobility: most students (76.00%) have a budget of between 20 and 50 euros to cover monthly transport costs. Additionally, 57.60% of students changed their transport habits following the COVID-19 pandemic. For question n. 10: *How much do you spend on average per day on public/private transport to get to your university campus?* 39.10% answered less than 30 minutes, 30.40% maximum 1 hour, 22.40% between 1 and 2 hours, and 8.10% more than 2 hours. For question n. 11: *If you were to prefer public transport, which means would you mainly use?* A

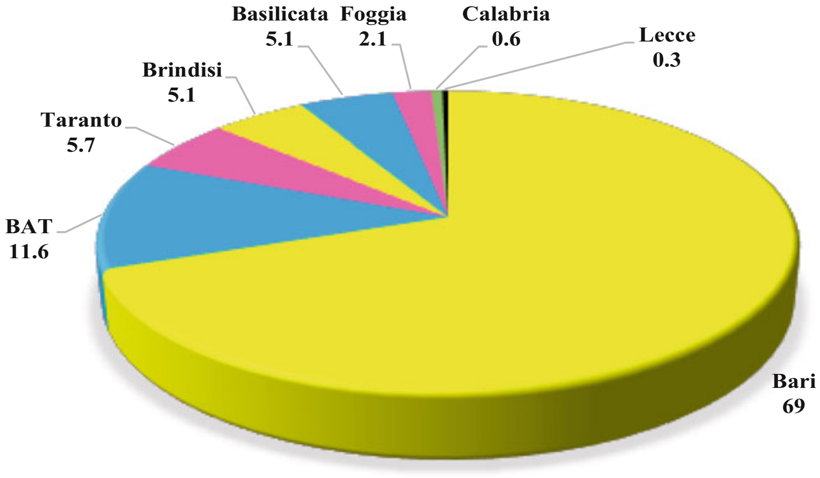

Fig. 26.1 Location of origin of the students' sample

total of 42.40% of students used buses, 26.30% state railway trains, 8.40% railway trams, 6.00% multimodal transport with more than two means, 5.70% local public transport, 4.80% regional railway trains, 3.90% bike, and only 2.70% bike and other means (e.g., train). According to question n. 12: *What reason would you prefer private transport over public transport? A total of* 47.50% of the sample preferred it for reduced travel times, 40.60% preferred private transport for comfort and suitable study travel time, 7.50% preferred it for economic savings, and 4.50% preferred car sharing. Moreover, 39.70% of the sample agrees on the fact that circumstances oblige them to frequently use the car, and 43.88% agrees on the difficulty in managing travel only by means of alternative transport to the car. However, more than 29.00% would be willing to buy a hybrid or electric car or electric bicycle in the future. The interviews also showed that 45.07% would prefer car sharing if they had to opt for an alternative transport to the public/private one. Unfortunately, more than 60.00% of the sample prefers the private way to reach the Economics campus. Finally, analyzing preferences and environmental awareness, 34.63% give up sustainable public transport and prefer private transport to reduce delays, considering the private vehicle the greatest guarantor of autonomy (72.84%). However, more than 80.00% of the sample is aware of the fossil fuel impacts associated with the use of means of transport, and approximately 60.00% is aware of the lower impacts generated by the use of public transport. In conclusion, 96.00% of the sample highlights that sustainable student mobility can improve environmental conditions and, for this reason, 87.00% ask for more cycle paths for the Economics Campus and 97.00% ask for greater economic incentives for the transition from traditional transport to less polluting alternative transport.

26.4.2 *Snapshot of the Impact Associated with Bari Students' Mobility*

The quantification of the CO_2 emissions associated with the use of a common city car (such as Fiat Panda produced by FCA) for arrival at the Economics Campus showed that urban mobility in the metropolitan area generates a greater impact than mobility from other areas, as most of the students live nearby (Table 26.1).

Analyzing the kind of power supply for the city car, the more sustainable is represented by the hybrid power supply; conversely, the most polluting is LNG, as it is not suitable for short distances.

26.5 Conclusion and Future Perspectives

The main outcomes of the questionnaire showed that students mainly use private transport (72.80%), and most of them live in the metropolitan area as the campus is located (69.60%). However, the results suggested that university students who attend the Bari Economics campus are willing to purchase alternative means provided that infrastructure is improved and economic incentives are provided. To provide more sustainable alternatives that must be implemented for the student community by public and private administration, considering that most of them live in the metropolitan area of Bari (approximately 70.00% of students), it is essential to increase the number of cycle paths, increase the city bus rides that connect all the neighborhoods, and discourage the use of the car to cover a few kilometers to/from the Economics Campus. The future perspectives of this research consist of an enlargement of the sample investigated, of quantifying the greenhouse gas emissions associated with other public and private transports, with the aim of presenting a complete overview to the stakeholders involved in urban mobility. Furthermore, on the basis of the critical hotspots identified, environmental improvements will be provided.

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Chapter 27
Life Cycle Costing in the Maritime Sector: The Case of the Extraordinary Maintenance of a Roll-On/Roll-Off Ferry

Giovanni Mondello, Roberta Salomone, Francesco Lanuzza, Giuseppe Saija, and Teresa Maria Gulotta

Abstract Among the different activities involved in maritime transport, maintenance plays an important role in the life cycle of a ship in terms of security and quality, as well as economic relevance. Thus, the evaluation of maintenance costs is fundamental for companies that want to optimize economic sustainability needs in addition to quality and security requirements. Life cycle costing (LCC) represents a valid method to assess the costs involved along the whole life cycle of a product, process, or service. In this context, this study aims to assess the potential economic impacts connected to the extraordinary maintenance activities of a roll-on/roll-off ferry by also including the costs associated with the environmental externalities, thus applying the environmental LCC method. The functional unit (FU) is referred to as "the extraordinary maintenance of the investigated Ro-Ro ferry implemented for 47 days," while system boundaries are defined following a "cradle-to-gate" approach. The main findings highlight that the LCC of the investigated ship maintenance accounts for €506,324.20 per FU. In addition, a negligible contribution of the environmental externalities in terms of economic impacts is noted. The study also underscores a trade-off between environmental and economic performance concerning the steel used in maintenance activities.

Keywords Ferry · Cargo ship · Life cycle costing (LCC) · Economic impact · Maintenance

27.1 Introduction

Among the different sectors in which the transportation of goods and passengers is involved, maritime transport is considered one of the most important sectors of the European economy. Indeed, Europe accounts for the largest maritime fleet

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worldwide (with over 40% of the world's ship fleet), moving around European ports 1.8 billion tons of goods (in terms of short shipping) and approximately 420 million passengers in 2019 (European Commission 2021; Fratila et al. 2021). Furthermore, among the seven identified blue economy sectors, maritime transport and the related services contributed 40% to the added value of the blue economy. In this regard, the gross value added of freight and passenger transport amounted to €11.8 billion and €7.6 billion in Europe in 2018, respectively (European Commission 2021). According to the data provided by the European Community Shipowners' Associations (ECSA 2020), the main economic impacts related to the maritime sector, and in particular to ship transport, are due to the indirect costs in which the shipping industries are involved among the supply chain phases, such as costs for goods and services purchased for shipbuilding or maintenance. This underscores the need for assessing such economic impacts by following a life cycle thinking (LCT) approach and thus applying the life cycle costing (LCC) method, which allows assessing the economic performance of a product, process, or service throughout its whole life cycle. In addition, the LCC method also permits accounting for the costs associated with the so-called environmental externalities (i.e., the indirect costs to be internalized that are caused by the environmental impacts) (Hunkeler et al. 2008). Among the different phases of the life cycle of a ship, extraordinary and ordinary maintenance is a very important activity because it ensures travel security, efficiency, and cost reduction. Nevertheless, the processes involved also require high expenditures in terms of materials purchased, labor, and services (e.g., dry-dock). As pointed out by Mondello et al. (2023), among the international scientific literature, different approaches have been used to evaluate the costs connected to maritime transport (e.g., capital expenditures, cost–benefit analysis, and so on), but few studies adopted the LCC, and none of these focused on maintenance activities. In addition, although the term LCC is mentioned in various analyses, the proposed methods are not commonly related to the LCT approach (Mondello et al. 2023). In this context, this study aims to evaluate the economic impacts related to the extraordinary maintenance activities of a roll-on/roll-of (Ro-Ro) ferry using the LCC method and including the costs associated with the environmental externalities.

27.2 Material and Methods

This section reports a brief description of the Ro-Ro ferry under investigation and the LCC method used for assessing the economic impacts.

27.2.1 The Ro-Ro Ferry

The naval unit investigated in this study is a Ro-Ro ferry used for the transportation of wheeled vehicles through short shipping routes. The characteristic of Ro-Ro cargo ships is that loading and unloading procedures are made without using cranes; indeed, vehicles move to the ship by rolling. The maintenance activities carried out on the investigated ferry are ordinary and extraordinary. The ordinary procedures are made every month and commonly include a general inspection of engines, outfitting and ship compartments. The extraordinary maintenance is carried out through dry-dock, thus suspending the transport activities. It implies the overall inspection and maintenance of the ferry, including refurbishment/restoration or substitution of components, as well as carpentry, washing, and painting processes in the hull and superstructure.

27.2.2 Life Cycle Costing

LCC is a method that allows the assessment of all costs, in monetary terms, related to a product, process, or service throughout its whole life cycle, from the production processes to the end of life (Rebitzer and Seuring 2003). According to Hunkeler et al. (2008), three different types of LCC can be implemented, i.e., conventional LCC, environmental LCC (ELCC), and societal LCC. In this study, an ELCC is performed. ELCC adds to the life cycle costs (accounted in a conventional LCC) the externalities that are expected to be internalized in the decision-relevant future. Thus, it allows the internalization of the costs, along the life cycle, connected to the "not-monetized" Life Cycle Assessment (LCA) results, related to the environmental impacts caused by the product, process, or service. This means that when the ELCC is implemented, an LCA shall also be applied (Swarr et al. 2011). The ELCC has been used here to assess:

- The costs connected to the extraordinary maintenance activities carried out on the investigated Ro-Ro ferry, including (i) dry-dock, (ii) engines and propellers, (iii) outfitting, (iv) valves and pumps, (v) pipes, and (vi) structures (i.e., hull and superstructure);
- The costs of the environmental externalities related to the utilities (electricity and water) used during the extraordinary maintenance, as well as the steel parts that were substituted during the maintenance activities (carpentry processes and pipes replacement). The focus on steel is because it represents the primary material of a cargo ship, and it is one of the principal contributors to the environmental impacts related to the life cycle of a ship (Tuan and Wei 2019).

The functional unit (FU) identified for carrying out the analysis is related to "the extraordinary maintenance of the investigated Ro-Ro ferry implemented for 47 days." In addition, system boundaries (SBs) are defined following a "cradle-to-gate" approach (Fig. 27.1), from the dry dock to the time in which the Ro-Ro ferry is ready to be launched. SBs also include purchased materials and energy sources as well as costs related to labor. As previously stated, the costs connected to the environmental externalities are accounted only for utilities and steel.

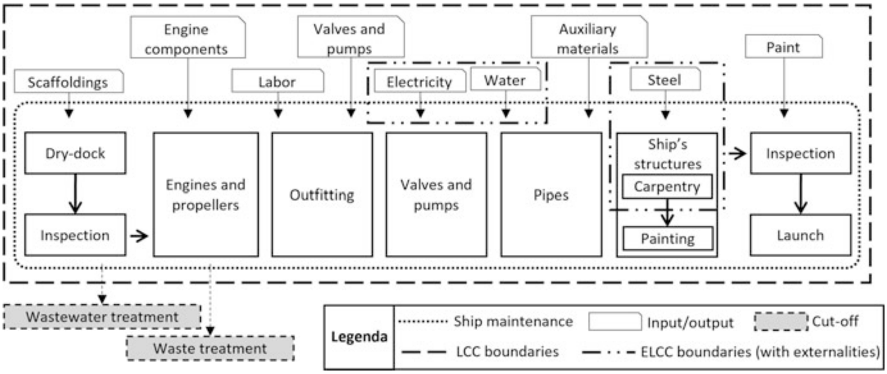

Fig. 27.1 System boundaries and cut-off

To build the life cycle inventory, data on costs were gathered through questionnaires and direct interviews submitted to a company operating in maritime transport.[1] The impact assessment for the LCC is based on the evaluation of all the costs related to the Ro-Ro ferry's extraordinary maintenance according to the identified FU and SBs:

$$\text{LCC} = \sum_{i=1}^{\text{Maintence activities}} (\text{Maintenance costs}) \qquad (27.1)$$

For the externalities calculation, the Environmental prices method (De Bruyn et al. 2018) is applied. This method allows the assessment of the potential environmental impacts using the characterization factors based on the ReCiPe 2008 Midpoint (Goedkoop et al. 2009) and IPCC (2013); in addition, it accounts for the costs related to the environmental externalities expressed as average European prices in Euros per kilogram of pollutant.

27.3 Results and Discussion

The economic impacts of the extraordinary maintenance activities of the Ro-Ro ferry under investigation are reported in Fig. 27.2.

The total costs associated with the processes involved in maintenance are equal to €506,324.20 per FU. The main contribution to the economic impacts is due to the ship's superstructure maintenance (26.8%), followed by engine and propeller

[1] Due to confidentiality issues, the detailed inventory of the costs related to the investigated maintenance activities cannot be shared.

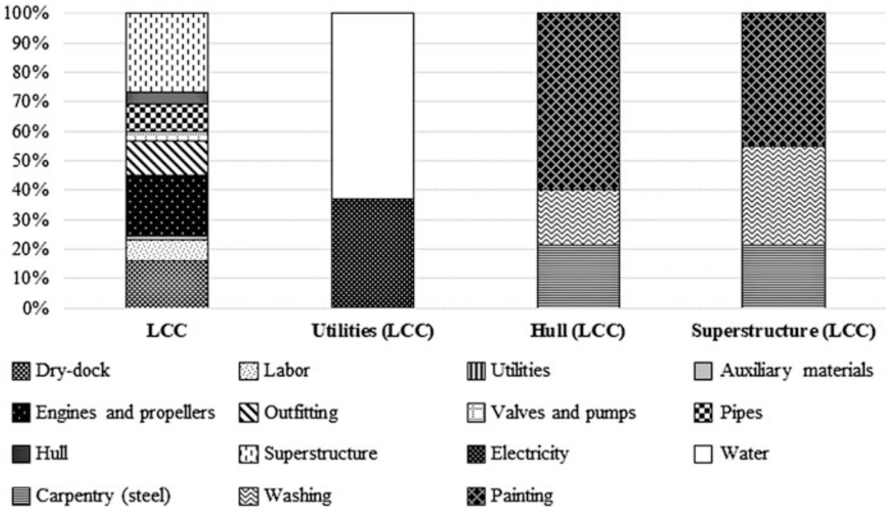

Fig. 27.2 Contribution analysis of the extraordinary maintenance of the Ro-Ro ferry (LCC results)

maintenance (20.4%) and dry-dock activities (16%). In contrast, the lower costs are related to the use of auxiliary materials and utilities contributing 1.2% and 0.3%, respectively, to the impacts. Regarding superstructure maintenance, the painting process is responsible for the highest impact. Indeed, the surface painted during the investigated maintenance activities is approximately 16,000 m^2 per FU, including single, double, or triple paint layers for walls, ceilings, railing, stairs, etc. For engines and propellers, the main contribution is associated with the check of two propellers and related screws, which includes the disassembly and reassembly of the parts as well as the substitution of specific components (e.g., springs, bearings, etc.). In addition, the results also highlight the high costs caused by dry docking related to the use of the crane, which accounts for approximately €40,500 per FU. An in-depth analysis of the ship's structural maintenance (Fig. 27.2) highlights that the painting processes cause the highest costs in both the hull and superstructure, while the washing activities, for which designated machinery (e.g., high-pressure cleaner and robot) are adopted, result in economic impacts ranging from 18.6% to 33.8%. In addition, the steel used in pipe replacement and carpentry is responsible for 15.5% of the impacts among all maintenance activities, resulting in €78,490.87 per FU. The results obtained through the application of the ELCC method are reported in Fig. 27.3.

Concerning the environmental performance of the investigated extraordinary maintenance activities, steel provides the main contribution to all the analyzed impact categories, except for agricultural land occupation and water depletion, for which the highest impacts are due to electricity and water, respectively. The costs related to the environmental externalities account for €2304.08 per FU, causing a negligible contribution (0.5%) to the total ELCC. In particular, as shown in

Environmental impacts (LCA)	Unit	Amount	Contribution (%) Steel	Electricity	Water
Climate change	kg CO_2 eq	9,097.52	89.13	10.84	0.03
Ozone depletion	kg CFC-11 eq	5.03E-04	76.04	23.90	0.06
Terrestrial acidification	kg SO_2 eq	25.60	86.70	13.27	0.04
Freshwater eutrophication	kg P eq	4.45	94.17	4.97	0.87
Marine eutrophication	kg N eq	1.65	83.06	7.42	9.52
Human toxicity	kg 1,4-DB eq	3,332.93	94.78	4.86	0.37
Photoch. oxidant format.	kg NMVOC	41.04	94.94	5.03	0.03
Particulate matter format.	kg PM10 eq	30.27	96.70	3.29	0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	0.23	91.71	8.12	0.17
Freshwater ecotoxicity	kg 1,4-DB eq	236.34	98.38	1.54	0.08
Marine ecotoxicity	kg 1,4-DB eq	232.91	98.39	1.53	0.08
Ionising radiation	kBq U235 eq	450.85	67.64	31.08	1.28
Agricultural land occup.	m^2a	92.28	43.48	56.08	0.44
Urban land occupation	m^2a	60.02	95.45	3.81	0.74
Natural land transf.	m^2	0.16	101.70	6.00	-7.70
Water depletion	m^3	294.95	16.57	6.15	77.28
Metal depletion	kg Fe eq	8,391.16	99.99	0.01	0.0003
Fossil depletion	kg oil eq	2,194.00	85.90	14.07	0.03

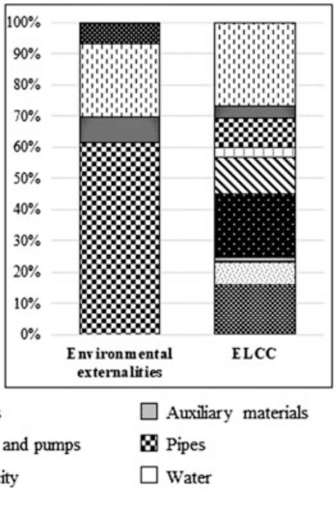

Fig. 27.3 ELCC results and related contribution analysis to the environmental externalities

Fig. 27.3, the highest contribution to the environmental externalities is due to the steel used in pipe replacement (€1141.17 per FU).

27.4 Conclusions

This study aims to evaluate the economic impacts related to the extraordinary maintenance of a Ro-Ro ferry, accounting for all the costs of the activities, materials, and utilities as well as for the expenses related to the environmental externalities, through the application of the ELLC method. The highest contribution to the economic impacts is caused by the painting process of the superstructure, followed by the propellers' maintenance and the use of cranes during dry docking. The main findings underscore that steel causes the highest impacts among all the investigated impact categories and that environmental externalities have a negligible contribution to the total ELCC. The results also point out a trade-off between the environmental and economic performance of the investigated extraordinary maintenance activities. Specifically, the trade-off refers to the steel used: despite its low contribution in terms of costs, it is responsible for the highest environmental impacts.

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Chapter 28
The Last-Mile Delivery Process from a Life Cycle Perspective

Sara Toniolo and Ivan Russo

Abstract More consumers shop online through their favorite channels, and e-commerce sales are growing rapidly. Most Italian digital shoppers make, on average, at least one online purchase per month. Companies are called to face new challenges, one of which is the greater complexity of logistics activities, considering delivery options to be one of the most important aspects of online shopping. Pick up points, drop off mode, parcel lockers, and door-to-door delivery mode will become the most important last-mile delivery solutions to serve the final customers. However, this phenomenon also generates environmental burdens related to emissions, traffic congestion, and air quality. The objective of this study is to explore what solutions can reduce the impacts associated with the last-mile delivery process from a life cycle perspective. This study presents a review based on 20 articles. A descriptive analysis is carried out to evaluate the main features of the articles; then, the articles are classified considering the solutions analyzed. This study highlights that the last-mile process is still underexplored from a life cycle perspective and presents the factors that can help direct towards its decarbonization.

Keywords Last-mile delivery · Decarbonization · Life cycle

28.1 Introduction

The years 2020 and 2021 have been exceptional due to the COVID-19 pandemic, and health and safety measures boosted online shopping across Europe (Lone et al. 2021). This phenomenon is witnessed worldwide. According to Eurostat, the share of e-shoppers among internet users is growing, with the highest proportions found in the youngest age group 16–24, closely followed by the age group 25–54 (Eurostat, 2022). As revealed by a survey carried out in March 2021 (Idealo 2021), most Italian digital shoppers make, on average, at least one online purchase per month. The

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advantages of online shopping include lower prices, convenience of home delivery, free/low-cost shipping, price comparison, fast shipping, discounts, more product options, and safety (Jungle Scout 2022). One of its main characteristics is the territorial dispersion of customers: customers usually order small quantities of goods, but they do so relatively often and in many cases remain outside of their homes. Parcel delivery to a recipient's address generates costs of customer service and greater environmental pollution (Moroz and Polkowski 2016). The debate concerning the environmental impacts of online shopping compared with traditional shopping is also growing (Ha et al. 2022). Even if e-commerce companies often claim the benefits of their online operations, these benefits are difficult to assess because of the great complexity of this phenomenon (Rizet et al. 2010). Innovative and viable last-mile delivery solutions include parcel lockers, crowdsourcing logistics, mapping the consumer presence at home, and dynamic pricing policies (Mangiaracina et al. 2019). However, little is known about consumers' preferences for environmentally friendly last-mile deliveries, although freight operators are noticing an increased consumer interest in sustainable deliveries (Caspersen et al. 2021). Despite its importance, knowledge about the environmental burdens of last-mile delivery is still limited, and the academic community is starting to perceive the need to extend this knowledge from a sustainability perspective (Ha et al. 2022). The feasibility of strategies in environmental terms is key to ensuring sustainable performance. Life cycle thinking can help go beyond the traditional focus to include the environmental, social, and economic impacts of a product over its entire life cycle. Life cycle assessment (LCA) and carbon footprint (CF) are the main operative tools of life cycle thinking, and they are recognized by practitioners and researchers worldwide (Petit-Boix et al. 2017). In this context, the aim of this paper is to provide a review of the literature on the application of life cycle tools to last-mile deliveries to explore what solutions can reduce the impacts associated with the last-mile delivery process from a life cycle perspective.

28.2 Materials and Methods

In line with the objective, this work addresses the following two questions:

- RQ1: What are the aspects of the last-mile process explored from a life cycle perspective?
- RQ2: What solutions may reduce the environmental impacts associated with the last-mile process from a life cycle perspective?

To answer the above questions, a literature review is conducted to synthesize and compare the empirical evidence, in line with Snyder (2019). The research is performed by adapting the framework proposed by Ha et al. (2022), which addresses the sustainability aspect in the last-mile delivery literature and follows the steps suggested by Durach et al. (2017).

28.2.1 Literature Search

The unit of analysis is defined as a single scientific paper published in journals, books, or conference proceedings. The literature search is developed as follows.

Paper Collection A search by keywords is performed in ISI Web of Knowledge with a time horizon from 2010 to 2022. The keywords are selected and combined to investigate the papers whose contents address the focus of our study. The resulting combination of keywords is ("last mile" OR "last mile") + (("LCA" OR "Life Cycle Assessment" OR "Life Cycle Analysis") OR "Carbon Footprint"). Only articles written in English were considered.

Paper Selection From the previous step, 28 papers are collected and then filtered. Only papers including consideration of the last-mile process and referring to or applying environmental life cycle evaluations are included. Finally, 20 papers were selected for an in-depth examination.

28.2.2 Literature Analysis

A descriptive analysis of the selected papers is performed to evaluate the papers' main characteristics, namely, year of publication, name of journal or conference, affiliation of the first author, and country of focus. The analysis of the content is based on the research questions and the framework proposed by Ha et al. (2022), and the following contents are addressed.

- Aspects of last-mile process explored (RQ1): last-mile dimension, namely, delivery, transportation, distributions and logistics; themes, namely, operational optimization, emerging trends and technologies, performance management, supply chain structures and policy; last-mile solution; last-mile actor, namely, delivery service or consumers.
- Solutions that may reduce the environmental impact (RQ2): environmental challenges addressed, such as cold storage, fuel consumption, air pollution, noise, greenhouse gas (GHG) emissions and life cycle application.

28.3 Results and Discussion

The results are presented based on the main characteristics of the articles and on the analyzed content.

28.3.1 Main Characteristics of the Articles

According to the analysis of the characteristics of the papers, the following results are obtained. With reference to the time horizon, the first two contributions date back to 2014; seven papers were published in 2021, showing that interest has been quite limited for more than a decade but is growing. The journal with the main contributions is the Journal of Cleaner Production, followed by Sustainability. The country with the most contribution is the USA (7), followed by Germany (5).

28.3.2 Review Based on Contents

Review of the Aspects of the Last-Mile Process Explored (RQ1) The literature analysis highlighted that the last-mile process is investigated from different points of view (Table 28.1). With reference to the themes, all of the studies explore the performance management of the last-mile process from an environmental point of view, and four studies also investigate economic performance. Another theme often addressed is operational optimization, especially with reference to transport planning. The last-mile dimension more investigated is last-mile transport, with 16 papers concentrating on moving goods from a hub to the final destination through different transportation modes, followed by last-mile distribution, with three papers concentrating on moving goods through different channels. Three papers explore innovative solutions, concentrating on drones, robots, and pick-up points. The main solutions explored are traditional transportation modes with diesel vehicles (11 papers) and electric vehicles (9 papers), which are often compared. The majority of the papers analyzed (15) explore the last-mile process performed by the delivery service, while 7 explore the case in which the last mile is performed by the consumer. Two papers analyzed the last mile in relation to public transportation, thus with different scopes.

Table 28.1 Aspects of the "last mile" process explored

Themes	N. articles	Dimension	N. articles	Solutions	N. articles
Operational optimization	8	Delivery	1	Innovative solutions	3
Emerging trends and technologies	2	Transport	16	Electric vehicles	9
Performance management	20	Distribution	3	Traditional vehicles	11
Supply chain structures	2	Logistics	2	Cargo-bikes	2
Policy	2			Walking (on foot)	3
				Public transport	2

Review of Solutions That May Reduce the Environmental Impact (RQ2) The main environmental challenge assessed is GHG emissions, followed by air pollution and by analyzing other environmental categories such as acidification. Cold storage and fuel depletion are investigated in only one paper. Among the analyzed papers, CF calculations are performed by seven papers, and a calculation of CO_2 emissions is presented by one paper. LCA is adopted by nine papers assessing the environmental impact of the last mile on other aspects beyond climate change. Three papers highlight the importance of the life cycle perspective, without quantitative applications.

28.3.3 Solutions and Challenges

The solutions and challenges revealed through this analysis can be distinguished as follows.

Transport Mode Compared to traditional vehicles, the adoption of electric vehicles is associated with an environmental impact reduction for global warming, photochemical smog formation, and acidification. However, the use of electric vehicles increases particulate matter emissions compared to diesel vehicles due to the carbon intensity of the national power system, showing that their environmental performance is closely related to the sources of the energy mix (Croci et al. 2021). Light electric vehicles facilitate a reduction in global warming potential and other environmental impacts related to specific transport performance due to their lightweight construction. Innovative technological solutions, such as drones and automated vehicles, can help reduce the environmental impact.

Distribution Siting urban points and route planning can help reduce the environmental impact; however, conflicting results can be obtained in combination with different transportation modes also considering the cases of cold transportation. Supporting neighborhood stores could limit the impacts.

Logistics The type and routing of van deliveries, the packaging used, and the energy efficiency of shop and center operations are significant aspects to consider. Service delivery can help reduce the environmental impact compared to consumer shopping trips, but it is dependent on the number of items, the drop density, the width of delivery windows, the failed deliveries, and the nature of the return operation. Encouraging consumers to reduce complementary shopping trips and maximize the number of items per delivery can help reduce the environmental impact. The nature of the consumer's behavior in terms of travel, choice of e-fulfilment method, and basket size can affect the environmental sustainability of the last-mile process. The influence of consumer choices is considerable, and mapping consumer behavior can help develop sustainability strategies.

28.4 Conclusions and Future Perspectives

In this study, 20 papers, including studies published in scientific literature and conference papers, were analyzed. They were categorized based on their characteristics, such as year of publication, source and geographical scope, and based on their content. First, the aspects related to the last mile process were explored, namely, themes, dimensions, solutions, and actors; second, the solutions that may reduce the environmental impacts were analyzed, highlighting the environmental challenges addressed and the life cycle perspective used. These solutions are electric vehicles, the optimization of siting points and route planning, the optimization of the packaging used, the energy efficiency of center operations, and finally encouraging consumers to reduce shopping trips and maximize the number of items. This literature review revealed many aspects of the last-mile process, but some elements should be further analyzed. Innovative solutions are still underexplored, and even if different studies highlight the central role of the consumer (i.e., Castillo et al. 2022; Merkert et al. 2022; Seghezzi et al. 2022), there is limited interest in mapping and using real data about consumer behavior in life cycle applications.

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Part VI
Circular Economy and Sustainability Issues in Several Sectors: Technical Materials and Products

Chapter 29
Concerns Deriving from the Sand Business and Potential Substitutes for a Sustainable Construction Sector

Giulio Paolo Agnusdei, Stefania Massari, Federica De Leo, and Valerio Elia

Abstract Among the different types of mining, the extraction of sand for buildings is one of the largest industries, not only in volume but also in value. Sand grabbing is also occurring at unprecedented rates in particular locations. Sand is a widely used construction material and is one of the most traded commodities in the world. Large amounts of sand are extracted from ancient glacial deposits, alluvial fans, ancient marine terraces, ancient and modern river and stream terraces, floodplains, and channels. The aim of this study is to check if the use of sand within the construction sector is a sustainable option or if potential substitutes are more adequate. The impacts of sand and gravel mining from various depositional environments, including river ecosystems, have been reported from many parts of the world. One of the principal causes of environmental impacts from in-stream mining is the removal of more sediment than the system can replenish. Much research has also been carried out on the environmental effects due to the mining of marine sand and gravel as well as the dumping of harbor dredging into the open sea for the construction of artificial islands. To increase sustainability in the building sector, many sand substitutes have been tested, such as recycled aggregates and industrial wastes, as alternatives with lower environmental impacts. River sand, which is the natural choice of the construction industry, has become scarce due to its overexploitation and increasing environmental concerns. There is a strong need for research on river sand substitutes for concrete production and cement sand mortar production.

Keywords Sand · Building sector · Sustainability · Substitution · Alternatives

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29.1 Introduction

Sand origins by rock erosion. Over the years, atmospheric agents have caused solid composites that constitute rocks to breakdown into small grains. Wind, water, and ice often transport the latter over long distances, subjecting them to mechanical abrasion and then rounding them. Finally, the grains of sand deposits in geological sites are partially agglomerated again to sandstone. All types of sand account for a relatively small proportion, making up a total of only approximately 10%, while gravel is twice the amount (20%). Sand is the key raw material in concrete, asphalt, and glass used for every infrastructure. It is also used for land reclamation, shoreline developments, road embankments, and flood protection in coastal areas to protect eroding coasts and address climate change impacts such as sea-level rise and increasingly severe storms (USGS 2012). As concrete is the most commonly used material in the construction sector at the global scale, and for concrete production, six to seven tons of sand and gravel are required per ton of cement, sand demand explosion is very evident (Peduzzi 2014). In the past three decades, the demand for sand of construction grade has increased exponentially in many areas around the world due to the economic development in many countries and the consequential growth in building activities. Sand, gravel, crushed stone, and aggregates (referred to as "sand resources") are the second most exploited natural resources in the world after water (Villioth 2014), and their use has tripled in the last two decades to reach an estimated 40–50 billion metric tons per year (UNEP 2019). The movement towards a circular future represents an opportunity to rethink sand extraction and sourcing practices, to substitute sand with other material and, eventually, to include sand in sustainable infrastructure standards.

In light of these challenges, the study aims to answer the following research questions:

RQ1: Is the use of sand in the construction sector sustainable?
RQ2: Are there any potential substitutes for sand?

The present study investigates whether the use of sand in the construction sector is sustainable from a holistic point of view and reviews some possible alternatives to sand within the domain of the circular economy.

29.2 Market Demand and Open Issues

After the approvals of recovery plans aimed at overcoming the negative externalities of the COVID-19 pandemic, infrastructural investment became a cornerstone of national, and indeed global, economic revival (UNEP 2021a). Sand is a material that has significant value not only from an environmental point of view but also because it is essential for the construction of critical infrastructure. Silica sand is also used in the field of the green economy, e.g., for the production of solar panels and renewable energy infrastructure but also for building critical infrastructures aimed at protecting people against emerging risks, such as coastal erosion and other severe adverse events. Due to population growth, urbanization, and the abovementioned phenomena, approximately 40–50 billion metric tons of sand resources per year are currently being exploited at a global level, 18 kg per person per day on average (Peduzzi 2014; Beiser 2018). In light of the increasing demand for infrastructure and accelerating climate change, sand must be recognized as a strategic raw material. Trying to limit the growing demand for sand resources represents a vital but scarcely perceived challenge (Torres et al. 2021). Sand production and use are not monitored worldwide. It is treated as an insignificant material by society, ignoring its fundamental function and value. A global inventory does not exist, as reserves were infinite. Since multiple issues are emerging worldwide regarding short- and mid-term sand supply, naturally occurring sand and gravel should undoubtedly not be taken for granted in the long term because current extraction exceeds their renewal rates (John 2009; Hackney et al. 2021). Given its strategic importance in many regions, sand exploitation and management would need relevant efforts in terms of regulation, monitoring, and governance to avoid several environmental and social consequences that have thus far been mostly overlooked (Peduzzi 2014; Bendixen et al. 2021).

29.3 Environmental Concerns

Sand resources play a strategic role in delivering ecosystem services, maintaining biodiversity, supporting economic development, and securing livelihoods within communities. The sand business affects all 17 Sustainable Development Goals (SDGs) either directly or indirectly. Ecosystem services delivered by sand resources are fundamental to achieve, for example, SDG 6, SDG 7, SDG 11, SDG 12, SDG 13, SDG 14, and SDG 15. Marine, delta, beach, river, and underground environments benefit from the role of sand in controlling erosion, delivering nutrients, contributing to food security, filtering water, and ensuring aquifer quality.

Sand also contributes to support biodiversity and has the vital role of providing habitats for diverse flora and fauna. While extracting sand from inactive deposits does not cause impacts beyond the immediate physical disturbance, the extraction from active sand bodies, resulting in changing rates of sand removal, could threaten communities and livelihoods, not only in the localized area of extraction but also within the whole affected system, therefore requiring environmental impact assessment, management, and potential mitigation. When mining sand from dynamic systems, such as riverine and active marine ecosystems, relevant environmental impacts are caused, such as erosion, land-use changes, air pollution, salinization of water reserves, threats to freshwater aquifers, marine fisheries, and biodiversity (UNEP 2019). In the natural environment, sand maintains biodiversity, simultaneously providing several ecosystem services and preserving deltas and coastal zones that are more vulnerable to climate change effects. In this sense, sand is an important asset that contributes to mitigating climate change impacts and the subsequent accelerating rise of the global mean sea level, protecting against coastal erosion, storm surges, and coastal flooding.

29.4 Societal Concerns

The growing demand for sand, as well as affecting ecosystems, is triggering socio-economic conflicts and is feeding concerns over sand shortages (Torres et al. 2021). Sand exploitation is globally not regulated or at most under-regulated. Due to the inadequate and uncertain governance settings, some actors within the sand business have ridden the absence of regulation and monitoring, often obtaining market control through coercion and even violence. Workers and communities face health and safety risks from drowning, subsidence, and landslides, among other hazards (Leal Filho et al. 2021). Large-scale infrastructure projects and sand extraction can change and/or damage the biodiversity of marine, coastal or terrestrial environments, having indirect repercussions on economic livelihoods. Due to the impacts of river sand mining and the subsequent declining water levels in the area surrounding excessively mined rivers, people who previously had easy access to drinking water were forced to search for other far water supply sources. In some extreme cases, the mining of marine aggregates has even changed international boundaries, such as through the disappearance of entire islands in Indonesia – since 2005, at least 24 small islands have disappeared as a result of erosion caused by illegal sand mining. Most of this sand has been exported to Singapore, which has expanded its surface area by 22% since the 1960s (Global Witness 2010). In response to this potentially heavy environmental toll, many neighboring countries (Indonesia, Malaysia and Vietnam) have now banned exports of sand to Singapore, but this has only shifted the problem to countries such as Cambodia. The conflicts caused by sand mining were brought to the attention of the general public for the first time through the documentary Sand Wars. Among many other outreach victories, the documentary inspired the United Nations Environment Programme (UNEP) to publish a Global Environmental Alert in March 2014 titled “Sand, rarer than one thinks.” In it, the authors state that “formed by erosive processes over thousands of years, they [sand and gravel] are now being extracted at a rate far greater than their renewal.”

29.5 Circular Economy and Sustainable Alternatives to Natural Sand

To be a viable alternative to sand and gravel derived from the natural environment, a material must demonstrate strong technical performance over its lifetime. Given concerns with technical performance, alternatives to sand often struggle to be

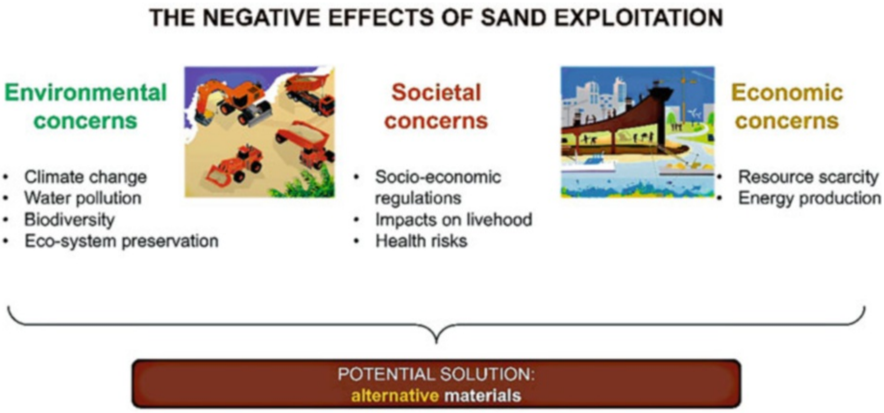

Fig. 29.1 Negative effects of natural sand exploitation from a holistic perspective and potential solution

considered a viable alternative, despite meeting the technical specifications. Technical standards and government guidelines, such as specifications for infrastructure works, are therefore essential.

Nevertheless, Boehme and Depoortere (2019) observed that several sand-like fractions out of industrial residues have become available over the years. The potential use of these secondary raw materials, fine recycled aggregates and other fine fractions as an alternative substitute for natural sand in the construction sector depends on the particle size distribution and on the requirements matching set by the standards for the use of sand in constructional applications and the standard specifications for road construction SB250. However, this is not the only obstacle to sustainable alternatives to natural sands, but stakeholder acceptability is also highly relevant. In fact, Zadeh et al. (2022) proposed recommendations on how to increase the use of sand substitutes within the construction industry, stating that assessing awareness of alternative or environmentally friendly materials plays a crucial role in the acceptance and adoption of such materials by all stakeholders (Fig. 29.1).

29.6 Conclusions

The impacts concerning the extraction, management, and use of sand have recently stimulated international attention. The resolution on mineral resource governance (UNEP/EA.4/Res.19) adopted at UNEA-4 specifically includes the challenges established by UNEP/GRID-Geneva in the report "*Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources*" (UNEP 2019). Since sand is a major resource for construction materials used in infrastructure, the same challenges are also highly relevant to the resolution on sustainable infrastructure (UNEP/EA.4/Res.5), as well as to the latest UNEA-5 resolution on minerals and metals management (UNEP/EA.5/Res.12). The IUCN (2020) confirmed the strategic importance of sand by adopting a motion titled “for the urgent global management of marine and coastal sand resources,” followed by the “International Good Practice Principles for Sustainable Infrastructure,” through which the UNEP (2021b) underlined the importance of considering sand in the context of minimizing resource use and closing material loops. The management of the current available quantity of sand resources must be balanced with changing societal and economic needs to be sustainable. Complete knowledge on occurrence and distribution, composition, and dynamics, integrated with the environmental and social impact assessment of extraction, is therefore crucial for elaborating long-term policies oriented to optimize sand resource use. Including technical feasibility among the constraints and assimilating the total “theoretical” availability (resource) to the extractable quantities (reserve), multicriteria decision-making analyses will lead to the identification of adequate management tools for a safe and secure supply of sands. To avoid sand extraction, in some sites, new land could be subtracted from the sea, or land elevation could be increased over rising seas through a natural approach and without anthropic interventions, resulting in a cost-effective adaptation strategy. Notwithstanding, any effort to limit sand extraction from specific environmentally sensitive locations should be complemented by accessibility to the abovementioned alternative sand resources. Climate change-induced pressures, such as temperature stress and precipitation, will speed up the need for upgrading or replacement, promoting nature-based solutions within the building sector that do not require sand. Due to its holistic approach, the contributions of this study are manifold. The main findings suggest that natural sand exploitation and management require relevant efforts in terms of regulation, monitoring, and governance to avoid severe environmental and social consequences. Since the circular economy is a leading innovation in the material construction sector to avoid the reckless use of sand, researchers and practitioners are investigating and testing alternative materials, such as industrial waste, to achieve the SDGs.

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Chapter 30
Reshoring and Nearshoring of Resources Towards Making the Manufacturing Chain of the Italian Ceramic Industry More Resilient and Sustainable

Andrés Fernández-Miguel, Antonella Zucchella, Maria Pia Riccardi, Davide Settembre-Blundo, Fernando E. García-Muiña, and Alfonso P. Fernández del Hoyo

Abstract The combined action of the pandemic first and geopolitical tensions later has highlighted the fragility of many global supply chains. An unexpected event in an interconnected world requires companies to react quickly to respond to change. This chapter analyzes critical issues emerging in the Italian ceramic industry supply chain, which is characterized by a high intensity of natural and energy resource use and a sourcing system with high geopolitical risk. Using the transdisciplinary methodological approach as a perspective for solving complex problems in manufacturing, alternative supply chain scenarios are outlined to identify nearshoring and reshoring strategies for a more resilient and sustainable supply for the Italian ceramic industry.

Keywords Supply chains disruptions · Manufacturing · Reshoring · Nearshoring · Resilience · Sustainability

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30.1 Introduction

After years of globalization, world economic integration is slowing down due to the consequences of the crisis caused by the pandemic and global geopolitical tensions that push nations towards forms of protectionism (Hameiri 2021). In this context of a global crisis, with disruptions in the supply chains of natural and energy resources, it has become imperative for manufacturing companies to optimize the use of production factors and reconfigure supply chains with reshoring and nearshoring strategies (van Hoek and Dobrzykowski 2021). This implies a major effort by industries to innovate processes, organizational models, products, and business models because the system of value creation has radically changed (Magableh 2021). Therefore, diversification of supply sources and building new supply chains that are more resilient, agile, and flexible to respond to sudden market disruptions are necessary (Miceli et al. 2021). The management of this change can be effectively supported using appropriate design tools and a cross-disciplinary approach to innovation, namely, no longer the mere overlap of technical and managerial knowledge but their effective integration (Khanuja and Jain 2021).

30.2 General Overview of Recent Reshoring/Nearshoring Trends

In manufacturing, industrial location represents the place where the company decides to source the factors of production (inputs) to process them and transform them into products (outputs) to be sold to its customers (Bogataj et al. 2011). It follows that localization is an integral part of the company's strategic planning process, considering the needs of all company areas, not just manufacturing ones (Gothwal and Saha 2015). Especially since the late twentieth century, there has been a tendency for manufacturing firms to offshore their production to emerging countries to reduce costs or to take advantage of sales opportunities offered by rapidly expanding markets, but over a longer time horizon, it carries the risk of losing control of operations and hindering performance (Baldwin and Venables 2013). However, currently, the reasons to relocate are no longer as pronounced. Over time, the difference in costs between the West and emerging countries, as well as labor and environmental protection regulations, has been progressively rebalanced, giving rise to an opposite phenomenon known as reshoring (Johansson et al. 2019). This is an operational model in which manufacturing firms return to domestic production in response to the need to reindustrialize developed economies and mitigate the risks of supply chains (Fratocchi et al. 2014; Barbieri et al. 2020). However, sometimes it is not possible to bring production back home, which happens due to the lack of raw materials nearby or due to the high investment in infrastructure needed. Firms can opt for nearshoring, a variant that involves relocating operational processes to countries close to the headquarters (Piatanesi and Arauzo-Carod 2019). Moreover, starting in 2020, the COVID-19 pandemic and subsequent geopolitical tensions related to regional conflicts have accelerated the phenomena of reshoring and/or nearshoring of production by many companies in advanced economies (Colamatteo et al. 2021). Although there is a large body of literature on reshoring and nearshoring strategies related to manufacturing processes (Merino et al. 2021), scholars have not yet sufficiently explored the same strategic options for input sourcing procedures (van Hoek and Dobrzykowski 2021). The raw material supply network represents one of the most critical elements of the production process in natural resource-intensive industries (Appolloni et al. 2022). However, the complexity of supply logistics became evident during the pandemic (Ikram et al. 2021), highlighting the need for manufacturing companies to employ optimal resource management systems (Ma et al. 2021). Therefore, managing the complexity of value chains in disrupted times requires the coexistence of a plurality of both engineering and socioeconomic skills. The first step towards effective problem solving could be interdisciplinarity, which occupies the space where disciplines can combine concepts, methodologies, and tools (Xu 2020). However, the real paradigm shift for complexity analysis is the transdisciplinarity approach, which aspires to develop new knowledge by going beyond and interweaving concepts and methods of individual disciplines (Broo 2022). This holistic and systemic view based on both engineering and socioeconomic expertise may prove to be the most appropriate for interpreting the complexity of supply chains and identifying solutions to sudden operating changes (Peruzzini and Stjepandić 2018). There are few examples in the literature of transdisciplinarity application in an operational environment as a perspective for solving complex problems (Peruzzini et al. 2020). This study aims to fill this gap by analyzing the criticalities emerging in the Italian ceramic industry, which is characterized by a high intensity of use of natural and energy resources and by a supply system with a high geopolitical risk.

30.3 Research Context and Methodological Approach

The ceramic industry is also among the natural resource- and energy-intensive industries (García-Muiña et al. 2020). In this context, the Italian and Spanish ceramic industries with the two production hubs of Sassuolo and Castellón are the most important clusters in Europe (Appolloni et al. 2021) since together, both industries have a turnover of approximately 11,000 million euros in 2021, generating direct employment for more than 36,000 employees (Table 30.1).

Sectoral numbers also show how the two clusters are strongly export-oriented: 84% of turnover for Italy and 75% for Spain. For both clusters, Dondi et al. (2021) highlighted the complexity of the raw material supply chains and emphasized the high concentration in the supply of sodium feldspars from Turkey and ball clays from Ukraine. This dependence on two main raw material sources caused supply chain disruptions following the Ukraine war in early 2021. Consequently, a preliminary feasibility study is presented to identify the most resilient and sustainable

Table 30.1 Key figures of the Italian and Spanish ceramic industry relative to the year 2021

Ceramic industry	Tiles production (Millions of m^2)	Turnover (€ Million)	Exports (%)	No. of employees
Italy: Sassuolo cluster	458	6100	84	19,000
Spain: Castellón cluster	587	4855	75	17,180

Sources: Values estimated for the year 2021 by industry associations in the two countries, Confindustria Ceramica (Italy) and ASCER (Spain)

sourcing strategies. The methodological approach is transdisciplinary oriented, combining different technical and managerial tools: sectoral scenario analysis, strategic design of alternative scenarios, environmental impact assessment, and technological performance analysis.

30.4 Results of the Transdisciplinary Analyses

30.4.1 Sectoral Scenario Analysis

The ceramic tile manufacturing process consists of several steps, as shown in the flowchart in Fig. 30.1 (Ros-Dosdá et al. 2018). Raw materials are transported to factories by employing different means (ship, train, truck) depending on the origin: foreign (mainly Ukraine, Turkey, Germany) or domestic (mainly Tuscany, Sardinia, Piedmont, Calabria, Emilia Romagna) (Vacchi et al. 2021). These raw materials are water milled using silica pebbles and/or sintered alumina spheres to obtain a slurry. Then, it is dried in a vertical spray dryer to obtain a granular powder and pressed to form ceramic manufacturers to subsequently be digitally glazed and decorated. The tiles are then transferred to roller kilns for firing at 1220 °C in cycles of 30–50 min. Finally, the tiles can be transferred directly to the quality selection, packaging, and palletizing department for the finished product to be sold.

The leading type of tile manufactured by Italian producers is porcelain tile, whose body is mainly composed of three main categories of raw materials: (1) kaolinitic or illitic-kaolinitic clays (ball clays), which provide the plasticity necessary for tile forming; (2) sodic, potassium, or sodium-potassium feldspars, which melt during firing to form a glassy phase of adequate viscosity for complete sintering of the product; and (3) feldspathic or quartz sands with a structural function necessary to limit dimensional changes in drying and firing (Dondi et al. 2014).

Since the war in Ukraine, clay supplies from the Donbas were suddenly disrupted, causing serious problems for ceramic companies. This event highlighted how risk analysis and management have not yet fully entered the corporate sustainability assessment system. As a complex problem, a possible solution can be found through functional decomposition, separating the complex problem into several elementary

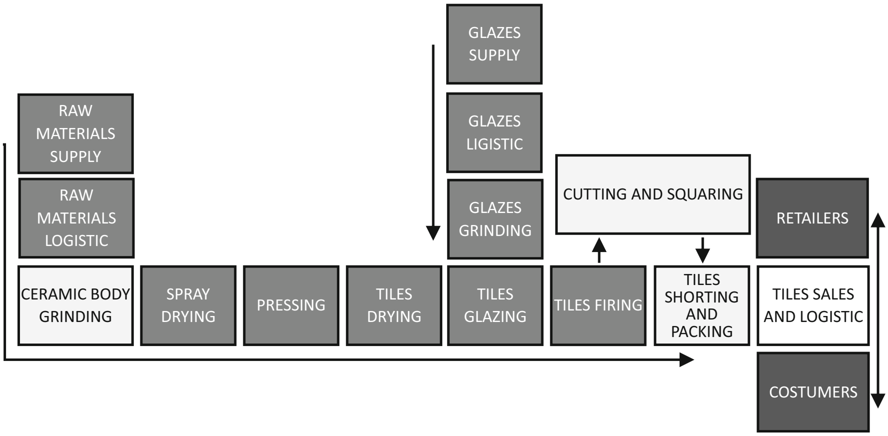

Fig. 30.1 Flow chart of the steps of ceramic tile manufacturing process. (Sources: Adapted from Garcia-Muiña et al. 2018)

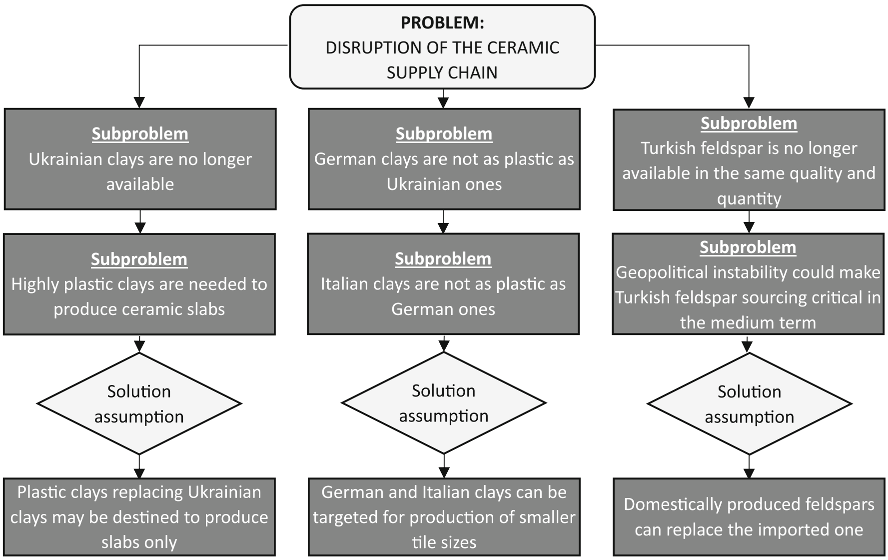

Fig. 30.2 Framework for the functional decomposition of critical issues in the Italian ceramic industry sourcing system

subproblems (Guo et al. 2021). Following this logic, Fig. 30.2 shows the functional decomposition scheme of the main complex problem and three possible solutions.

In the case of the ceramic industry, the main problems can be decomposed into three main subproblems: (1) Ukrainian clays are no longer available, (2) German clays are not as plastic as Ukrainian clays, and (3) Turkish feldspar is no longer available in the same quantities with the same quality. Corresponding to these are three other subproblems: (1) plastic clays are needed to produce large ceramic slabs, (2) Italian clays are not as plastic as German clays, and (3) regional geopolitical tensions could make the Turkish feldspar sourcing system critical in the medium term. Following the logic of abductive inference already adopted in other managerial studies (Zucchella and Previtali 2019; Settembre Blundo et al. 2019), the following three corresponding explanatory hypotheses were assumed for each of the three subproblem categories: (1) alternative plastic clays to Ukrainian clays, given their low availability in terms of quantity, could be destined exclusively for the production of the large slabs; (2) Italian and German clays, of lower plasticity than Ukrainian ones and available in larger quantities, could be destined for the production of the smaller sizes of ceramic tiles; and (3) sodium, sodium-potassium, and potassium feldspars could be more widely used for at least partial replacement of imported ones.

30.4.2 Strategic Design of Sourcing Alternative

Following the criticality functional decomposition scheme (Fig. 30.2) and abductive inference, five possible ceramic body compositions (S1÷S5) were hypothesized as alternatives to the sector average (S0), as shown in Table 30.2.

The S0 composition represents the average for the Italian industry, obtained by cross-referencing data on raw material arrivals by ships at the port of Ravenna and trains directly to the Sassuolo ceramic district before the spread of the pandemic and the war in Ukraine. Compositions S1, S2, and S3 correspond to the solution assumptions presented in the sectoral scenario analysis. On the other hand, compositions S4 and S5 consider a type of raw material not currently considered in tile production: red bed clays (Fiori et al. 2011; Vázquez and Jiménez-Millán 2004). These materials are rich in iron oxide and were mined and used as the main raw material for tile production in Italy and Spain, giving the ceramic body a characteristic red color. With the S4 and S5 compositions, ancient materials are recovered to

Table 30.2 Overview of ceramic body compositions corresponding to different sourcing scenarios

		S0	S1	S2	S3	S4	S5
Raw materials	Sourcing criticisms	Ceramic composition percentage (%)					
High plasticity ball clay	5 (Ukraine)	25	10				
Medium plasticity ball clay	2 (Germany)	10	25	30	30	25	20
Low plasticity kaolinitic clay	1 (Italy)	10	10	15	30	25	30
Medium plasticity red beds clays	3 (Italy)					10	15
Sodium feldspar	4 (Turkey)	35	35	35	20	20	15
Potassium feldspar	1 (Italy)	10	10	10	15	10	10
Quartz sand	1 (Italy)	10	10	10			

Table 30.3 Chemical composition and criticism level of ceramic body sourcing

wt%	S0	S1	S2	S3	S4	S5
SiO_2	67.70	68.76	69.73	69.79	69.02	68.82
Al_2O_3	19.42	18.40	17.46	17.35	17.46	17.24
Fe_2O_3	0.85	0.89	0.91	1.09	1.67	2.03
TiO_2	0.64	0.64	0.59	0.56	0.57	0.54
MgO	0.44	0.42	0.40	0.,38	0.57	0.65
CaO	0.87	0.86	0.86	0.61	0.56	0.53
Na_2O	3.99	3.94	3.97	2.60	2.72	2.34
K_2O	2.47	2.37	2.44	3.22	3.14	3.41
Criticism level	3.15	2.70	2.35	1.90	2.05	1.95

reduce the criticality of the supply chain. Therefore, with their use, the aim was to rebalance the clay component of the ceramic body to the advantage of a local raw material (S4) and reduce the amount of imported feldspar due to the iron acting as a melting agent (S5). Table 30.2 also provides an estimate of the level of supply criticality for each raw material considered and expressed on a scale of 1 (very low) to 5 (very high). The highest criticality is attributed to Ukrainian clay due to supply disruption, followed by Turkish sodium feldspar due to quality problems and regional geopolitical instability. Red bed clays have a medium criticality since their mines have been closed, and restoring operations could take a long time or be refused by the regulatory authorities.

Table 30.3 shows the chemical analysis and criticism level of the alternative compositions to the one before the supply problems occurred (S0). The use of fewer plastic clays causes a gradual decrease in the amount of aluminum oxide, and red bed clays instead cause an increase in the amount of iron oxide. As a result, the new compositions should have less plasticity and a darker color. The technological feasibility of these assumptions should be confirmed with empirical evidence.

30.4.3 Environmental Assessment of Sourcing Alternative

The environmental performance of alternative scenarios is determined by the life cycle assessment (LCA) following the midpoint analysis approach to determine the global warming potential (GWP) as a key indicator (Saracevic et al. 2019).

The LCA analysis was conducted following the ISO 14040 and ISO 14044 standards. 1 m^2 of porcelain tiles as a functional unit with a mass of 21 kg/m^2 corresponding to the average value of the Italian ceramic industry. Instead, the system boundaries comprise the stages of raw material extraction and transportation to the manufacturing units (Cucchi et al. 2022), assuming the rest of the phases are similar among the different scenarios. In addition, in this environmental prediction, it was decided to calculate the impact of logistics activities based on the GWP as a key

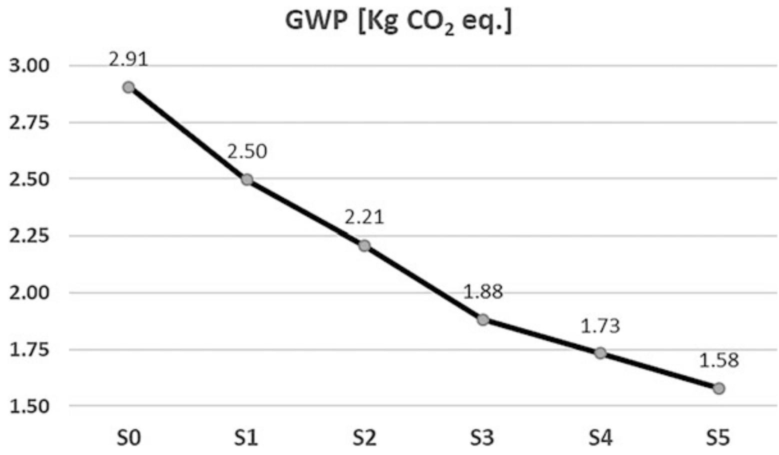

Fig. 30.3 Global warming potential (GWP) of 1 m^2 of porcelain tiles, referring to the phase of extraction and transportation to factories of different compositions of ceramic bodies

indicator directly related to transportation consumption. Figure 30.3 shows the results clearly showing that the strategies of reshoring (compositions S1–S3) and nearshoring (compositions S4 and S5) for raw material sourcing result in a reduction in CO_2 emissions.

30.4.4 Technological Performance Analysis

The different sourcing scenarios were tested in a laboratory environment to verify their actual industrial feasibility. For this purpose, the six body compositions were processed following a laboratory protocol capable of reproducing industrial operating conditions. The 646 × 646 mm prototypes were fired at a maximum temperature of 1220 °C with a 40-min cycle. Table 30.4 shows the results obtained.

Under current ISO standards for ceramic tiles, the following technological parameters were checked: dimensional compliance (ISO 10545-2); water absorption compliance (ISO 10545-3); and bending strength (ISO 10545-4). All compositions comply with standards, and only composition S5 is dimensionally slightly below acceptable thresholds. To solve this problem without intervening in the formulation of the body, it would be sufficient to reduce the nominal length that is set by each manufacturer. An average length, representative of the entire industry, was adopted for this study. These tests allowed us to demonstrate through a laboratory protocol the technological feasibility of reshoring scenarios (S1÷S3) or nearshoring (S4-S5) without intervention in the production process.

Table 30.4 Technological properties of the ceramic bodies

Technological performance	Composition of ceramic bodies					
	S0	S1	S2	S3	S4	S5
Sourcing strategy	Start point	Reshoring			Nearshoring	
Length (nominal L = 604 mm)	603.8	603.5	603.1	602.9	602.5	601.9
Dimensional conformity (ISO 10545-2)	L ± 2.0 mm	L ± 2.0 mm	L ± 2.0 mm	L ± 2.0 mm	L ± 2.0 mm	L ± 2.0 mm
Water absorption (%)	0.29	0.31	0.35	0.41	0.28	0.18
Water absorption conformity (ISO 10545-3)	≤0.5%	≤0.5%	≤0.5%	≤0.5%	≤0.5%	≤0.5%
Bending strength (N)	1780 ± 1	1759 ± 1	1734 ± 1	1691 ± 1	1682 ± 1	1715 ± 1
Bending strength conformity (ISO 10545-4)	≥1300 N	≥1300 N	≥1300 N	≥1300 N	≥1300 N	≥1300 N

30.5 Conclusions

In this study, functional decomposition was applied to analyze the complexity of the material supply chain for the Italian ceramic tile manufacturing industry and identify solutions to the critical issues that the pandemic and geopolitical tensions have generated since 2020. It is also highlighted that complex problems need to be analyzed through a transdisciplinary approach, which, supported by both technical and managerial disciplines, can capture the interdependencies between the variables at stake. The context analysis allowed three assumptions as possible solutions to the sudden interruption of plastic clay supplies from Ukraine. In one case, for large ceramic slabs that represent a niche, the use of the few very plastic clays that may still arrive from Ukraine or other places being identified may be envisaged. On the other hand, for conventional ceramic tiles, nearshoring and reshoring of sourcing systems are strategies that might be considered. These scenario assumptions were validated in a laboratory to demonstrate their technical feasibility. Five porcelain ceramic bodies were formulated and tested from both technical and environmental impact perspectives. Making use of European and local clays and feldspars, compositions were proposed that were less critical from a sourcing system viewpoint than the average industry composition in use before the pandemic and geopolitical crisis. Laboratory tests have shown that all solutions could be industrialized and comply with ISO standards for ceramic tiles. Finally, the environmental assessment, focusing on global warming potential (GWP) as an impact category of life cycle assessment (LCA) analysis, showed how moving mining sources closer to production factories significantly reduces CO_2 emissions from transportation. From the managerial perspective, this research contributes to the knowledge of the combined effects of pandemic and geopolitical tensions on production chains through the transdisciplinary approach. The ceramics industry analysis, as an example of a raw material-intensive sector, also shows that the implementation of nearshoring and reshoring strategies not only reduces sourcing risk but also decreases environmental impact with direct benefits on the overall production process. These results also offer important implications for practitioners because the empirical analysis of a major European manufacturing industry demonstrates that the complexity of the business environment can be most successfully addressed by a holistic approach between engineering and management skills. Finally, the limitations of this research must be emphasized. First, the analysis conducted on the Italian ceramic industry would like to replicate the Spanish one because of their similarities. The unavailability of primary data prevented conducting a parallel study. Thus, strategic scenario analysis lacks the economic assessment that is fundamental to any business decision. This research was conducted at a time of uncertainty and volatile prices of raw materials and other production inputs, making any economic forecast unrepresentative.

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Chapter 31
Definition of Indicators Relating to the Extraction of Minerals Used in the Ceramic Sector for LCA

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Abstract Among the main criticalities that the ceramic supply chain has to address in the logic of industrial symbiosis is the difficulty of finding primary data relating to the processes of supplying raw materials and the distribution and use of the final product. As part of the Mise REDuce REuse Ceramic Tiles (REDiRECT) project (https://www.redirect.gresmalt.it/), which aims to design and validate a Circular Industry 4.0 model, the environmental sustainability of the extraction processes of raw materials used in ceramic production was evaluated using the Life Cycle Assessment methodology. The study was based on the definition of new indicators related to the depletion of the mineral Eurite in the IMPACT 2002+ calculation method, which allow the environmental damage due to the extraction of the mineral resource to be attributed dynamically. Finally, through an environmental impact assessment using the life cycle assessment methodology, it was shown that the damage categories obtained from the new indicators affect the total damage related

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to the extraction and processing of the resource by a value within the range [0.20%; 1.96%].

Keywords Life cycle assessment · Mineral extraction · Circular Industry 4.0 · Mining · Depletion of natural resources

31.1 Introduction

In life cycle assessment (LCA) studies related to the building sector, analysts encounter difficulty in finding primary data for raw material extraction processes. This lack of data is currently addressed by the adoption of secondary data, mainly through the use of database processes, which are fundamental in the representation of background processes but may deviate from the reality under investigation. Consequently, a large amount of secondary data can greatly influence the final result of an environmental assessment. In addition, in the literature, there are LCA analyses related mainly to metal ores (Farjana et al. 2019), precious metals (Islam et al. 2020), and rare earths (Bailey et al. 2020), while studies related to minerals used in the ceramic sector, as well as LCA assessments of national mining sites, are not available. To address this gap in relation to the supply of raw materials, within the framework of the Mise REDuce REuse Ceramic Tiles (REDiRECT) project (https://www.redirect.gresmalt.it/), which aims to design and validate a Circular Enterprise 4.0 model, the environmental sustainability of the mining processes of raw materials used in ceramic production was assessed by means of the LCA methodology, according to ISO 14040 and ISO 14044 (UNI EN ISO 2021). Specifically, this work focused on the extraction and processing of the mineral Eurite, used in the ceramic sector as a replacement or partial replacement for common feldspars, obtained from the "La Crocetta" mine located in Porto Azzurro on the Island of Elba (LI) by the mining company Eurit S.r.l. In particular, to create a site-specific inventory with a high level of representativeness of the reality, not only were the mining processes specific to the reality analyzed modelled, but new indicators related to the depletion of the mineral Eurite were also introduced in the IMPACT 2002+ calculation method (Jolliet et al. 2003), which was used by the authors for the environmental impact assessment. This modification to the calculation method should have concerned the *mineral extraction* category, which allows environmental damage to be attributed to the inventory data relating to the extracted resource, but instead a new dynamic and time-varying category was created, i.e., dependent on the year in which the resource was extracted. Indeed, it is the authors' belief that environmental damage should increase as the availability of the resource decreases over time. Finally, with the Life Cycle Assessment (LCA) analysis, the incidence of the damage categories thus created was analyzed with respect to the total damage due to the entire mineral extraction and processing. It should be noted that, for confidentiality reasons, it was not possible to report the numerical values of the inventory data, so the procedures adopted are only illustrated qualitatively.

31.2 Material and Methods

31.2.1 Introduction of Eurite Mining Indicators Within the IMPACT 2002+ Method

The function of the calculation method is to connect the inventory data, i.e., the quantity of extracted resources, with the corresponding damage, i.e., the depletion of resources (generally expressed by the *mineral extraction* category). This conversion is done by defining appropriate factors, which are applied successively in the various steps of impact analysis. First, as many impact categories, expressed in tons of extractable resources, as the years of extraction licence were introduced to account for the variability of the increasing damage due to the rarefaction of the resource, and a new resource, *Eurite x year*, not previously evaluated by the method, was included within the categories. This new resource was associated with an initial factor, called the characterization factor (F_C), equal to 1 ton of extractable resource/ton of extracted resource. As a precaution, the unit value was set as the resource extracted in the inventory corresponding to the extractable resource according to the impact category created. Related damage categories were also created. For the normalization step, which consists of relating the characterized impact to a reference value, i.e., the annual consumption of the site, expressing it as extractable ton of resource/ annual ton of resource consumed, a normalization factor F_{norm} was inserted into the method. In particular, the annual resource consumption was taken as the reference since it was assumed that resource extraction equals resource consumption. The annual consumption was estimated by assuming to add to the primary data provided of extracted finished product, a part of Eurite that is extracted but leaves the system as air emission or remaining trapped in the bag filters of the extraction equipment. The normalization factor was derived from the following equation (Eq. 31.1):

$$F_{\text{norm}}\left[\frac{\text{year}}{\text{ton}}\right] = \frac{1}{\text{annual site} - \text{specific resource consumption}\left[\frac{\text{ton}}{\text{year}}\right]} \tag{31.1}$$

Therefore, it can be affirmed that F_{norm} appears to be the inverse of the annual resource consumption for the site under analysis. Furthermore, it was assumed that the annual consumption remained unchanged during the years of the mining licence, and in particular, it was decided to consider an average value since the real value would only be obtained at the end of each specific year. Consequently, the F_{norm} factor also remains unchanged during the mining licence years, so there is only one normalization factor valid for each year of extraction. For the weighing step, which aims to assign a weight to the category, the comparison was made between the annual resource consumption of the site under analysis compared to the total resource availability, which was calculated net of consumption that occurred in previous years. For the calculation, it was decided not to take into account the Eurite present on the site at the end of the mining works, as it is characterized by a considerably lower quality that is not suitable for the ceramic sector. Consequently, the weighting factor F_{weight} was derived from the following equation (Eq. 31.2):

$$F_{\text{weight}}\left[\frac{1}{\text{year}}\right] = \frac{\text{annual site} - \text{specific resource consumption [ton/year]}}{\text{total availability of the site resource [ton]}} \tag{31.2}$$

As many weighing factors as the years of extraction of the resource were included in the method. F_{weight} increases with the passing of the years; in fact, the damage resulting from the extraction and consumption of the resource should depend on the year of extraction since the availability of the resource gradually decreases with time, e.g., the damage associated with Eurite extracted in the first year of activity should be lower than that associated with Eurite extracted in the last year of the mining licence. As an example, the following is an application of the indicators thus derived to calculate the environmental damage associated with Eurite mining:

Characterization (Eq. 31.3):

$$\text{inventory data}\left[\frac{\text{ton}}{\text{year}}\right] * Fc\left[\frac{\text{ton}/\text{year}}{\text{ton}/\text{year}}\right] = \text{extractable site} - \text{specific resource}\left[\frac{\text{ton}}{\text{year}}\right] \tag{31.3}$$

Normalization (Eq. 31.4):

$$\text{extractable site} - \text{specific resource}\left[\frac{\text{ton}}{\text{year}}\right] * F_{\text{norm}}\left[\frac{\text{year}}{\text{ton}}\right] = \text{annual exctractable resource over annual resource consumption}\left[\frac{\text{ton}/\text{year}}{\text{ton}/\text{year}}\right] \tag{31.4}$$

Weighing (Eq. 5):

$$\text{annual exctractable resource over annual resource consumption}\left[\frac{\text{ton}/\text{year}}{\text{ton}/\text{year}}\right] * F_{\text{weight}}\left[\frac{\text{ton}/\text{year}}{\textit{ton}}\right] = \text{annual resource } \textit{consumption} \text{ over resource availability}\left[\frac{\text{ton}/\text{year}}{\text{ton}}\right] \tag{31.5}$$

31.3 Life Cycle Assessment

31.3.1 Goal and Scope Definition

The objective of the study is the environmental impact assessment, through the LCA methodology, of the damage due to the extraction and processing of the mineral Eurite, i.e., porphyritic aplite, a fine-grained magmatic rock composed of potassic feldspar, quartz, and clay minerals, with possible carbonate alteration. It is a mineral obtained from the La Crocetta mine located on the Island of Elba (LI) and operated by the Eurit S.r.l. mining company.

31.3.2 System, Functional Unit, and Function of the System to Be Studied

The function of the system is the production of Eurite for the ceramic industry as a replacement or partial replacement for common feldspars. The system studied is the La Crocetta mine located on the island of Elba (LI). The functional unit was set as 1 ton of Eurite extracted and processed. This unit quantity was chosen to respect the confidentiality constraint, so the analysis is only representative.

31.3.3 System Boundaries

According to the cradle-to-gate approach, the system boundaries include all phases from the removal of the scotic on the Eurite cultivation area to the delivery of the finished product to the end customer.

31.3.4 Data Quality

To realize a site-specific LCI with a high level of representativeness of reality, a high percentage of primary data was used. In particular, the primary data provided included the quantity of finished product obtained annually, data on the mining site, and data on the individual processing stages in terms of energy consumption, machinery, and hours of use. When absent, data were estimated, or literature data or data taken from commercial websites were used. The method used for the damage calculation is IMPACT 2002+ (Jolliet et al. 2003) modified by the study group (Pini et al. 2014) (Ferrari et al. 2019) and implemented with the damage indicators described in Sect. 1.2.1. The calculation code used is SimaPro 9.3 (Pré Sustainability

SimaPro 2022), while the database is Ecoinvent database v.3.8 (Ecoinvent Center 2021).

31.4 Results and Discussions

To obtain a qualitative analysis, the functional unit used to calculate the damage was one ton of resource extracted. In particular, the damage assessment showed a total damage of 3.24E-2 Pt, of which 61.65% was due to the delivery of Eurite to the end customer. The end-point analysis shows that 30.83% of the total damage is due to the damage category *Human health* in particular for the substance *Particulates, < 2.5 μm* (29.78%). The second largest contribution is provided by *resources* with 20.85%, mainly due to the substance *coal, hard, in raw* (36.40%), followed by *climate change* for 20.62% with the substance *carbon, dioxide, fossil* (92.76%). *Ecosystem quality* affects 12.03% for the substance *zinc in soil* (42.46%). These damage categories are mainly affected by the transport process of the finished product to the final customer located in the Sassuolo ceramic district. The damage categories referring to the depletion of the Eurite resource identified in the present work are characterized by environmental damage within the range [6.35E-05 Pt; 6.35E-04 Pt]. On a percentage level, these damage categories affect the total damage by range values [0.20%; 1.96%]. The reason why it was decided to report a range of values is because the damage referred to the depletion of the resource is dynamic and varies depending on the year the resource was extracted; however, as mentioned in Sect. 1.1, for reasons of data confidentiality, it was not possible to indicate the number of years the resource was extracted and consequently the number of damage categories referred to the depletion of the resource specific to each year of extraction. Finally, entering more specifically into the mining activity and excluding the process relating to the transport of the finished product to the end customer, it emerged that, at the end-point level, 30.64% of the total damage was due to *Human health* for the substance *Particulates, <2.5 μm, in air* (31.52%) due to the emission of fine particulates generated during the particle size reduction.

31.5 Conclusions and Future Developments

This work focused on the identification and introduction of new indicators referring to the depletion of the Eurite resource, a mineral intended for the ceramic sector as a replacement or partial replacement for common feldspars, not assessed by the IMPACT 2002+ damage calculation method, to attribute environmental damage to the inventory data referring to the extracted resource. In particular, these new indicators allow us to connect the extracted resource inventory data with the relative damage caused by the depletion of the resource. This was made possible through the use of parameters, such as the annual site-specific resource consumption, assumed to be equal to the annual quantity of extracted resource, and the availability of the resource estimated on the basis of the years of extraction licence. The variability of this damage over time is the result of the authors' belief that environmental damage should increase as the availability of the resource decreases. Damage assessment analysis was performed using the LCA methodology, which showed that 1 ton of Eurite mined and processed produces an environmental damage of 3.24E-2 Pt and the damage categories related to the depletion of the Eurite resource affect the percentage level in the range [0.20%; 1.96%] with a value in terms of damage point varying in the range [6.35E-05 Pt; 6.35E-04 Pt]. The present work also includes a number of significant limitations that may translate into possible future perspectives, such as the assumption of an unchanged annual resource consumption over the years of the mining licence. This assumption was made since the actual amount could be known only at the end of each specific year. It follows that a possible future development could be to introduce realistic resource consumption for each year of extraction into the method. Another assumption was to calculate the availability of Eurite as the amount of ore mined annually multiplied by years of mining licence, without taking into account the Eurite remaining on site at the end of mining. This assumption was necessary since all Eurite with suitable characteristics for the ceramic sector is mined during the set time frame, so the remaining resource may no longer be applicable in the ceramic sector.

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Chapter 32
Personal Protective Equipment Recycling Scenarios for the Production of Reinforced Bituminous Conglomerates

Mattia Gianvincenzi, Marco Marconi, Enrico Maria Mosconi, and Francesco Tola

Abstract Due to the COVID-19 pandemic, global personal protective equipment (PPE) volume demand increased by 300–400% between 2019 and 2021. In Italy, in 2021, an average quantity of 473 tons of masks and 958 tons of gloves were disposed of in landfills or incinerated daily. This study aims to propose and validate an innovative circular-economy-based supply chain for PPE waste, reusing waste polymeric textile fiber derived from PPE to produce reinforced bituminous conglomerates. Several studies have confirmed the value of plastic in the mixture for asphalt production to extend its useful life. Despite that, none of these studies investigated the potential of the PPE; therefore, the scenario of this study is unique in the scientific panorama. The results demonstrate the feasibility of the proposed scenario. Using end-of-life masks and gloves in the mix, improvements were observed in the asphalt in terms of indirect tensile strength, stiffness, and ductility. From an environmental point of view, a longer lifespan and less material usage lead to a reduction in long-term impacts. At the same time, the reduction in the disposal of PPE in landfills and incinerators means a significant reduction in the environmental impact of masks.

Keywords Sustainable EoL · PPE reuse · Green cities · Closed loop · Reinforced asphalts · Waste management

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32.1 Introduction

During the COVID-19 pandemic, the production of personal protective equipment (PPE) has grown considerably. In detail, in the period spanning from 2019 to 2021, it is estimated that the global PPE volume request expanded to three or four times that of pre-pandemic figures (FCDO 2020). There are different types of PPE, but masks were the most relevant flow, with an increase of 25 to 30 times over the course of a year, transitioning from less than 5% of the total PPE market share in 2019 to over 25% in 2020 (FCDO 2020). This is mainly because protective masks were recommended (even imposed) to the entire population throughout the pandemic period (Barbanera et al. 2022). However, the largest market share among PPE is gloves, which accounted for 60–70% in 2019 and 2020, with their demand experiencing a surge of roughly one-third during the year. Globally, estimates suggest that on a monthly basis, the usage necessitating subsequent disposal encompasses approximately 129 billion gloves and 65 billion masks (WHO 2022). To get even more specific, the situation of Italy (Table 32.1) was taken as an example (ISPRA 2021). Considering that approximately 72% of PPE is made up of PP (Harussani et al. 2022) and a 50/50 division between nitrile and latex gloves (FCDO 2020), in Italy alone in 2021, there was an annual production of 126,789.252 t of PP waste, 174,771.855 tons of nitrile and latex waste.

Therefore, this study aims to investigate the feasibility of a circular economy model for the sustainable management of the end of life of surgical masks and gloves by highlighting the environmental benefits that would lead to the reduction of the impacts generated by the consequences of the COVID-19 pandemic.

32.2 Literature Review

Several scientific literature studies have investigated the use of plastics in asphalt mixtures (Appiah et al. 2017; Biswas et al. 2020; del Rey Castillo et al. 2020). An interesting study evaluated at the laboratory scale the use of three commercially

Table 32.1 Estimations on the use of masks in Italy

	Year	U.M	2020	2021	2025
Masks	Daily requirement	n° (mln)	37.5	43.3	3.6
	Daily waste production	t	410	473.1	39.4
	Annual requirement	n° (mln)	13,687.5	15,792.6	1316.1
	Annual waste production	t	149,650	172,665.9	14,388.85
Gloves	Daily requirement	n° (mln)	75	86.6	63.7
	Daily waste production	t	830	957.7	705,5
	Annual requirement	n° (mln)	27,375	31,585.3	23.267,8
	Annual waste production	t	302,950	349,543.7	257,497.2

Sources: (FCDO 2020; ISPRA 2021)

available recycled plastic products in the same asphalt mixture for the purpose of extending and modifying the binder. The results confirmed that the recycled plastic improved deformation and fracture resistance, had minor effects on moisture resistance, and increased the structural contribution of asphalt to pavement (White and Reid 2019). In addition, the use of textile fibers derived from the disposal of end-of-life tires to produce reinforced asphalt was tested. The application has shown increased asphalt drainage, leading to a significant increase in fatigue resistance (Landi et al. 2018, 2020). Closely related to the present study is a recent experimentation about the introduction of shredded face masks (SFM) in a recycled concrete aggregate (RCA) for base/subbase flooring applications (Saberian et al. 2021). In the experimental program, shredded surgical masks (without nose pads and ear loops) 0.5 cm in width and 2 cm in length were used. The chopped templates were mixed with 1%, 2% and 3% (wt%) dry RCA, with an observed increase in strength and stiffness but also improvements in terms of the suppleness and flexibility of the RCA/SFM blends. The scenario of the present study is configured as original since the use of PPE as reinforcement in bituminous conglomerates has never been investigated in previous research or development experiences, as also confirmed by a patent search in the Orbit database. At the same time, the scenario seems feasible because it is based on very widespread ideas such as the use of reinforcements in construction materials.

32.3 Material and Methods

Through the context analysis and the literature review, the study was oriented towards the experimentation of an innovative product based on the reuse of PPE, widely used during the COVID-19 pandemic, and currently disposed of in landfills or incinerated. The product will be a bituminous conglomerate intended for construction and civil markets, particularly for the construction and maintenance of road infrastructures. Four different bituminous conglomerates were tested, one representing the reference scenario without the use of PPE and three mixing bitumen with PPE in percentages representing realistic scenarios based on previous studies: (1) reference hot mix asphalt (HMA) bituminous conglomerate, without PPE; (2) HMA bituminous conglomerate with masks; (3) HMA bituminous conglomerate with masks and gloves; and (4) warm mix asphalt (WMA) bituminous conglomerate with masks. The details of the tested mixtures are reported in Table 32.2.

Several tests were performed during the experimental phase. For each mixture, four specimens were compacted with a rotary press according to the UNI EN 12697-31 standard. The void content of these specimens was measured according to the UNI EN 12697-6 standard using the dry method. Subsequently, the specimens were broken in an indirect tensile configuration according to the UNI EN 12697-23 standard. From this test, the indirect tensile strength (Rt), the indirect tensile coefficient (CTI) and the cracking tolerance index (CT-Index) were determined. Furthermore, bitumen extraction (UNI EN 12697-1) and then a visual analysis of the

Table 32.2 Tested bituminous conglomerates

Mixture	Components
Mixture 1 Standard HMA	Virgin aggregate 80%, T = 180 °C Milled 20%, T = room temperature Virgin bitumen 4.3% (total bitumen approximately 5.3%), T = 150 °C
Mixture 2 HMA – Masks	Virgin aggregate 80%, T = 180 °C Milled 20%, T = room temperature Virgin bitumen 4.3% on the mix (total bitumen approximately 5.3%), T = 150 °C PPE masks (75% PP masks, 25% PET/PBT masks) = 0.5% on the aggregate, T = room temperature
Mixture 3 HMA – masks +gloves	Virgin aggregate 80%, T = 180 °C Milled 20%, T = room temperature Virgin bitumen 4.3% on the mix (total bitumen approximately 5.3%), T = 150 °C PPE masks + gloves (45% PP masks, 15% PET/PBT masks, 20% latex gloves, 20% nitrile gloves) = 0.5% on the aggregate, T = room temperature
Mixture 4 WMA – Masks	Virgin aggregate 80%, T = 145 °C Milled 20%, T = temperature 4.3% virgin bitumen on the mixture (total bitumen approximately 5.3%), T = 150 °C Iterlow type additive 0.5% on the weight of the bitumen (to be mixed with the bitumen before adding it to the mix) PPE masks + gloves (75% PP masks, 25% PET/PBT masks

residual solid material was carried out on the loose bituminous conglomerate collected at the end of the mixing to evaluate the effect of the high processing temperatures on PPE. The environmental benefits, instead, have been preliminarily estimated on the basis of literature data derived from previous studies on similar topics, conducted by using the life cycle assessment methodology (Barbanera et al. 2022; Landi et al. 2018).

32.4 Results and Discussions

The results of the tests (Fig. 32.1) show that the introduction of the masks increases the content of the voids and therefore the porosity, passing from 4.5% to 6.5% in mixture (2) and even to 8.5% in mixture (4). As porosity increases, mechanical strength generally decreases because the bonds between the granules of the conglomerate decrease. This can be explained through the visual analysis, which shows a large amount of masks that did not dissolve and remained present among the aggregate granules in the form of fibrous filaments. In the case of mixture (3) with masks and gloves, the nitrile component, with a melting point of approximately 120°, melted and was incorporated into the binder, increasing its volume and reducing its voids, reaching a similar result to mixture (1). Most likely, an even higher percentage of gloves would lead to a lower porosity. Regarding the indirect tensile strength, mixtures (1) and (2) have a similar result, while mixture (3) has a

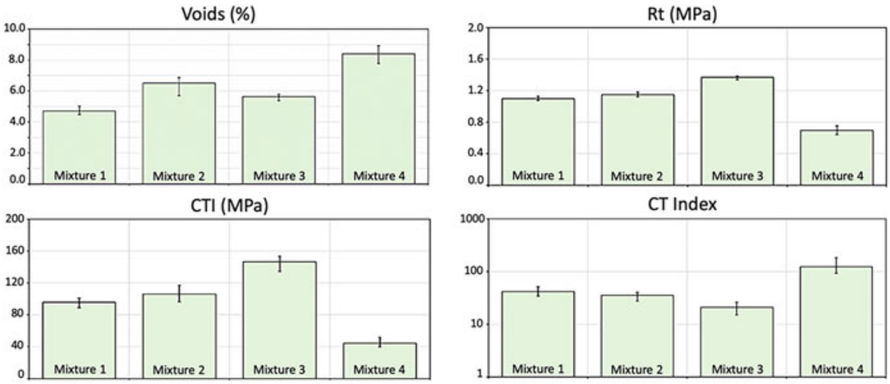


Fig. 32.1 Void, Rt, CTI and CT-Index test results

25% higher (Rt) than the first, and mixture (4) is nonclassifiable. The same trend is also observed for the CTI in which mixture (2) shows a slight improvement in stiffness and ductility, mixture (3) shows a significant improvement of 50%, and mixture (4) worsens the characteristics originating in the standard HMA. Greater stiffness in certain soil conditions (i.e., stable grounds) allows asphalt to last longer. In contrast, regarding crack resistance, mixture (4) leads to the best results, while mixture (3) has the worst crack resistance.

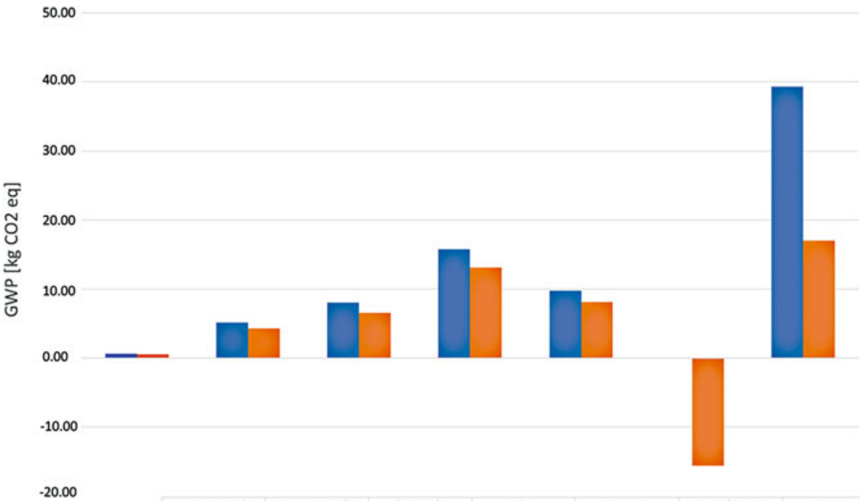
By deriving data from the abovementioned LCA studies, it was possible to carry out a preliminary environmental assessment considering the materials used to produce and maintain 1 m^2 of asphalt in a time horizon of 30 years. On the basis of a previous LCA on reinforced bituminous conglomerates (Landi et al. 2020) and of the present tests, it was possible to deduce that a road pavement made with mixture (3) (i.e., the most promising) has a life span higher than the standard HMA mixture with an increase of 17% for base, 10.7% for binder, and 12.5% for wearing course layers. Table 32.3 reports the materials used to produce 1 m^2 of asphalt using HMA + Mask/Gloves.

Figure 32.2 shows the results of the simplified environmental assessment in terms of the global warming potential (GWP) midpoint indicator, obtained by comparing mixture (1) and mixture (3) with the split of contributions for each material. Regarding the amount of masks/gloves, analogous to the study (Barbanera et al. 2022), approximately 1680 of the PPE between masks and gloves were used in 1 m^2 of asphalt for a duration of 30 years. These PPEs are recycled instead of disposed of in incinerators or landfills, avoiding polluting the environment.

According to Fig. 32.2, the reuse of masks and gloves significantly impacts the result, which indicates how the mixture (3) scenario impacts the environment with a GWP index of less than 56.79% compared to the standard HMA. In addition to this item, the lower impacts of the other materials must be considered. As described above, the life cycle of the reinforced asphalt is greater, which results in fewer pavement remakes over the time horizon considered.

Table 32.3 Inventory of materials to produce and maintain 1 m^2 of asphalt for 30 years

Materials	HMA + Mask/Gloves mixture					
	Base %	Binder %	Wearing %	Tot mass (kg)	Tot mass %	GWP kgCO2eq
Limestone12/20	16	16	32.3	199.6	20.2	0.5424
Limestone 8/16	30	30	32.3	366.7	37.1	4.2792
RAP	17.9	15	0	121.6	12.3	0
Sand 0/4	30	31.7	23	229.3	23.2	6.5844
Filler	1.8	2	6.1	42.5	4.3	13.0944
Bitumen	4	5	6	23.7	2.4	8.1048
Mask/gloves	0.5	0.5	0.5	4.9	0.5	−15.6147
				988.3	100	16.9910



	Limestone12/20	Limestone 8/16	Sand 0/4	Filler	Bitumen	Mask/Gloves	Total
Standard HMA	0	5.16	8.03	15.72	9.74		39.32
HMA+Mask/Gloves	0	4.27	6.58	13.09	8.10	-15.61	16.99

Fig. 32.2 GWPs of standard and reinforced HMA

32.5 Conclusions

As a first conclusion, it is possible to confirm the technical feasibility of the proposed scenario since the reuse of PPE waste as asphalt reinforcements does not lead to a worsening of the performance of the original asphalt. Second, the use of gloves together with masks, recommended due to the presented forecasts for 2025, has given promising results, as nitrile and PP significantly improve tensile strength, stiffness, and ductility compared to other blends. Third, the use of masks and gloves seems to significantly reduce the GWP related to road pavement construction and maintenance. Further studies will focus on the experimentation of additional mixtures by increasing the dosage of masks/gloves. Indirect tensile stiffness modulus and fatigue resistance laboratory tests are required to better estimate the potential useful life of the PPE-reinforced asphalt, as well as testing of mixtures in operating environments. Finally, full LCA, cost, and social LCA studies will be performed to establish the sustainability benefits.

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Chapter 33
Environmental Performance and Efficiency in the Semiconductor Fabrication Sector

Marcello Ruberti

Abstract Semiconductor manufacturing has followed the fate of a large part of industrial production: many companies, around the world, have maintained higher functions (design and engineering) and outsourced other production stages to third-party manufacturers, located mostly in Asia. Chip companies have thus become "fabless" firms, commissioning their product "fabrication" to wafer "foundries" or "fabs." The aim of this chapter is to investigate, by elaborating the most important key environmental performance indicators (KEPIs) of corporate social responsibility (CSR) reports, the environmental performance and efficiency of the world's leading semiconductor foundries. The result is that, unlike what happens in many other sectors, in the semiconductor industry, larger company size and advanced products are not always related to lower quantities, per unit of production, of energy, waste and GHG emissions. It is hoped that, for the future, those foundry firms with the most advanced technologies will invest much more to optimize their energy use and to adopt efficient recovery and recycling systems to further reduce the amount of their GHG emissions and waste, especially of hazardous ones.

Keywords Chips · Foundries · CSR reports · KEPIs · Energy · Emissions · Waste

33.1 Introduction

Semiconductors or semiconductor devices are also known as chips, microchips, or integrated circuits (ICs). They are not only the beating heart of the digital age in which we live but also the key strategic tools of current and future global geopolitical assets and digital and energy transition policies (US 116th Congress 2020; US 117th Congress 2020; European Commission 2022), being critical components in many different fields (consumer and industrial electronics, telecommunications, automotive, military equipment, etc.). According to the World Semiconductor Trade

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Statistics (WSTS 2022), the global semiconductor market, in 2021, reached a total revenue of over US $ 550 billion, up 26.2% compared to the previous year; nearly one-fifth of this revenue (i.e., US $ 107.5 billion) is attributable to the wafer fabrication sector only (TrendForce 2022). Semiconductor manufacturing is one of the most complex, globalized, and interlinked industrial supply chains in the world (Varas et al. 2021). It basically consists of three major steps or phases, each of them with high know-how intensity levels (core intellectual property, IP): (1) Design; (2) "Fabrication"; and (3) "Assembly, Testing and Packaging" (ATP). All three phases can be carried out: (a) in-house (rarely), by a single company ("integrated device manufacturer" or IDM), as for Intel; (b) or, as is much more common, by different agents. In fact, a company ("design-only firm" or "fabless firm"), such as AMD, Qualcomm, Broadcom, Texas Instruments (TI), and ST Microelectronics, could simply design its ICs and outsource some other phases, e.g., wafer fabrication to a specific facility ("pure play foundry" or "fab") and the ATP stage to an "outsourced semiconductor assembly and testing (OSAT) firm" (Khan et al. 2021; US DOE 2022). The wafer fabrication step has the highest environmental impact on the entire semiconductor value chain since it involves the management of huge quantities of raw material, energy, waste, and emissions. The aim of this chapter is to investigate, by a benchmark analysis of the Key Environmental Performance Indicators (KEPIs), the environmental performance and efficiency of the world's leading semiconductor "foundries" or "fabs," i.e., of those firms that deal exclusively with the fabrication phase, turning raw silicon into ICs.

33.2 Materials and Methods

This study was focused on the analysis of the environmental contents (KEPIs) of the Corporate Social Responsibility (CSR) reports of the foundries only, i.e., excluding the IDM companies, the fabless firms, and the OSAT companies, to avoid the risk of invalidating the benchmark analysis, taking into account substantially different manufacturing processes and environmental impacts.

Fabrication firms that, in 2021, recorded the largest market shares of global foundry revenue (equal to US $ 107.5 billion) were the following: TSMC Ltd. (53% revenue share), based in Hsinchu (Taiwan); Samsung Semiconductor Global (18% share), based in Taegu (Southern Korea); United Microelectronic Corporation (UMC, 7% share), based in Hsinchu (Taiwan); GlobalFoundries (GF) Inc. (6% share), based in Malta (NY, USA); Semiconductor Manufacturing International Co. (SMIC, 5% share), headquartered in Shanghai (China); Hua Hong Semiconductor Ltd. (HHS Group, 2% share), based in Shanghai (China); Powerchip Semiconductor Manufacturing Corp (PSMC, 2% share), based in Hsinchu (Taiwan). The 2020 CSR reports of these companies were used, with the exception of Samsung Group because, from the annual Samsung Electronics Sustainability reports, it was not possible to find the KEPIs of its Semiconductor Division alone. In general, it was necessary to overcome some difficulties in obtaining the necessary data for this analysis because not all the foundry KEPIs are immediately available in a standard common format. For example, many companies do not disclose their annual production (e.g., number of wafers produced or total area of wafers); in addition, the analyzed firms use different manufacturing parameters to normalize their own performance data. In this way, an immediate benchmark analysis is not possible, and data homogenization operations need to be made. Due to the above, and for the purpose of obtaining the eco-efficiency indicators starting from the KEPIs available – or, very often, obtained by processing – in the CSR reports, it was chosen to adopt a common divider or an industry standard Manufacturing Index (MI), and necessary conversions were carried out. This parameter is equivalent to the total area of the wafers annually produced (wafer-m^2 or wfr-m^2)[1] by a specific foundry, taking into account the number of wafers annually manufactured and the number of masking steps or layers required for wafer fabrication (AMD 2022). This MI is directly related to the complexity of the production process, to the quantities of inputs (raw material, energy), to waste and to production costs.

From 2020 and 2021 foundry CSR reports, all four available or calculated values of KEPIs were analyzed: greenhouse gas (GHG) emissions (Scope 1, Scope 2 and fluorinated GHG or F-GHG), energy consumption (electricity and natural), water resources (water intake/withdrawn, water consumed, water recycled, wastewater) and waste (general waste and hazardous waste).

33.3 Results

By the reporting or processing of KEPIs of the CSR reports of the analyzed companies (TSMC, UMC, GF, SMIC, PSMC and HHS), Table 33.1 was obtained.

By the consequent processing of the KEPIs contained in the table above, eco-efficiency indicators were obtained, allowing for the related benchmark analysis. The most significant related results of these operations are shown in the following graphs.

33.4 Discussions and Conclusions

Figure 33.1 – in which the conditions of the six companies regarding their respective revenue per unit of production are shown – will be substantially adopted as a reference basis for the benchmark analysis below. TSMC, SMIC, GF, and UMC, offering the most advanced products, are also the foundries with the highest unitary

[1] As it is known, a mask layer is a device, usually made of glass, through which, by an articulated and very expensive photolithographic process, the image of the electrical circuit is transferred, in a much smaller form, on wafer surface.

Table 33.1 World major wafer foundries performance (2020)

	TSMC	UMC	GF	SMIC	PSMC	HHS	Total
Revenue (million USD)	45,969	5959	5959	4256	851	851	63,845
Production – Wafer-m^2 (in 000)	938.7	224.8	194.6	123.9	122.7	64.2	1669
GHG emissions – Scope 1 (000 tCO_2e)	2450.3	717.0	423.5	550.1	107.9	18.1	4267
GHG emissions – Scope 2 (000 tCO_2e)	7460.2	1852.4	214.8	1579.2	565.1	430.5	12,102
GHG emissions – Scope 1&2 (000 tCO_2e)	9910.5	2569.4	638.3	2129.3	673.0	448.6	16,369
F-GHG emissions (000 tCO_2e)	1311.5	461.4	318.0	416.9	459.5	223.6	3191
Electricity consumption (GWh)	16,053.7	3519.8	3019.0	1625.0	1128.1	720.8	26,066
Natural gas consumption (GWh)	865.4	241.8	196.0	150.1	137.8	110.3	1701
Total energy consumption (GWh)	16,919.1	3761.6	3215.0	1775.1	1265.9	831.1	27,768
Water withdrawal (000 t)	129,110	22,748	27,258	26,629	6114	15,938	227,797
Water consumption (000 t)	77,300	18,440	3472	13,459	2101	9908	124,680
Wastewater discharge (000 t)	51,810	4308	23,786	13,170	4013	6030	103,117
Total water recycled/saving (000 t)	173,020	33,228	10,630	22,397	10,583	4042	253,900
General waste generated (t)	277,340	25,107	20,401	33,878	10,934	6143	373,803
Hazardous waste generated (t)	298,400	31,634	41,503	28,706	6247	9262	415,752
Total waste generated (t)	575,740	56,741	61,904	62,584	17,181	15,405	789,555
Waste to incineration or landfill (t)	32,661	6303	10,682	8574	2435	2356	63,011
Recycled waste (t)	543,079	50,438	51,222	54,010	14,746	13,049	726,544

Sources: Elaboration of data of TSMC (2020), UMC (2020), GF (2021), SMIC (2020), PSMC (2020), HHS (2020)

values of revenue. Semiconductor fabrication involves, as seen from Table 33.1, the production of a considerable amount of GHG emissions (estimated according to the GHG Protocol and the ISO 14064-1 standard). Only two companies (TSMC and UMC) disclose their own GHG emissions Scope 3 data; for this reason, it was decided to exclude them from this study.

Indirect emissions (Scope 2), generally, are much higher than direct emissions (Scope 1), related, as is known, to the activities controlled by an organization. Between them, the corresponding emission average ratio is approximately 3:1 (Table 33.1). There are cases, however, in which this ratio has very higher values

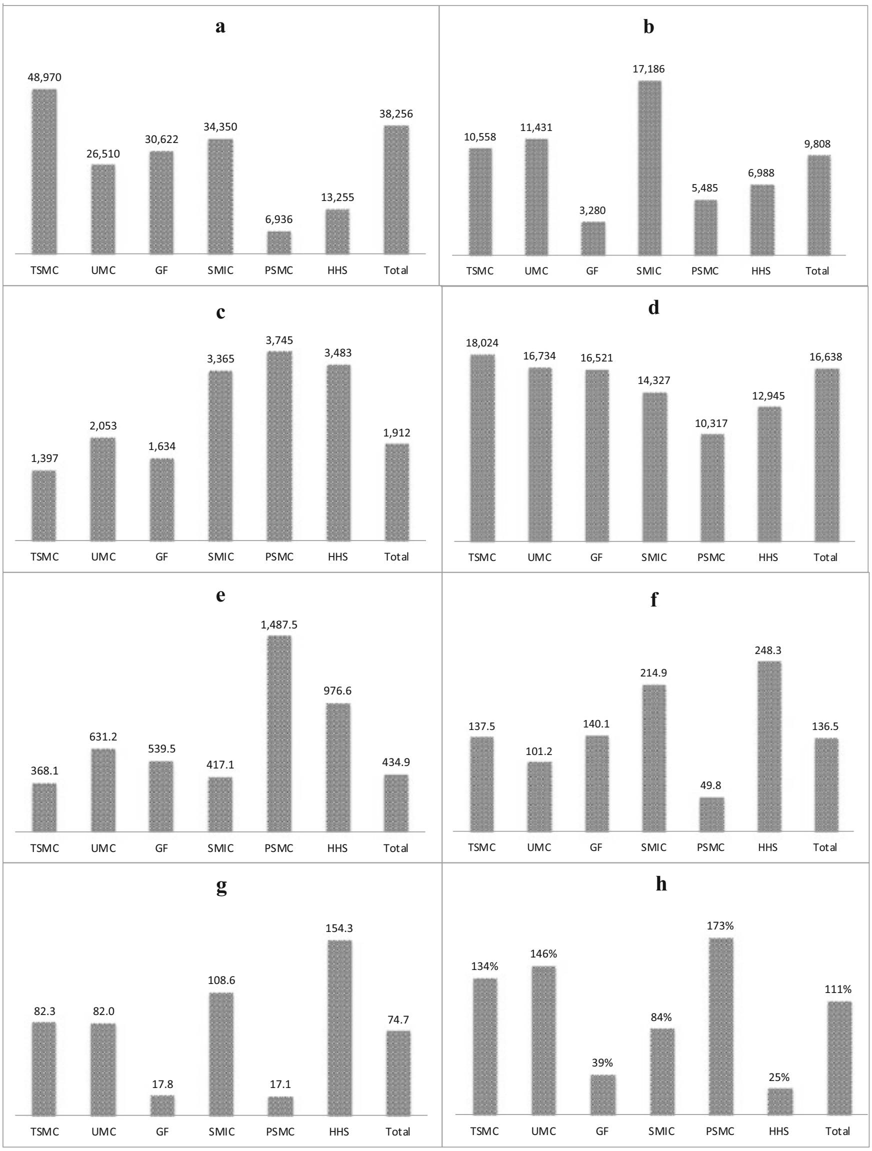

Fig. 33.1 Revenue per Unit of Production (USD/wfr-m^2) (**a**); GHG Emission Intensity – Scope 1&2 (kg CO2e/wfr-m^2) (**b**); F-GHG Emission Intensity (kg CO2e/wfr-m^2) (**c**); Energy Intensity (MWh/wfr-m^2) (**d**); Energy Efficiency (MWh/Mio USD) (**e**); Tons of Water Withdrawn per wfr-m^2 (**f**); Tons of Water Consumed per wfr-m^2 (**g**); (Water Recycled)/(Water Withdrawal) (**h**)

(e.g., almost 24:1 for HHS); this occurs when most of the production processes are carried out by third parties. The GHG emission (Scope 1 and Scope 2) intensity is, on average, 9800 kg CO_2e/wfr-m^2 (Fig. 33.1). Those foundries that significantly have values below this average value (GF, PSMC, and HHS) probably use more renewable energy sources (such as photovoltaic sources) or outsource some upstream and downstream phases of their wafer manufacturing. Obviously, the complexity of wafer architecture affects production costs, energy consumption, and the related GHG emissions; TSMC, UMC, and SMIC are examples of this situation. Large quantities of different fluorinated compounds (i.e., CH_3F, CHF_3, CH_2F_2, CF_4, C_2F_6, C_3F_8, NF_3, SF_6, etc.) with high global warming potential (GWP) are used by semiconductor fabs to print circuits on wafers, to clean chemical vapor deposition (CVD) chambers and as fluorinated heat transfer fluids (FHTFs) (US EPA 2018; IPCC 2022). The largest quantities of F-GHG emissions per unit of production pertain to the processes of PSMC, HHS, and SMIC (Fig. 33.1). The company with the most advanced recovery systems of these gases, directly in the chambers of production tools (TSMC 2020), is TSMC (1397 kg CO_2e/wfr-m^2).

Energy in the semiconductor industry, almost entirely as electricity, is mainly used to power production machines and tools and to constantly guarantee high critical cleanroom standards (PG&E 2011). The highest overall energy intensity values per unit of production (Fig. 33.1) are related to the fabrication processes of those firms having the highest production volumes and the best energy efficiency performances compared to revenue (Fig. 33.1): TSMC, UMC, GF, and SMIC.

Many thousands of tons of ultrapure water (UPW) are required for the production of a single square meter of wafer. UPW, which must be absolutely free of dissolved particles, ions, and gases, is used in wafer cleaning processes (Hoo et al. 2009). Smaller and more complex wafers require more UPW. Generally, almost all water intake becomes UPW (TSMC 2020; UMC 2020).

The water used per unit of production varies widely, ranging from 50 t/wfr-m^2 for PSMS to almost 250 t/wfr-m^2 for HHS (Fig. 33.1). The TSMC indicator is on average. HHS has the highest water intensity, the highest volumes of water intake and the highest unitary levels of water consumed, probably because its plants recycle very little resources: approximately 25% of the water withdrawn (Table 33.1).

Many different wastes are produced by semiconductor fabrication processes. The waste flows generated can be divided, as usual, into general or non-hazardous waste (e.g., processing waste, waste solvents, waste ammonium sulfate, sludge from water treatment, containers, waste mixed hardware, domestic waste, and others) and hazardous waste (e.g., waste acids, waste solvents, waste copper sulfate, containers, and others) (UMC 2020). Even in this situation, it appears that advanced and complex processes and products lead to greater waste generation. In fact, the foundries that have the highest values of total waste per wfr-m^2 (Fig. 33.1) and hazardous waste per wfr-m^2 (Fig. 33.1) are also those (PSMC and SMIC) that have the highest revenue per unit of production, producing wafers with the most advanced and complex architecture.

It can be stated, thus, that, unlike what happens in many other industrial sectors, in the semiconductor fabrication phase, larger company size and advanced products are not always related to lower quantities, per unit of production, of energy, waste, and GHG emissions. In fact, those foundry firms that have the highest revenue per unit of production (TSMC, SMIC, GF, UMC) (Fig. 33.1), because they probably produce the most advanced semiconductors, are the same ones that have the highest GHG emission intensity indicators (Fig. 33.1) – excluding, in this case, the situation of GF, which stated, in its CSR report, values of indirect GHG emissions much lower than the direct ones – with the higher energy intensity of their products (Fig. 33.1) and with the highest waste generation per unit of production (Fig. 33.1).

It is hoped that, for the future, those foundry firms with the most advanced technologies will invest much more to optimize their energy use and to adopt efficient recovery and recycling systems to further reduce the amount of their GHG emissions and waste, especially of hazardous ones.

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Chapter 34
The Recovery of Materials and Management at the End of Life of Ships. Models and Strategies for a Critical Raw Materials Circular Market in Europe

Francesco Tola, Enrico Maria Mosconi, Marco Marconi, and Mattia Gianvincenzi

Abstract The recovery of end-of-life ship components and materials requires a complete demolition process as well as the realization processes of reuse that can guarantee the circularity of raw materials from the perspective of economic and environmental sustainability. Since the introduction of the Ship Recycling Regulation, the European Union legislative framework has moved toward opening green markets related to the dismantling of ships. The objective is to value the critical materials and to change the design techniques in shipbuilding aiming at the total recyclability of ships. The rationale of the research is to develop a systemic model of the market for the circularity of materials from the recovery of medium-large ships. The objective of the study focuses on the potential valorization of the members and the materials of the ships in light of the tightening European legislation. The results take interesting considerations, especially for what concerns recognize opportunities for green business and markets in the field of ship recycling.

Keywords Ship recycling · Circular economy · Systemic review · Circular business model

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34.1 Introduction

Maritime transport represents the world economy backbone, contributing to nearly 90% of global goods trades, and is physically impossible to replace with another type of transport (Unctad 2019). The current world merchant fleet comprises 99.800 ships (Geneva 2021), of which only 1–2% is recycled (Karvelis et al. 2020). Ship recycling refers to the dismantling process of ships with the aim of extracting and recovering materials, in particular steel, which represents approximately 95% of the material used, hardened steel, hardened copper alloys, titanium, alloys of titanium, aluminum, lead, and various electronic equipment that can be reused or disassembled for the recovery of precious materials (Hiremath et al. 2016). Approximately 95–98% of a ship's LTD weight is made up of recyclable materials (Jain et al. 2017). Although ship recycling leads to huge economic and environmental benefits from ship recycling, there are some barriers within the current system. The coasts of South Asia bear witness to an industry whose environmental and health balance is urgently in need of change. Such pressures are due to poor quality dismantling techniques and the standards of recycling plants that do not comply with international standards (Devault et al. 2017).

34.2 Literature Review

Table 34.1 shows the most significant regulatory frameworks to overcome the problems introduced previously.

The political attempt to induce a globalized California effect in the ship recycling industry has not resulted in the raising of the desired environmental and social standards. The ease of circumventing international law through the practice of flag

Table 34.1 End of Life Ship regulatory frameworks

Regulation	Year	Description
Basel Convention	1992	Regulates the Control of Movement of Hazardous Wastes (Moen 2008) Offers guidelines on end-of-life ships that guide their destination, but its full application is difficult to control, as end-of-life ships are considered to be both ships and waste dangerous, so they can legally navigate to non-OECD countries (Gregson et al. 2016)
Hong Kong Convention	2009	Regulates the design, construction, operation, and preparation of ships for sustainable recycling. Prohibits the use of some hazardous materials. Waiting to take effect (Glinski 2022).
Regulation (EU) No. 1257/2013	2013	Ship recycling regulation. From 31 December 2018, EU-flagged ships over 500 GT must be recycled in safe and environmentally friendly recycling facilities (Article 2). The list includes structures operating in EU and non-EU territory. 44 suitable EU plants and 9 suitable non-EU plants are recognized. No plant located in Southeast Asia is on the list.

changing is a common practice. The main routes of destination in the recycling centers of these ships took place in the countries of South Asia with the stranded method. The capacity of recycling facilities located in OECD countries is less than 5% of the demand for recycling ships. Data combining analyses of the economic, environmental, and social impacts of ship recycling are limited. Furthermore, there are many differences in the recycling markets between the different types of ships (Choi et al. 2016). The main studies on quantifying the impacts of ship recycling mainly focus on handling hazardous materials and ensuring health and safety during ship recycling activities (Zhou et al. 2021), proposing green supply chains during ship dismantling (Ozturkoglu et al. 2019). The shipbreaking industry is expected to thrive as the number of ships produced around the world continues to increase (Kong et al. 2022).

The circular economy is the main tool in this sector, opening the secondary raw materials market (Geissdoerfer et al. 2020).

The present study aims to investigate the opportunity, feasibility, and potential effects for the creation of a circular business model for ship recycling to improve knowledge on the subject and provide a framework that can be used for future research, analyzing the economic feasibility, the environmental impact, the social aspect, the technology, and the regulatory aspect.

34.3 Material and Methods

A systematic review was conducted to summarize the investigations and key topics in this area and to report and reflect on the trends and themes of the literature for all the clusters under observation. The method applied in this document consists of three stages (Fig. 34.1):

1. The research was conducted on the Scopus and ScienceDirect databases using "ship recycling" as keywords. A total of 25,298 articles were collected. Studies concerning maritime power generation, international trade, ship navigation waste, ship sinking, marine biology, etc., and studies prior to 2014 were eliminated in the skimming phase. A total of 582 articles were valid.
2. The articles were imported into the Mendeley database and revised. Through an analysis of the content of the definitions, a coding scheme was developed and applied to obtain an overview of the types of studies and dimensions. The most cited and useful keywords for further research were extracted from the analysis.
3. The articles included were deepened, summarized, addressed in the various research themes, and inserted in a matrix.

The limitation of the research lies in the low number of studies reviewed; however, it can be considered the first systematic review of ship recycling combined with sustainable development.

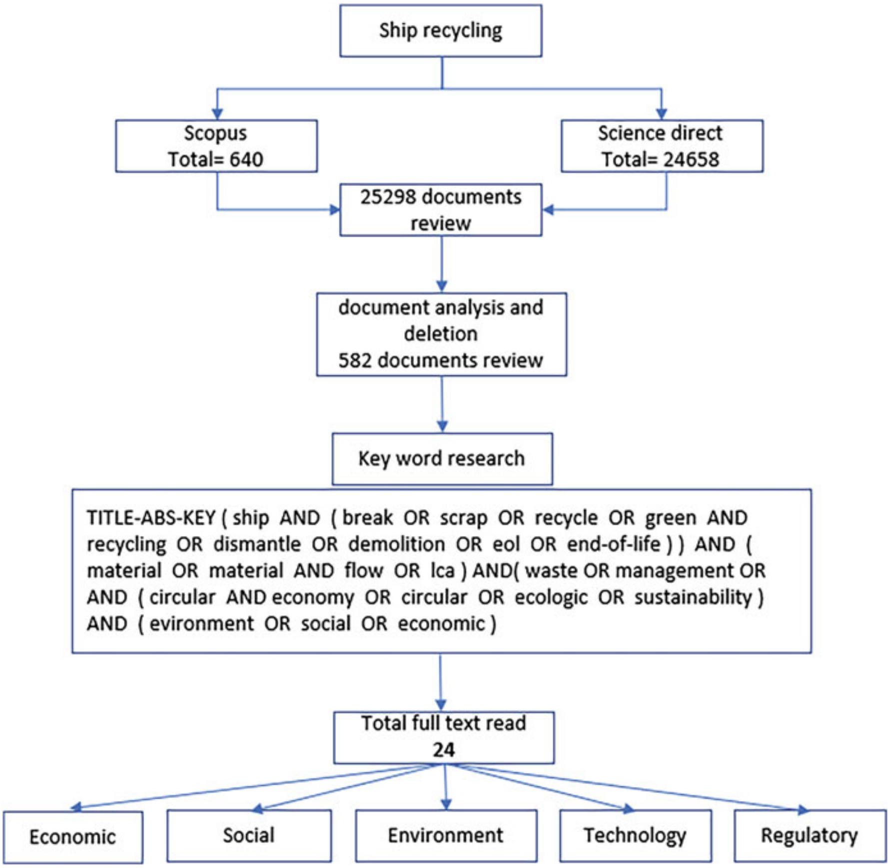

Fig. 34.1 Concept map of systematic literature search and selection method

34.4 Results and Discussions

Table 34.2 is the summary matrix of the systematic review in which the reviewed articles are placed in the reference clusters.

The review opens new ideas for a ship recycling industry capable of making the economic, environmental, and social spheres interact through the use of new technologies and top-down policies. Table 34.3 shows the conclusions for each cluster.

Table 34.2 Summary matrix

n°	Study	Sustainability				
		Economic	Social	Environment	Technology	Regulatory
1	Ozturkoglu et al. (2019)	✓	✓	✓	✓	
2	Jain and Pruyn (2018)	✓			✓	
3	Du et al. (2018)	✓	✓	✓	✓	
4	Ocampo and Pereira (2019)	✓			✓	✓
5	Senavirathna et al. (2022)	✓		✓	✓	
6	Yujuico (2014)	✓				✓
7	Kong et al. (2022)	✓			✓	
8	Schøyen et al. (2017)	✓	✓	✓	✓	
9	Devaux and Nicolaï (2020)	✓				✓
10	Gregson et al. (2016)		✓			
11	Solakivi et al. (2021)					✓
12	Zhou et al. (2021)	✓		✓	✓	
13	Mizanur and Mayer (2015)	✓	✓			
14	Steuer et al. (2021)	✓	✓	✓		✓
15	Sujauddin et al. (2017)	✓	✓			
16	Yan et al. (2022)	✓			✓	
17	Moncayo (2016)					✓
18	Hossain et al. (2016)	✓		✓		
19	Jain et al. (2016)	✓			✓	
20	Fachry Indianto (2020)	✓			✓	
21	Sunaryo et al. (2020)	✓				
22	Jain et al. (2017)	✓		✓	✓	
23	Rahman et al. (2016)	✓	✓	✓		✓
24	Handler et al. (2016)	✓	✓	✓		

34.5 Conclusions

The economic value of a ship's materials at its end of life can be a crucial sector for the creation of secondary markets for critical raw materials. From an eco-neutral perspective, a green ship must have all aspects related to sustainability under control at the end of its life. It would be the result of a circular design, made with advanced methods of using materials and energy, in which all components are designed to be continuously reused in future projects, reducing waste. An incessant disassembly, recovery, and reassembly system, made up of the development of cross-sector green markets and related supply chains, to originate an industry made up of circular flows of resources. To guide all the actors toward the path of a system strategy, not only is an extensive network of consultation of the parties involved on the common field of

Table 34.3 Cluster analysis

Cluster	Description
Economic cluster	Studies agree that there is an inverse correlation between economic growth and ships sent for scrapping (Kong et al. 2022; Steuer et al. 2021). Studies by (Yujuico 2014) analyze the demand and price of steel, showing that South Asian wreckers offer higher figures for end-of-life ships due to high domestic prices for steel scrap. Material Flow Analysis (MFA) is an important tool for improving the management of materials and waste during the recycling phase, enabling the optimization of resources (such as labor, machinery and equipment) to obtain maximum income (Jain et al. 2017). According to (Devaux and Nicolaï 2020), a possible recycling licence for ships flying the European flag could trigger an improvement in the trend in the EU territory. Innovation and investment in demolition plants are difficult to implement (Schøyen et al. 2017).
Social cluster	Ship recycling in Europe is a low-frequency activity. Analyses of the work situation state that in European construction sites, work fails to attract local labor and instead relies on migrant workers (Gregson et al. 2016). The establishment of industrial networks in a community can establish advanced development conditions aimed at continuous improvement (Mizanur Rahman and Mayer 2015). The licence strategy would make it possible to internalize the social costs of ship dismantling (Devaux and Nicolaï 2020). The guidelines for safety on construction sites proposed by (Hossain et al. 2016) can be followed to mitigate the impact that demolition yards have on the environment, as well as to promote sustainable practices for demolition activities.
Environment cluster	Current end-of-life management problems exist mainly due to the lack of ecological integration in the design and production processes (Senavirathna et al. 2022). The implementation of a holistic framework for risk management could lead Southeast Asian shipyards to be regulated according to environmental standards, as well as technical (i.e., type of ships) and economic standards (i.e., currency exchange) (Ozturkoglu et al. 2019). From the LCA on steel recovered from ships conducted by (Rahman and Mayer 2015) emerges that there is a substantial environmental advantage in recycling steel compared to virgin raw material. The outcomes of the green supply chain can help from the point of view of organization, on-site management, technology and equipment, use of clean energy etc. (Zhou et al. 2021)
Technology cluster	The ship is not designed for disassembly and recycling (Du et al. 2018). The high demand for the materials extracted from the ship add value to this activity (Ocampo et al. 2019). Revenues can be increased through a heat treatment plant on construction sites for the transformation of waste into secondary raw materials (Jain and Pruyn 2018). The installation of facilities such as floating piers, wastewater treatment plants, storage facilities and asbestos pretreatment, can improve the technical conditions of recycling (Steuer et al. 2021). The quantification of materials to facilitate disassembly through the ship's stability manual and the WBS classification system was found to be a feasible and practicable technique (Jain et al. 2016)
Regulatory cluster	Future global and European demand for ship dismantling has been politically underestimated (Solakivi et al. 2021). International treaties usually do not represent the interests of developing countries and there is a lack of a harmonized definition of naval waste (Rahman et al. 2016). Local policy makers need to improve local ship recycling rules from the point of view of environmental protection structures and plans, ecological environmental protection etc. (Zhou et al. 2021). Currently, until the dispute between the waste regime and ship recycling has been resolved, the ships at the end of their operational life will continue to land on the coasts of South Asia (Argüello Moncayo 2016).

the resources necessary resource value, but it is also necessary to validate their real economic, financial, and environmental feasibility to be able to realize a safe new business for the maritime industry.

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Part VII
Quality, Circular Economy, and Sustainability: A Miscellaneous of General Facts

Chapter 35
Entropic Limits of Circular Economy

Pasquale Giungato, Roberto Leonardo Rana, Caterina Tricase, Mariarosaria Lombardi, and Zenon Foltynowicz

Abstract The world has become enchanted with the idea of the circular economy, as it is seen as a remedy to solve most ecological problems. Reintroduction processes, such as recycling or refurbishment, undoubtedly support the objectives of a circular economy but inevitably result in material waste or the production of undesirable byproducts. Initially, the circular economy descriptions completely ignored the relationship between natural and economic systems, which are the most important problem in ecological economics. The circular economy is criticized, inter alia, for not considering the physical limits of recycling. In each recycling cycle, some materials are lost or degraded (downcycling), which leads to an increase in entropy. When recycling on an industrial scale, increasingly more materials are scattered and lost with each cycle, leading to waste and emissions. The present paper aims to provide an overview of the approach used to evaluate such entropy increase by conducting a systematic literature review using the indexed databases of Web of Science and Scopus. The expected results show that the application of statistical entropy analysis to complex products is useful for minimizing waste production and making people aware that the zero-waste strategy is a utopia.

Keywords Entropy · Circular economy · Zero waste strategy · Relative statistical entropy · Material flow analysis

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35.1 Introduction

The conventional economy is characterized by the "buy, use, throw-away" concept, whereas the circular economy (CE) is intended as the transformation of fluxes of input materials (and of both wastes and emissions into the environment as output) into cycles that minimize material use, energy flows, and environmental impacts without compromising economic, social, and technical progress (Stahel 2022). Ellen MacArthur renewed the definition of CE (MacArthur 2015), stating that it "aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption." On the promise of this suggested decoupling, Stephan (2022) advises on the presence of physical limits to decoupling, pointing out that if basic principles of thermodynamics are taken seriously into account, such an idea of a CE remains an illusion. In fact, if we considered a material flow analysis (MFA) approach, which in its simplest version says that fluxes of materials in input equal that of both wastes and emissions into the environment, as output, it will induce us to think that recycling will allow a complete decoupling of economic activities from nature. This material and energy balance approach is the application of the first law of thermodynamics in the economic environment, which states that in an isolated system, the energy sum always remains constant, and energy can only change its state form. Georgescu-Roegen clearly stated that production and consumption are accompanied by an irreversible change in the quality of energy and raw materials, introducing entropy, a concept from thermodynamics, in economic theory (Georgescu-Roegen 1971). This represents the application of the second law of thermodynamics as isolated thermodynamic systems strive in the long run towards a state of maximum entropy and thus minimum structure and order. In other words, once the energy is completely transformed into heat, the opposite transformation is not entirely possible. Transformation of the existing economy into a more sustainable one requires minimizing the rise of entropy, realizing the only realistic sustainable CE (Stephan 2022). With the development of more energy efficient technologies, this rise in entropy may slowly decrease but never be eliminated. According to the second law of thermodynamics, the recovery and recycling of materials, waste, and end-of-life product disposal require energy and resources, which increase in a nonlinear manner as the percentage of recycled material rises. Consequently, in this work, the authors will investigate new analytical tools that could represent the best approach to quantitatively apply the second law of thermodynamics to the economy by conducting a systematic literature review using the indexed databases of Web of Science and Scopus. As the subject is attracting the attention not only of scholars but also of policy makers, the recent trends of the scientific literature on this intriguing issue will be depicted with the aim of revealing the best approach that has actual practical application and future developments.

35.2 Relationships Between Thermodynamics and Economics

CE has been recognized as a movement for over 10 years promoting the decoupling of economic development from the unsustainable consumption of natural resources (Kirchherr et al. 2017; Muradin and Foltynowicz 2019). There is a general agreement to end the linear economy, but not necessarily what to apply instead: eco-design, recycling, short cycles, resource efficiency, etc. Reintroduction processes, such as recycling or refurbishment, undoubtedly support the objectives of a circular economy but inevitably result in material waste or the production of undesirable byproducts. Basically, relations between thermodynamics and economics are relationships between natural and economic systems and represent the most important problem in ecological economics (Ciegis 2008; Hammond and Winnett 2009). Georgescu-Roegen was the first economist to recognize the importance of thermodynamic constraints in economic theory (Georgescu-Roegen 1971), whereas Solow and Stiglitz recognized the existence of the laws of thermodynamics but argued that they had no significant consequences for economic analyses and could therefore be safely ignored (Daly 1997; Germain 2019). The increase in entropy on Earth (as a whole) is only reversible because there is a complex biosphere powered mainly by solar radiation, which is the main source of exergy influx. Most of this energy is returned to extraterrestrial space; however, some of it is converted by plants and living organisms to chemical energy, and some of it becomes a backup carbon source (hard coal, oil, natural gas) with low entropy. The energy flowing on Earth is part of open cycles: solar energy is provided, and heat is expelled. Flows of energy and matter from the ecosphere to the economy (techno sphere) and back to ecological reservoirs are called “throughput.” The distinction between natural (ecosphere) and technical (technosphere) systems does not mean that the former are purely cyclical and waste-free, while the latter are purely linear and waste-generating. Many industries rely on the recycling of matter and energy from production processes and consumer waste. At the same time, the biosphere eliminates “carbon” in natural landfills. In natural systems, cycles are local, decentralized, and developed towards increasingly closed cycles with the consequent reduction of emissions and waste. In technical systems, cycles are increasingly global, reliant on transport and developed to be open, with the consequent increase in emissions and waste. The green economy and movements for sustainable development assume that the techno sphere will contribute to resolving the conflict between economic growth and environmental protection. Different approaches exist: Cradle to cradle; Industrial ecology, Natural capitalism, CE. Will these approaches enable sustainable economic growth in an environmentally friendly manner in the long term? Do they correctly interpret, appreciate/ignore the biophysical limits set by the dynamics of systems and thermodynamics? The potential contribution of industrial symbiosis and the CE to sustainable development and to the Sustainable Development Goals set in the United Nations Agenda 2030 is under discussion by scholars (Cecchin et al. 2021). Eco-design and “cradle to grave” see the possibility of ensuring continuous economic growth in an environmentally friendly way, considering the entire life cycle of the product. They are criticized for not considering the physical limitations of recycling. When recycling, for example, plastics, on an industrial scale, we disperse and lose an increasing amount of materials with each cycle, leading to waste and emissions (Foltynowicz 2020). Achieving closed material cycles will therefore require the segregation and treatment of high-entropy waste for recycling and reuse as a low-entropy resource.

35.3 Statistical Entropy Analysis (SEA)

A systematic literature review using the indexed databases of Web of Science and Scopus was conducted, retrieving 104 papers with "Circular Economy" and "Entropy" as keywords. Among the papers, 81 were articles and were taken under consideration, but after discarding proceedings (15) and reviews (8), duplicates, and those that were too theoretical, five significant papers presented the best applicative approach to the issue. The results reveal SEA, the most useful and significant measure of the entropic limits of the circular economy. SEA quantifies the changes in the substance concentration or distribution throughout an MFA, which instead assesses flows and stocks of materials within a system. In other words, a process can concentrate, dilute, or leave a substance concentration/distribution unaltered. MFA is an invaluable tool for evaluating the most important processes and flows in an industrial metabolism useful for optimization, but the analysis does not cover qualitative changes in material flows that occur during all the processes that transform input flows into output flows. The processes should be clustered into steps to calculate the degree of dilution of substances and SEA that decreases in processes such as mining, refining, separate waste collection, mechanical sorting, and recycling, whereas it increases in all processes that dilute a substance, e.g., mixing, or emission into an environmental compartment such as the atmosphere. A single substance MFA represents the lowest SEA equal to zero (pure and most concentrated); the more uniformly a substance is distributed, the closer the statistical entropy value will reach the maximum. The method has been successfully applied in the following selected case studies: (1) on the recycling and reuse of components of a simplified car (Parchomenko et al. 2020); (2) to reliably assess the recyclability of plastics (Nimmegeers et al. 2021); (3) for the optimization of separation and purification processes such as a sieving process for waste lithium-ion batteries (Velázquez Martínez et al. 2019); (4) to measure the recyclability of municipal solid wastes with a slightly different approach using the EWRI index (Tong et al. 2021); and (5) to evaluate the best recycling process of thermoelectric devices, solid-state devices capable of converting a temperature gradient into electric power (Velázquez-Martinez et al. 2020).

35.4 Conclusions and Future Perspectives

The thermodynamic limits of the CE are emerging issues in the scientific literature posing serious problems in realizing zero-waste strategies. MFA assesses flows and stocks of materials within a system assuming the quality of the flows remain constant, whereas SEA calculates qualitative changes of material flows during transformation of input into output flows. SEA is the analogy of entropy in thermodynamic systems and fixes insurmountable limits to the application of CE paradigms. Recycling or refurbishment, the reintroduction processes, foster the objectives of a circular economy, but inevitably, material waste or undesirable byproducts are generated. Research efforts are directed towards the application of SEA in different production and recycling areas to make the approach useful to minimize waste production and to choose the best strategy to apply for a recycling process. Another interesting and useful perspective of this approach will be to use this tool and its scientific approach to make stakeholders aware that the zero-waste strategy is a utopia.

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Chapter 36
Circular Bioeconomy: An Analysis of Operational Principles and Limits

Giulia Abbati, Alessia Acampora, Maria Claudia Lucchetti, and Olimpia Martucci

Abstract The necessary transition from a linear to a circular system based on second raw material, biomass, and renewable energy sources has paved the way for new, more stable, resilient, and sustainable production models. Circular economy (CE) strategies have defined closed economic cycles, where the use of biomass to produce materials is preferred, promoting ad hoc bioeconomy strategies. In these economic cycles, waste ceases to be called such to acquire added value for reuse in the same or new productions, becoming a secondary raw material. Over time, the synergies between the two concepts led to the concept of circular bioeconomy (CBE). In this context, although there is particular interest in the scientific field, there is still no clear definition of the concept, much less how to apply it. Therefore, the purpose of the paper is to provide a first analysis of the circular bioeconomy (CBE) concept, outlining its basic characteristics and defining the operational principles through which it operates and its limits.

Keywords Circular bioeconomy · Biomass · Cascading · Biorefinery · Waste management

36.1 Introduction

The global challenges deriving from climate change, biodiversity loss, and soil degradation, together with demographic increase and the careless management of natural resources, have, for some time now, highlighted the need to rethink the production and consumption model from linear to circular.

The circularity of the economy is now understood as an irreversible transition of modern economies. For this reason, many countries in the world, including the European Union, have initiated this change through common policies, strategies,

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and overall visions (Marcinek and Smol 2020). The circular economy (CE) is defined as a restorative and regenerative economy. This type of production model is designed to eliminate waste, promoting the circularity of products and materials at their highest value and ensuring the sustainability of the process. In the CE field of research, a distinction between different types of materials to be reinserted into the economy is often necessary. It is, therefore, possible to define two types of materials: those of a technical nature and materials of biological origin. The bioeconomy deals with the latter. This concept refers to the production, use, and conservation of biological resources (Summit on the bioeconomy 2018). The bioeconomy is often seen as the renewable component of the CE and as part of the solution for starting a more sustainable economy and society (Carrez and van LeeuWeen 2015). The interconnection between the concepts of CE and bioeconomy has given rise to the concept of “circular bioeconomy” (CBE) (Stegmann et al. 2020). The CBE concept is frequently used in regard to biologically derived productions, such as agriculture (Kircher 2022). However, in the literature, there is still a gap related to its definition and the definition of its operational principles. This paper aims to define the characteristics of the concept of CBE through the analysis of its main operational principles. Furthermore, the paper explores the principal limits of its application.

36.2 Methods

The paper explores the operational principles behind the CBE, trying to define the dimensions and limits of this concept.

First, the characteristics and dimensions of the CBE have been highlighted. Then, the cascading concept has been analyzed in light of the CBE concept, underling the main differences and similarities between the two. Finally, the main limitations of the CBE concept are highlighted. To conduct the analysis, a literature review (scientific and grey) was performed through keyword research in different scientific databases. These keywords are “Circular Bioeconomy,” “Circular economy AND Bioeconomy,” “Cascading effect,” and “Cascading effect AND Circular Bioeconomy.” The consulted databases are Google Scholar, Scopus, and Research Gate for scientific paper. The grey literature was selected from institutional and international organizational websites. Moreover, we selected papers published in the last 10 years, given that CE is a topic that has been especially developed in recent years.

36.3 Results and Discussion

The concept of circular bioeconomy is still vague today in the scientific literature. At the moment, there is no single definition, nor are the operational principles through which it operates clear (Tan and Lamers 2021). In particular, CBE is a concept that derives from the intersection of CE and the bioeconomy, whereby the use of biobased materials can be reintroduced into the economy in multiple ways and cycles. The two components not only coincide in some aspects but also play an enabling role for each other (Tan and Lamers 2021). Considering the literature regarding the operational principles of CBE, a common practice appears to be the concept of biomass "cascading" (Stegmann et al. 2020). A concise definition of the term regards the transformation of biomass into a biobased final product that is used at least once for different uses and ultimately for energy purposes (Fehrenbach et al. 2017). However, Bezama (2016) suggests considering some dimensions within the concept, including the quality of material flows and the often-neglected spatial dimension.

In particular, concerning the "quality of material flows" dimension, other authors have also stressed that cascading can be interpreted as an order of priority of different biomass transformations (Olsson et al. 2018), which goes from the highest added value to the lowest (Stegmann et al. 2020; Zabaniotou 2018). In this sense, biomass is initially exploited for the production of high-added-value products for different industries before the final use of the remaining material as an energy source. The added value can be considered either financial, environmental, or social depending on the possible uses of the waste material (OECD 2018). On the other hand, the "spatial" dimension appears to be one of the characteristics of the bioeconomy. The cascading use of biomass is capable of interconnecting different value chains (OECD 2018). This produces a ripple effect resulting from the fact that countries adopting circular practices must be able to make the most of the networks of companies present in their regional industrial landscapes. Different regions may have different biological resources or be strong in different sectors of technology or research, depending on local conditions (Global Bioeconomy Council 2018). In every industrial landscape (geographically limited), the production plants interact with each other in synergy (Bezama 2016), creating important opportunities to produce networks where waste materials are used circularly. These local networks, or clusters, make it possible to initiate important industrial symbiosis processes, with positive repercussions in environmental and economic terms. A more complete view of the operational principles of the CBE can be outlined considering that the cascading use of biomass goes hand in hand with the application of the waste hierarchy. Directive n. 98 European Commission of 2008 provides for waste management practices in order of priority consisting of waste prevention, reuse, recycling, recovery for energy purposes, and controlled landfilling. Figure 36.1 summarizes the main characteristics of the CBE analyzed thus far.

The main technology of this cascading process is the biorefinery. This technology, typical of bioeconomy processes, is understood as the sustainable transformation of biomass into a spectrum of marketable products and energy (International Energy Agency Bioenergy Task 42 Biorefinery 2012). At the same time, OECD (2018) points out that this technology adapts to the concept of CE, complementing it. The biorefinery makes it possible to reuse organic waste materials in ways that go beyond the classic CE practices, such as reuse and recycling or regeneration. The

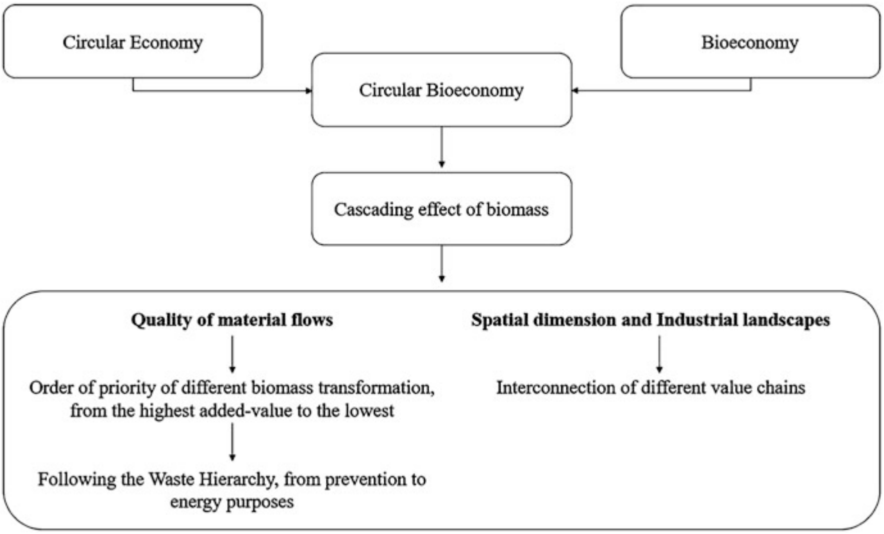

Fig. 36.1 Circular bioeconomy. (Sources: Authors' elaboration based on literature review)

biorefining process produces completely new materials using waste materials and waste as secondary raw material.

In this sense, to close the biological cycle by eliminating waste, in terms of a CBE, it is necessary to consider all the principles, dynamics, dimensions, and technologies previously highlighted. An important question remains for the future, which is essentially identified by a gap in the scientific literature in the univocal definition of the concept of cascading, aligning, and adapting the terminology of the topic. In this context, it is necessary to set up a monitoring system with indicators that effectively indicate the circularity of the bioeconomy. This need is complemented by research that, according to Stegmann et al. (2020), must concretely analyze how these cascading chains can be applied in practice and institute efforts to identify under which circumstances multiple cascading of biomass can prove to be more sustainable (environmentally, socially, and economically).

These considerations then must necessarily clash with the reality of the places where the CBE must be applied. Its efficient and optimal application, being closely related to the network of companies able to collaborate to achieve common objectives, must involve as many players as possible. In particular, it is necessary to start a serious debate between the various local actors and stakeholders (companies, consumers, engineers, etc.) to design optimized and efficient synergies (Bezama 2016; Stegmann et al. 2020). Finally, it is necessary on the part of politics to overcome the current contradictions. In particular, the creation of "virgin" products from secondary raw materials makes it difficult to classify biorefining within the classic waste hierarchy (OECD 2018). In this sense, it becomes necessary to update the policies by overcoming this contrast. In fact, despite all the actions implemented and the investments in new plants, the lack of a clear regulatory framework capable of leveraging the strengths and high-quality standards remains one of the main obstacles to the development of the CE (CNBBSV 2020), thus losing the ability to exploit the mitigation potential of the total environmental impacts deriving from the CBE.

36.4 Conclusions

The synergies between the concepts of the circular economy and bioeconomy have led over time to the concept of CBE. In this context, even if there is particular interest in the scientific field, there is still no clear definition of the concept, much less an agreement on how to apply it. From a first analysis of the scientific literature, it seems evident that the concept of CBE draws key characteristics from both the concepts of CE and bioeconomy and that the two components not only partially coincide but also play an enabling role for each other. The cascading use of biomass seems to be in the literature the key principle of application of CBE, with the use of biomass for different productions and finally for energy purposes. Although the literature can find agreement on some technical characteristics of this concept, there is still little practical development and effective application of the CBE, which often depends on the clear, economic technical characteristics of the regional industrial landscape in which it is to be applied. Finally, the most important limitation remains the political one, as a clear regulatory framework is still lacking today that is an essential element for encouraging investments.

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Chapter 37
Comparison and Contrast Between Corporate Social Responsibility and Corporate Social Innovation

Atifa Amin, Maria Claudia Lucchetti, and Laura Di Pietro

Abstract Noteworthy issues encountered by the business world have been nailed through corporate social responsibility (CSR) and corporate social innovation (CSI). Nevertheless, several issues remain to be addressed through comparative studies and the integration of both concepts. However, research comparing both concepts has not been comprehensively examined. This article explores how CSR and CSI are executed in integrating diverse key components of an organization and how they vary in practice. A systematic literature review was conducted to provide a comprehensive comparison. Thirty articles were systematically selected and thematically analyzed. The significance of CSR and CSI practices shows that CSR is business-oriented with organizational goals; in contrast, CSI collaborates with various social aspects. This article contributes to a true historical account of CSR and CSI visions from evolution to organizational implementation with comparison and contrast based on the literature.

Keywords CSR · Social innovation · Corporate social innovation

37.1 Introduction

Rising environmental challenges and societal misery require corporations to take a proactive approach to sustainability (Amran et al. 2021). By integrating CSR into their strategic plans, companies fulfil their commitment to society's well-being. Institutions and enterprises must move beyond CSR's conventional nature to a new paradigm since they can no longer use it to meet social commitments without a monetary return (Jali et al. 2017). Discussions in this direction have prompted multiple disciplines to evaluate the new paradigm beyond economic resolves, prioritizing innovative initiatives and solutions (Laville 2010). Corporate social innovation (CSI) has emerged as a new paradigm for innovation, attracting the

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attention of enterprises worldwide that want to realize commercial-driven gains while advancing humanity and society (Benneworth and Cunha 2015; Iizuka (2013). CSI's theoretical foundations and implementation suffer from conceptual overlaps (Iizuka 2013). Generally, less is understood about the contrast between CSR and CSI in practice and the borders and delineation of these two ideas (Tabares 2022). A thorough understanding of CSR and CSI is needed (Jali et al. 2017). Hence, this research systematically compares CSR and CSI to address gaps in the literature. This investigation provides an understanding of how differently CSR and CSI perform in the diverse key components of a company.

37.2 Review of the Literature

Bowen (1953) introduced a set of thoughts for corporations to address societal obligations and classified entrepreneurs' behaviors that affected stakeholders, customers, and employees' quality of life. Carroll (1979) argued that a firm's social responsibility includes legal, economic, discretionary, and ethical obligations. As stated by European Commission (2011), CSR is an outlook through which companies integrate environmental and social goals into their operational procedures and voluntarily collaborate with stakeholders. Hence, CSR indicates that businesses have organizational and mutual responsibilities beyond legal obligations. This obligation can be explained by applying the sustainability triple bottom concept containing social, economic, and environmental dimensions (Weisenfeld 2012). Moving to the CSI literature, the concept emerged in the undeveloped world to construct innovative markets to mitigate distress. CSI drives a company toward societal innovation and uses all business assets to tackle issues (Herrera 2015). Through CSI, a firm can respond to diverse stakeholder obligations (Herrera 2015), combat environmental issues (Moulaert et al. 2005), and control internal issues more effectively (Van Der Have and Rubalcaba 2016). Many firms have implemented this core capability to manage social concerns, as per Mirvis, Googins (2017, p. 2): "Corporate social innovation is a strategy that combines a unique set of corporate assets in collaboration with other sectors and firms to cocreate breakthrough solutions to complex economic, social, and environmental issues that bear on the sustainability of both business and society." CSI has grown over two decades, reinforcing traditional CSR to embed social influence more rapidly in organizational policies, ventures, and alliances (Mirvis and Googins 2017).

37.3 Material and Methods

A systematic literature review (SLR) was selected as the research methodology. It is a transparent and rigorous approach to recognize relevant articles and contemporary knowledge (Linnenluecke et al. 2020). Our research compares contemporary

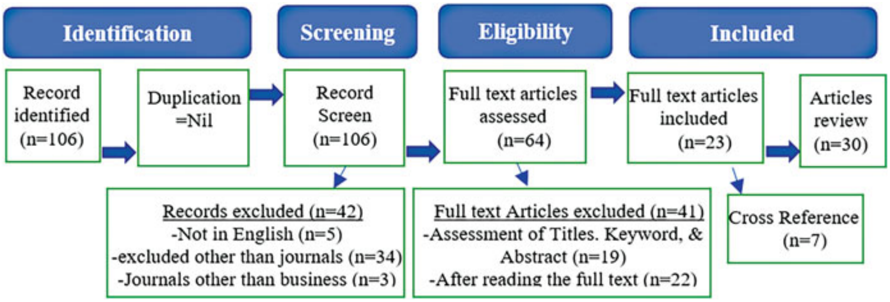

Fig. 37.1 PRISMA flowchart

concepts, CSR with CSI. Hence, SLR is a compatible method due to its comprehensive approach to the business model and sustainability literature (Fobbe and Hilletofth 2021). Scopus identifies the top CSR, CSI, and SI studies (Comin et al. 2020). Article title, abstract, keywords, and topic were used to search databases. Appropriate keywords for our research inquiry were employed as follows: (TITLE-ABS-KEY ("Corporate Social Responsibility") AND TITLE-ABS-KEY ("Social Innovation") OR TITLE-ABS-KEY ("Corporate Social Innovation")) AND (LIMIT-TO (LANGUAGE, "English")).

To simplify the trackability of articles included/excluded, Fig. 37.1 shows the PRISMA flowchart (Moher et al. 2015). Initially, 106 records were found, and then we formed a manual and independent assessment of the papers to match the objective of the SLR (Krey et al. 2022). Thus, 30 articles were rigorously investigated. The thematic analysis is considered a fruitful synthesis approach in managerial SLRs (Shu et al. 2021). It is suitable for comparing and contrasting CSR and CSI grounded on a qualitative scope, which identifies key emerging concepts (Linnenluecke et al. 2020). In this context, 30 papers were analyzed, and details regarding the existing practices of CSR and CSI were extracted and systematized, allowing the development of factors pertinent to the research aim (Denyer and Tranfield 2009).

37.4 Results and Discussions

The thematic analysis of the articles included in the SLR revealed seven key aspects of the business-oriented organizations that have different influences on CSR and CSI activities, and some have similar treatments and outcomes. The key components are workforce, stakeholders, social marketing, economic performance, competitive advantage, knowledge exchange, and pandemics or emergencies (Table 37.1).

Table 37.1 Differences and similarities between CSR and CSI approaches

Company's perspective			
Key aspects	CSR significance	CSI/SI significance	Differences/similarities
Workforce	Ethical labor practices (Harazin and Kósi 2013), employees behavior (Panagopoulos et al. 2016), low staff turnover (Carroll and Shabana 2010)	Decent work, reducing inequalities (Tabares 2022), collaborative learning opportunities (Bennett and McWhorter 2019), broad perspective, and stimulates creativity (Roszkowska-Menkes 2018)	Emotional intelligence (Gul et al. 2015), creativity at the workplace (Carmeli et al. 2014), creative toward society, enhance organizational citizenship behavior and value cocreation (Chen et al. 2021)
Stakeholders	Two-way communication (Mattera and Baena 2015), value-based demand ranking (Wickert and Risi 2019)	Stakeholder engagement (Herrera 2015), individuality (Carvalho 2022), local stakeholders (Nguyen et al. 2020)	Corporate value through stakeholders satisfaction (Shin et al. 2022), stakeholders projects (Turker and Ozmen 2021)
Social marketing	Brand positioning (Andrianova and Yeletskikh 2012), goodwill (Williams et al. 2020)	Social resolutions, corporate brand equity (Andrianova and Yeletskikh 2012)	Societal marketing, planning process enhances SI (Andrianova and Yeletskikh 2012)
Economic performance	Women entrepreneur (Kapoor 2019), financial returns (Santos 2014)	New sources of revenue (Williams et al. 2020)	
Competitive advantage	Improves the R&D technological innovation (Huang et al. 2021)	Shapes society (Bennett and McWhorter 2019), taps conscious consumers (Roszkowska-Menkes 2018), innovations (Yang and Yan 2020)	Sustains competitive advantage (Mattera and Baena 2015), innovative strategy (Mirvis and Googins 2018), social bond (Tabares 2022)
Knowledge exchange	Knowledge sharing with stakeholders on nonpecuniary bases (Roszkowska-Menkes 2018)	Institutionalized, cross-sector mergers (Bennett and McWhorter 2019), interactive, experiential (Mirvis et al. 2016), emerging economies (Bennett and McWhorter 2019)	
Pandemic/ emergencies	Charity and donations (Tabares 2022)	Boosts in emergencies (Rabbani et al. 2021)	Business and social intensions (Tabares 2022)

37.4.1 Workforce

CSR emphasizes work ethics as favorable and autonomous working conditions (Harazin and Kósi 2013). CSR undertakes commitments that influence employees' behavior (Panagopoulos et al. 2016), improve organizational commitment and lower staff turnover (Carroll and Shabana 2010). In contrast, CSI observes a transformative agenda in line with global SDGs, reducing inequalities, encouraging decent work, and emphasizing organizational culture (Tabares 2022). SI proposes possibilities for intraorganizational collaboration, and sectoral boundary-crossing contributes to new ideas and learning (Bennett and McWhorter 2019). CSR engages resourceful and emotionally intelligent employees (Gul et al. 2015) to accomplish innovative work (Carmeli et al. 2014), while employees engaged through SI are creative toward the community and eager to address problems (Roszkowska-Menkes 2018). Both strategies value employee and human rights (Harazin and Kósi 2013). Effective CSR and SI directives can strengthen value cocreation and organizational citizenship (Chen et al. 2021).

37.4.2 Stakeholders

CSR specifies channels to communicate with stakeholders and encourage participation in innovative plans (Mattera and Baena 2015). SI activities are conditional on stakeholder engagement (Herrera 2015) and often occur due to individual stakeholders' determination (Carvalho 2022). It handles acute social issues through business solutions that benefit the company and local stakeholders (Nguyen et al. 2020). CSR attains corporate business value, contributing to societal stakeholders' happiness with corporate resources. SI is the most influential path to integrating companies with the community (Mattera and Baena 2015). Sometimes integration of CSR & SI works together, as suggested by the SDG 17 "Partnership for the Goals"; when CSR projects lack expertise, collaboration with other organizations provides a joint social innovation (Turker and Ozmen 2021).

37.4.3 Social Marketing

Companies choose CSR avenues based on how righty that initiative serves their brand identity. It is similar to the brand positioning, or extent of societal value-added, i.e., influence drawn by the company on the specified CSR issue, and a positive reaction reflects on both profitability and brand value. Companies prefer CSI to address social and environmental issues within business opportunities and prefer stakeholders' interests, which ultimately enhances corporate brand equity (Andrianova and Yeletskikh 2012).

37.4.4 Economic Performance

CSR activities empower women economically in an underdeveloped country such as India (Kapoor 2019). Microlevel CSR generates financial returns but has no significance for global sustainability (Santos 2014). CSI augments socially relevant innovative avenues for firm financial gains (Williams et al. 2020).

37.4.5 Competitive Advantage

CSR significantly lifts the investment level of R&D in high-growth companies; its dimensions, e.g., employee responsibility and shareholder responsibility, refine technological innovation (Huang et al. 2021). Alternatively, SI creates and sustains competitive advantages through technology and economic outputs and shapes institutions and social structures (Bennett and McWhorter 2019). SI also improves supply chains, taps socially aware and green consumers, and reaches markets at the pyramid's base (Roszkowska-Menkes 2018). CSR improves intellectual assets, reinforcing the sustainable competitive advantage (Mattera and Baena 2015). As an innovation in the organizational sphere, CSI is necessary to sharpen and sustain competitive advantage (Mirvis and Googins 2018).

37.4.6 Knowledge Exchange

As a part of organizational CSR strategy, businesses communicate a small piece of knowledge and innovation with stakeholders regarding donations for pro bono initiatives or open-source projects for society (Roszkowska-Menkes 2018). SI tends to be institutionalized in centers that teach SI processes, with or without higher education collaboration. These learning centers enrich cross-sector collaborations, increase individual and organizational capability, and provide knowledge and resources to distressed communities (Bennett and McWhorter 2019). CSI actions are highly experimental and interactive, and knowledge transfer is multilateral (Mirvis et al. 2016). SI enhances the link between markets and technical breakthroughs, strengthening the classical paradigm of ecosystems (Yang and Yan 2020).

37.4.7 Pandemics/Emergencies

During COVID-19, companies perform CSR activities through charity (Tabares 2022), and SI tends to flourish through innovative social solutions (Rabbani et al. 2021). CSR initiatives work for enterprises only, while SI enhances collaboration with society.

37.5 Conclusion and Future Perspectives

The present study covers CSR and CSI/SI practices implemented in key organizational components. The main contribution of the SLR review is to identify diverse key aspects and to answer the research question of how CSR and CSI perform in diverse components. CSR and CSI significantly enhance employee workplace and capabilities. CSR focuses on organizational benefits, while CSI addresses social challenges. Both promote brand reputation, but in distinct ways. CSR strengthens economic performance, competitive advantage, and knowledge exchange; however, CSI generates more earning and learning avenues and assists in gaining competitive advantages. Both benefit society, although business motives vary. Limitations in this study are openings for prospective studies. The present study has conducted SLR on only journals; future studies may include all other records or be conducted on a case study basis. Furthermore, studies can examine the integration of both practices.

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Chapter 38
Transition to Social Organizational Life Cycle Assessment: Connections with Social Responsibility Tools

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Abstract Social Organizational Life Cycle Assessment (SO-LCA) is a methodology that assesses the social and socioeconomic aspects of a company, or a part of it, from a life cycle perspective. According to the Guidelines for Social Life Cycle Assessment and Organizations 2020, which describe its methodological framework, SO-LCA can be applied moving from a company's previous experience with management, assessment, and certification tools following three pathways. The first one (Pathway 1) is based on previous applications of tools to verify and certify the company's compliance with social responsibility requirements. This study provides an overview of the links between the social issues assessed in social management and certification tools and the subcategories foreseen by the Guidelines. The aim is to highlight how and to what extent these tools, already used by a company, can support SO-LCA implementation. This study shows that the social themes addressed by the considered tools partly correspond to those foreseen by the Guidelines. Further development will focus on which data acquired in relation to these themes can also be used for SO-LCA.

Keywords Social organizational life cycle assessment · SO-LCA · GRI · SA8000 · ISO 26000 · Corporate social responsibility

38.1 Introduction

Social sustainability plays an essential role in achieving the economic performance of companies (Carter and Rogers 2008; Krause et al. 2009; Yawar and Seuring 2017), as well as in providing a better understanding of environmental effects on the community. Compared to the other sustainability dimensions (i.e., environmental and economic), the social dimension is less addressed by companies (D'Eusanio et al. 2022a) despite its relevant role being recognized by them (Walker et al. 2021).

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This is due to the absence of standardization of the social assessment process; thus, companies mainly orient their efforts to social management tools and approaches based on qualitative evaluations, such as surveys, interviews and stakeholder engagement, and on national and international initiatives and frameworks, such as Social Accountability 8000 (2014) and Global Reporting Initiative (2021) (Walker et al. 2021). These approaches consider the social aspects with regard to the boundaries of the company (Gold et al. 2010) without a systemic approach involving the whole supply chain (D'Eusanio et al. 2019). Instead, a systemic perspective is relevant for understanding the role of each actor along the supply chain since they are an intrinsic element of it. Indeed, the way in which the actors influence the entire supply chain with their social sustainability practices is relevant (Nakamba et al. 2017). For this reason, integrating different social decision support tools and approaches within the same methodological framework and adopting a life cycle perspective allows for sharing information needed for the decision-making process.

Life cycle thinking (LCT) and related methodologies are oriented toward reaching an overall representation of the sustainable aspects that affect the entire life cycle (from the raw material extraction phase to the end of life) of a product and the entire supply chain of the companies. In particular, Life Cycle Assessment (LCA) assesses the environmental impacts of products (ISO 14040:2021; 14044:2021); Life Cycle Costing (LCC) investigates the costs related to the entire life cycle of the product (Parent et al. 2013); and Social Life Cycle Assessment (S-LCA) evaluates the social aspects, both negative and positive, of products (UNEP 2020). Considering the social aspects allows for the assessment of the social "externalities" of organizations, which are crucial to reach economic, social, and technological development for resilient production and sustainable consumption models. The multidisciplinary approach of the commodity sciences plays an important role in addressing these issues. The typical object (i.e., products and/or services) evaluated by life cycle-based methodologies was extended to organizations with the latest introduced Organizational Life Cycle Assessment (O-LCA) (UNEP 2015; ISO/TS 14072: 2014) and Social Organizational Life Cycle Assessment (SO-LCA) (UNEP 2020) methodologies considering environmental and social issues, respectively.

Among them, S-LCA and SO-LCA are methodologies that assess the social performance of organizations. Social performance indicates "the principles, practices, and outcomes of businesses' relationships with people, organizations, institutions, communities, and societies in terms of the deliberate actions of businesses toward these stakeholders as well as the unintended externalities of business activity measured against a known standard (Wood 2016)" (UNEP 2020, p. 26). Usually, social performance is evaluated at the level of an inventory indicator (i.e., reference scale approaches) (UNEP 2020).

The aim of this study is to understand which social themes included in the Guidelines for Social Life Cycle Assessment and Organizations 2020 (UNEP 2020) are covered by the selected social responsibility tools. In particular, the analysis focused on SA8000, GRI, and ISO 26000 by highlighting how and to what extent the social sustainability tools already used by a company can support

SO-LCA implementation. The final goal is to provide an overview of the common points between them regarding the addressed social themes.

38.2 Material and Methods

SO-LCA was proposed by Martínez-Blanco et al. (2015) for assessing the social aspects and potential positive/negative impacts related to an organization as a whole or part of it (e.g., a brand, a facility, a geographical area, etc.) from a life cycle perspective (UNEP 2020). It is a newly developed approach and is still poorly implemented (D'Eusanio et al. 2022b). SO-LCA can be considered a social complement of O-LCA even if it shares several features with S-LCA (UNEP 2020). Indeed, it has the same methodological framework (i.e., Goal and Scope Definition, Life Cycle Inventory, Life Cycle Impact Assessment, and Life Cycle Interpretation) (Martínez-Blanco et al. 2015; UNEP 2020).

According to the Guidelines (UNEP 2020), SO-LCA can be applied starting from the company's previous experience with other tools by following three pathways. Among them, Pathway 1 is followed if the company has already applied social responsibility tools, while Pathway 2 is followed if it has previous experience with environmental life cycle approaches and Pathway 3 in the case of practices with product social life cycle approaches (UNEP 2020). For the purpose of this study, which focuses on SO-LCA implementation based on Pathway 1, social responsibility tools such as Social Accountability 8000 (SA8000), ISO 26000, and Global Reporting Initiative (GRI) were considered. These are international initiatives for promoting the social responsibility of companies in their business activities. In particular, SA8000 is a certification standard at the international level that supports the management system of organizations (without size and location limits) for improving their social sustainability (SA8000 2014). GRI is an international standard that provides parameters for organizations to verify their economic, environmental, and social impacts to be disclosed to stakeholders through sustainability reports (GRI 2021). ISO 26000 is an international standard, not certifiable, that provides a guide focusing on the identification of the different social topics for which organizations are responsible (ISO 26000 2021).

To implement SO-LCA starting from a previous experience of the organizations with social responsibility tools, the social themes addressed by each of them were investigated. In particular, each social responsibility tool was analyzed by identifying the covered social themes and comparing them with the subcategories (i.e., social themes) identified by the Guidelines (UNEP 2020) and the Methodological Sheets for Social Life Cycle Assessment (UNEP 2021).

38.3 Results and Discussions

Table 38.1 shows the presence of the social themes in each analyzed tool.

From the conducted analysis, it is evident that the most corresponding subcategories are those related to "workers" stakeholders. In fact, all analyzed social responsibility tools cover themes such as "Freedom of association and collective bargaining," "Child labour," "Fair salary," "Working hours," "Forced labour," "Equal opportunities/discrimination," and "Health and safety." Instead, the new subcategories introduced by the Guidelines UNEP (2020) (i.e., "Sexual Harassment" and "Smallholders including Farmers") are not addressed by any of them, while "Social Benefits/Social Security" and "Employment Relationships" are only covered by ISO 26000 and GRI.

Regarding the "Local Community" stakeholder, there is no subcategory covered by all the social responsibility tools. Indeed, the social themes "Safe and Healthy living conditions" and "Respect of Indigenous Rights" are addressed by only two of them (i.e., ISO 26000 and GRI); "Local employment" and "Delocalization and Migration" are only covered by ISO 26000, while GRI addresses "Secure Living Conditions" and "Access to Material Resources." As far as "Value Chain Actors" stakeholder is concerned, the subcategory "Promoting social responsibility" is addressed by all the social responsibility tools, while none of them includes "Wealth distribution." The social themes most recurring for "Consumers" stakeholder are "Health and safety," "Consumer privacy," and "Transparency" (within ISO 26000 and GRI). Regarding the subcategories related to "Society" stakeholder, none of the analyzed social tools includes the subcategory "Ethical treatment of animals." Finally, regarding the "Children" stakeholder, recently introduced by the Guidelines (UNEP 2020), only the "Education provided in the local community" subcategory is considered by ISO 26000. More specifically, ISO 26000 covers the highest number of subcategories included by the Guidelines (UNEP 2020) (i.e., 73% of them), followed by GRI (57%) and SA8000 (20%). This is because SA8000 is mainly focused on working conditions, while ISO 26000, by providing general guidelines for companies, includes a section about human rights that includes several social themes.

38.4 Conclusions and Future Perspectives

This study shows that the social themes considered by the analyzed social responsibility tools partly correspond to those foreseen by the Guidelines (UNEP 2020). In particular, SA8000 covers mainly subcategories related to the stakeholder "Workers," while GRI considers social themes also related to the stakeholders "Local Community" and "Consumers." Finally, ISO 26000 refers to several subcategories ranging from working conditions to children's education within the local community. Based on the obtained results, further research will focus on how these

Table 38.1 Social theme comparison

Social theme	Subcategories provided by UNEP (2021)	SA 8000 (2014)	GRI (2021)	ISO 26000 (2021)
Worker	Freedom of association and collective bargaining	✓	✓	✓
	Child labour	✓	✓	✓
	Fair salary	✓	✓	✓
	Working hours	✓	✓	✓
	Forced labour	✓	✓	✓
	Equal opportunities/discrimination	✓	✓	✓
	Health and safety	✓	✓	✓
	Social benefits/social security	–	✓	✓
	Employment relationship	–	✓	✓
	Sexual harassment	–	–	–
	Smallholders including farmers	–	–	–
Local community	Access to material resources	–	✓	–
	Access to immaterial resources	–	–	–
	Delocalization and migration	–	–	✓
	Cultural heritage	–	–	✓
	Safe and healthy living conditions	–	✓	✓
	Respect of indigenous rights	–	✓	✓
	Community engagement	–	✓	✓
	Local employment	–	–	✓
	Secure living conditions	–	✓	–
Value chain actors	Fair competition	–	✓	✓
	Promoting social responsibility	✓	✓	✓
	Supplier relationships	–	✓	–
	Respect of intellectual property rights	–	–	✓
	Wealth distribution	–	–	–
Consumers	Health and safety	–	✓	✓
	Feedback mechanism	–	–	✓
	Consumer privacy	–	✓	✓
	Transparency	–	✓	✓
	End-of-life responsibility	–	–	✓
Society	Public commitment to sustainability issues	–	✓	–
	Contribution to economic development	–	✓	✓
	Prevention and mitigation of armed conflicts	–	–	✓
	Technology development	–	–	✓
	Corruption	–	✓	✓
	Ethical treatment of animals	–	–	–
	Poverty alleviation	–	–	✓
Children	Education provided in the local community	–	–	✓
	Health issues for children as consumers	–	–	–
	Children concerns regarding marketing practices	–	–	–

issues are evaluated in the analyzed social responsibility tools with the aim of understanding which indicators, and thus data, can be derived for an SO-LCA study.

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Chapter 39
A New Approach to Improve Sustainability: The Role of Organizational Life Cycle Assessment (O-LCA)

Giuliana Vinci, Fabrizio D'Ascenzo, Marco Ruggeri, and Mary Giò Zaki

Abstract When preparing an emissions assessment report, life cycle assessment, originally defined for products, can be extended to organizations under the name O-LCA. This is a methodology for identifying the environmental impacts of activities associated with an organization using a life cycle approach, and compared to LCA, which is generally seen as an isolated assessment at the product level, it has greater transferability to the company because it considers the company's entire production range rather than just one product. However, assessing the impact of organizations can be complex because it considers a network of relationships with partners and suppliers related to the organization whose data are not always available. Thus, a detailed understanding of GHG-emitting activities is essential for the development of an effective corporate sustainable strategy, as value chain emissions can be used to guide overall policy, implement sectoral allocation, or initiate engagement with companies. Therefore, O-LCA could be a useful tool for investigating emissions at the organizational level and thus aid in the pursuit of corporate objectives. In light of this, this paper aims to present an overview of O-LCA and how it could serve as a sustainability tool to meet different interests between companies and stakeholders.

Keywords O-LCA · SO-LCA · Organizations · Materiality matrix

39.1 Introduction

In recent years, the global average temperature has increased by +1.5 °C above preindustrial levels, inducing an increase in the frequency of extreme events (IPCC 2021). Therefore, the international community has identified several goals for the decarbonization of the economic-industrial system, such as climate neutrality by

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2050 (Horowitz 2016), through which CO_2 emissions will need to be reduced by − 85% from 1990 levels (WRI and WBCSD 2011). Therefore, organizations should take steps to reduce and prevent the production of greenhouse gases (GHGs), and in this context, adopting a holistic approach to assessing value chain impacts could help. In preparing an emissions assessment report, life cycle analysis, originally defined for products, can be extended to the assessment of organizations under the name Organizational Life Cycle Assessment (O-LCA) (ISO 2014; Martinez Blanco et al. 2015). However, assessing the impact of organizations could be complex because it considers a network of relationships with partners of the organization whose data are not always available. Therefore, a detailed understanding of the activities that produce GHGs is critical for the establishment of an effective organization's sustainable strategy. In this regard, it is possible to distinguish organizations' emissions between Scope 1 (those produced directly from sources owned by the organization), Scope 2 (those associated with the purchase of electricity, steam, heat, or cooling), and Scope 3 (those associated with activities and assets not controlled by the organization, but which nevertheless indirectly impact the organization) (Fig. 39.1) (Hertwich and Wood 2018). Until recently, many companies have mainly focused their attention on emissions from their operations, managing to keep operational (Scope 1 and Scope 2) emissions under control but sometimes encountering difficulties in controlling those related to the supply chain and product use (Scope 3) (Martínez-Blanco et al. 2020). Currently, organizations are trying to find ways to reduce Scope 3 emissions, especially those related to the purchase of goods and services and product use, which account for a significant share of Scope 3 emissions (CDP 2018), while still protecting the pursuit of profitability and value creation. Value chain emissions, therefore, represent an important source of impacts, which organizations can be incentivized to reduce, and their consideration can improve the assessment of risks and opportunities for transition, although emissions reporting remains voluntary and is low (Ducoulombier 2021).

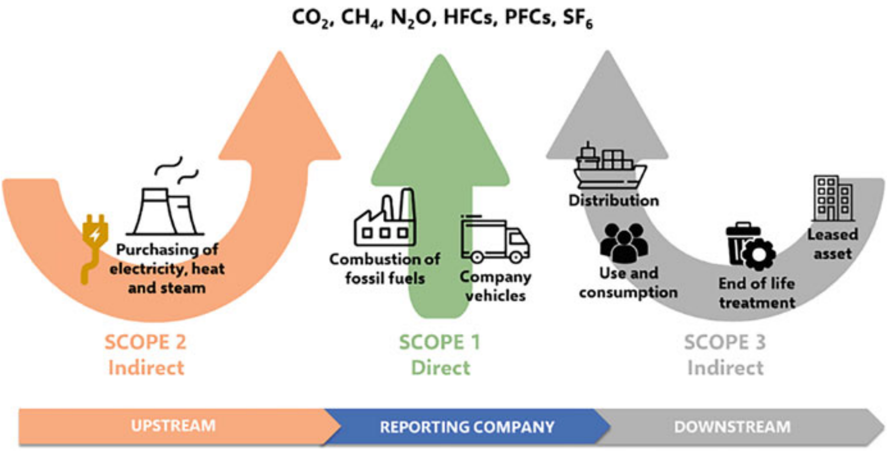

Fig. 39.1 Overview of GHG Protocol scopes

Value chain emissions can be used to guide overall policy, implement sector allocation, or initiate engagement with companies. Therefore, value chain considerations can be included in asset selection through specific security-level performance metrics and/or corporate commitment to decarbonization, such as through a materiality matrix. O-LCA could be a useful tool for investigating emissions at the organizational level and thus aid in the pursuit of Scope 3. In light of this, this paper aims to present a general overview of O-LCA and how it could serve as a sustainability tool to intersect different interests between companies and stakeholders.

39.2 O-LCA: Description and State of the Art

The LCA has evolved until the development of some "variants" that arise mainly as a result of the need to identify impacts along the entire supply chain to consider the entire value chain according to a multi-impact approach. LCA is an isolated assessment at the product level, with limited transferability to organizations. However, since most companies produce a wide range of products, an LCA related to a single product will analyze only a small part of the company, whereas it would make more sense to evaluate the company's entire production. For these, the O-LCA and the Social Organizational Life Cycle Assessment (SO-LCA) (Martinez Blanco et al. 2015) have emerged in recent years. O-LCA could be considered an extension of the application of LCA to organizations (Fig. 39.2) and could help in finding environmental hotspots where the organization should focus its interventions throughout the value chain.

O-LCA is regulated by ISO/TS 14072, which provides additional details for its proper implementation. LCA and O-LCA share most of the requirements defined by ISO 14040 and 14044, with minor additions and changes in terminology (Table 39.1).

O-LCA is still an unexplored area of research, so much so that entering the keyword "O-LCA" on Scopus yields approximately 20 articles. Among them, the papers all have different objectives (framework development, literature reviews, case studies), and one can certainly point out significant growth potential. Few studies have applied O-LCA to assess the environmental performance of organizations, such as universities (Bueno et al. 2022), packaging (Rimano et al. 2021), textiles (Resta et al. 2016), beverages (Manzardo et al. 2016), cosmetics (Moreira de Camargo et al. 2019), and renewable energy (Marx et al. 2020). Recently, O-LCA has also been extended to the assessment of social impacts through the development of SO-LCA, which although it follows the same guidelines as S-LCA, varies from it mainly to address a methodological shortcoming of S-LCA, according to which there is some difficulty in identifying social indicators at the product level since social impacts generally occur at the organizational level (Martinez Blanco et al. 2015). SO-LCA, in the face of two literature articles, also remains an understudied area of research.

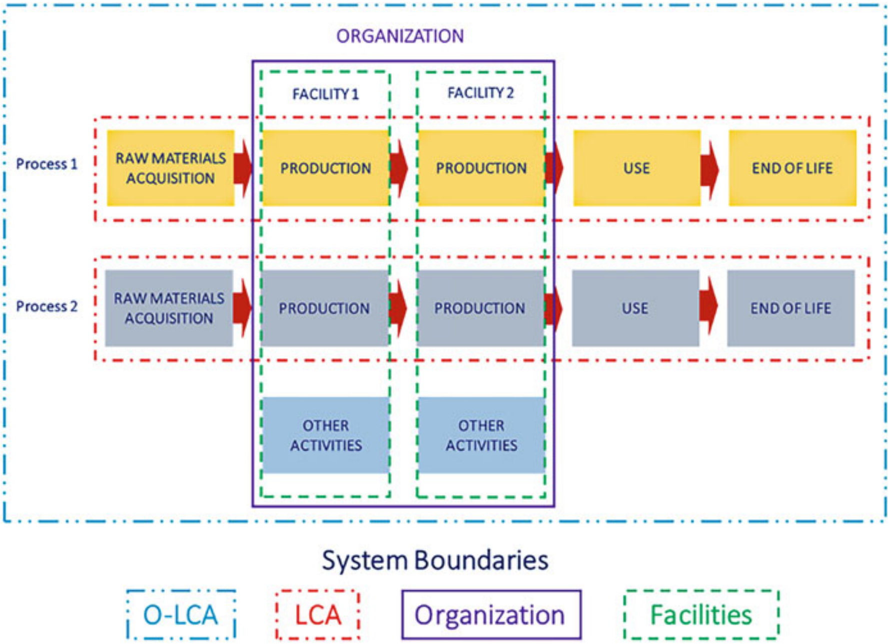

Fig. 39.2 O-LCA description. (ISO 2014)

Table 39.1 Comparison of O-LCA and LCA

	O-LCA	LCA
Scope	Organizations	Products or processes
Reference	ISO/TS 14071	ISO 14040 and 14044
Standardization year	2014	2006
Object of study	Reporting Unit	Functional Unit
Outputs measures	Reporting flow	Reference flow
Goal	Monitoring the performance of an organization	Assessment of environmental impacts of products or processes
Phases	4	4
Consolidation methodology	Yes	No

39.3 O-LCA as a Tool for Organizations' Disclosure

Over the past few years, organizations have needed to describe strategic assets and report differently on their activities, as well as justify corporate strategies. Organizations, therefore, resort to a different form of reporting, called Different Disclosure Not Financial (DDNF). To identify the different balance points that can efficiently intersect the interests of the organization with those of the stakeholders, a materiality matrix has been proposed. This is a qualitative matrix that facilitates organizations' disclosure in showing their strategies to stakeholders and identifying environmental and social hotspots. It makes it possible to identify everything that could impact the organization and vice versa, demonstrating a company's commitment to sustainability and reflecting strategic priorities in sustainability areas relevant to the group. The matrix, which can be customized to suit the needs of the individual organization, has a basic structure in which, on the x-axis is the relevance of a given issue to the company, while on the y-axis is the relevance of a given issue to stakeholders, as shown in Fig. 39.3. Strategic priorities, based on the different levels of detail of information, can be determined in various ways, but for the approach of this study, they were identified according to the six macroareas identified by Legislative Decree 254/2016, namely, society, environment, employer, human rights, corruption, and crossing. The matrix can be divided into four quadrants: 1 (very relevant to stakeholders and not very relevant to the company), 2 (very relevant to stakeholders and very relevant to the company), 3 (not very relevant to stakeholders and very relevant to the company), and 4 (not very relevant to stakeholders and not very relevant to the company). The company's goal will be to shift its targets as far as possible toward quadrant 2 (top right) to focus on pursuing and meeting goals that have a significant impact on the organization's economic, social, and environmental performance and

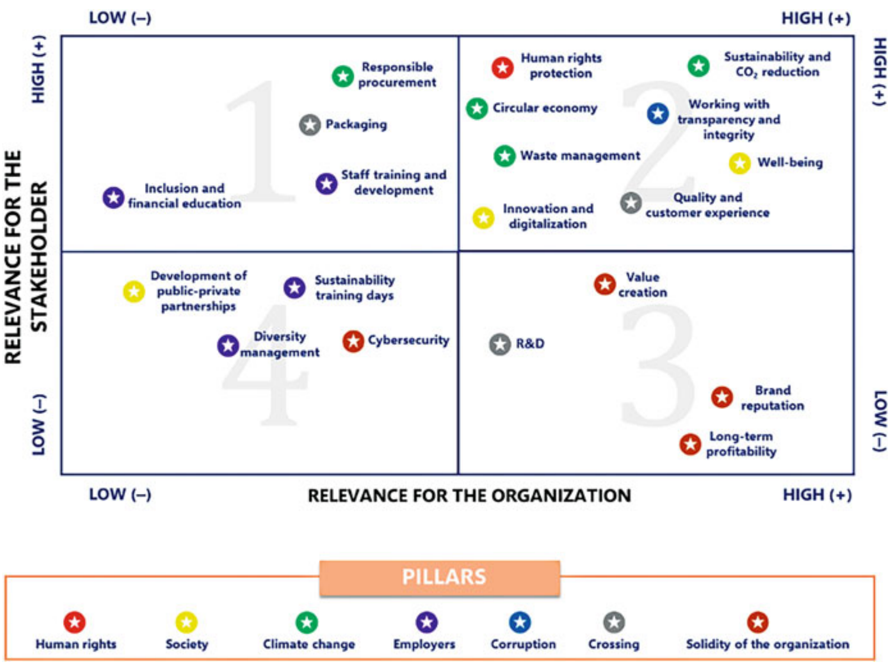

Fig. 39.3 Example of the materiality matrix

that could substantially influence stakeholder assessments and decisions. As constructed based on the two criteria described above, the widespread sensitivity to air pollution underscores the need within organizations to have to effectively communicate to their stakeholders what they have achieved in terms of emissions abatement. Indeed, Fig. 39.3 shows that in quadrant 2, in which all elements characterized by high relevance to the organization and stakeholders are placed are environmental sustainability and CO_2 emission reduction, Scope 1, 2, and 3. To this end, companies will need to employ tools for effective process analysis, and O-LCA and SO-LCA could be of great help. The matrix presupposes such survey and evaluation activities that a set of indicators and performance measures that define operational guidelines can be identified. O-LCA and SO-LCA could thus be supportive of the organization's search for objective indicators and metrics through which to measure these objectives, not least because investments in strategic assets and sustainability initiatives are difficult to explain through financial data. O-LCA could then allow companies to assess value chain activities upstream and downstream of the value chain, identifying direct and indirect emission sources and production hotspots. O-LCA is part of an evolving and particularly favorable regulatory environment that organizations could take advantage of and is also supported by ISO 14067:2018, giving organizations a better understanding of the opportunities through which they can reduce emissions. Currently, the ISO is working on the drafting of the new ISO 14068 (2023), and now the current normative reference is PAS 2060 (BSI 2014) (2010), which serves to guide companies in improving their environmental performance, with particular reference to the pursuit of carbon neutrality through a decarbonization pathway. Therefore, O-LCA could be further "enhanced" by taking advantage of a favorable regulatory environment, recently revised and with future developments. However, while the application of the O-LCA is limited to the environmental impacts of the organization, the integration of the SO-LCA allows for the addition of a social inventory and the identification of social hotspots in the organization's supply chain for the fulfilment of the remaining elements included in Quadrant 2, such as well-being, transparency, integrity, and human rights protection.

The application of O-LCA is not immediate. In fact, it will be challenging to adopt the method in the case of the service sector, given the difficulty of quantifying the organization's performance, which is necessary for activity reporting, as well as the boundaries of the system (Marx et al. 2020).

39.4 Conclusions

The objective of this study was to present a general overview of O-LCA and to show how it can support organizations in intersecting the different interests of the company and stakeholders. Thus, an approach was proposed based on the construction of a materiality matrix based on the six pillars identified by Legislative Decree 254/2016, through which it might be possible to facilitate corporate disclosure in showing stakeholders their corporate strategies. Since organizations often need objective data, through O-LCA and SO-LCA, it might be possible to provide quantifiable parameters for proper disclosure and the pursuit of the most relevant strategic objectives for both the organization and the stakeholders, including for example, the control of Scope 3 emissions, those least controllable by organizations.

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Chapter 40
The Proposal for the New Corporate Sustainability Reporting Directive (CSRD): Towards Better Environmental Data in Sustainability Reporting

Valentino Tascione, Katia Corsi, and Gavina Manca

Abstract On April 21, 2021, the European Commission adopted a proposal for a Corporate Sustainability Reporting Directive (CSRD) to amend Directive 2014/95/EU, known as the Non-Financial Reporting Directive (NFRD), transposed in Italy in 2016. It aims to make the relevant provisions more consistent with the European Green Deal and The Action Plan on Sustainable Finance. The proposed directive provides for new features, including the development of new mandatory European reporting standards and the improvement of data quality. In the new mandatory standards released over the next 2 years, there will be a reference to a comprehensive environmental footprint, and new environmental aspects to detect and communicate are introduced. The concept of the life cycle and the use of impact categories related to life cycle assessment are becoming increasingly popular within sustainability reports. Therefore, it might be interesting to understand the role of life cycle-based tools in non-financial reporting concerning environmental performance. This study aims to analyze the innovations expected in the CSRD and to understand how the new reporting standards can improve the quality of environmental data, their comparability, and what role life cycle-based tools will play in sustainability reporting.

Keywords Corporate Sustainability Reporting Directive · Life cycle · Sustainability report

40.1 Introduction

In 2014, the European Commission (EC) introduced the regulation of environmental and social performance reporting approving Directive 2014/95/EU, known as NFRD (Non-Financial Reporting Directive), which was planned to be revised starting in

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2021. The revision of the NFRD 2014/95/EU is part of the goals of the European Green Deal (EC 2019), which aims to reduce net greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels and to be climate neutral by 2050 (EC 2019). The NFRD aims to improve transparency, consistency, comparability, and the disclosure of non-financial information such as environmental information, social and employee-related aspects, respect for human rights, and the fight against active and passive corruption (Dir. 2014/95/EU). The proposal for a directive adopted by the EC on 21 April 2021, called the CSRD (Corporate Sustainability Reporting Directive), which will be approved by the end of 2022, introduces substantial novelties compared to the NFRD. This paper aims to highlight the main differences between the NFRD and the future CSRD and investigates how life cycle thinking and related tools will positively contribute to increasing companies' transparency.

40.2 Review of the Literature

Adopted in 2014 by the EC and transposed into the Italian legal framework in 2016 (Leg. dec. 254/2016), the NFRD was the first measure introducing the mandatory disclosure of non-financial risks according to the OECD guidelines (Poma and Saccani 2022). The target audience of the NFRD is "large undertakings (...) exceeding on their balance sheet dates the criterion of the average number of 500 employees during the financial year." These companies are required to report "environmental matters, social and employee-related matters, respect for human rights, anti-corruption and bribery matters" (Dir. 2014/95/EU). The principle of "double materiality" is the requirement of companies to provide information on how sustainability issues affect the company itself. In addition, their impact on people and the environment must be complied with (Dir. 2014/95/EU). However, the information communicated by the companies is not easy to compare, and there is little trust in the information reported (COM/2021/189 final). Venturelli et al. (2020) claimed that, paradoxically, reports edited following the NFRD were less comparable than reports before the NFRD came into force. Thus, there is a problem with the consistency with the requirements of Directive 95/2014/EU. Furthermore, the most important effect of introducing the NFRD is the increased number of published reports (Venturelli et al. 2020). Therefore, to overcome these and other limitations of the NFRD, on 21 April 2021, the European Commission adopted the CSRD to amend some articles of the previous NFRD. Among others, the proposed Directive (i) extends the scope of application to all large companies and all companies listed on regulated markets; (ii) requires mandatory audit (that is, assurance) of reported information; (iii) introduces specifications on reporting requirements (e.g., "double materiality" is clarified); (iv) introduces mandatory EU sustainability reporting standards; and (v) requires companies to digitally provide the information in the report to create a publicly accessible European database.

Thus, the new CSRD will be applied to all large companies (with more than 250 employees) and to all companies listed on regulated markets (including listed SMEs but not listed microcompanies). However, listed SMEs will be allowed to report under more straightforward rules, while unlisted SMEs may choose to use them voluntarily. Another innovation concerns the involvement of the supply chain; thus, large companies will have to include suppliers in their reporting. Finally, the sustainability report must be present within the management report; therefore, the company will no longer be free to choose whether to draw up a single or separate document. The NFRD establishes that "Member States shall provide that the parent undertaking may rely on national, Union-based or international frameworks," specifying "which frameworks it has relied upon." Although the most widely used standard is the one developed by the GRI (Global Reporting Initiative), another limitation of the NFRD is the lack of a harmonized reference standard, thus making it difficult to compare non-financial information (La Torre et al. 2018).

The new directive aims to overcome this limitation, recommending a single standard. To reach this objective, EFRAG (European Financial Reporting Advisory Group) is commissioned to develop EU sustainability reporting standards. EFRAG will consider current international standards and will integrate with other standards such as SFDR (Sustainable Finance Disclosure Regulation) (Reg. 2019/2088), European Taxonomy, European Pillars on Social Rights, and the pending Sustainable Governance and Due Diligence Directive. The EU reporting standards will be compatible with the systems already widely used internationally. Furthermore, they will have to contribute to the International Financial Reporting Standard (IFRS) initiative to introduce common standards globally (COM/2021/189 final). Moreover, according to the proportionality principle, an appropriate standard for SMEs is to be developed. The first set of standards, expected to be released by 31 October 2022, should include guidelines on "double materiality" and information quality. These are "basic" standards, such as the most relevant and commonly used information and the information needed to support the sustainable finance agenda (EFRAG 2021). In addition, the concept of "double materiality" will be better specified. Environmental and social impact materiality and financial materiality will be discussed. The first includes all issues related to the environment that are affected by the business (such as the supply chain) or affect the business (e.g., GHG emissions, energy efficiency, environmental footprint). Social considerations include, for example, working conditions and equal opportunities in the value chain. Another objective of the directive is to improve the quality of information. The development of standards that ensure relevance, faithful representation, comparability, comprehensibility, and reliability/verifiability could help overcome the limitations of the NRFD. The second set of standards, expected by 31 October 2023, should be related to (1) connectivity ("anchor" points to help companies link financial to sustainability reporting), levels and boundaries of reporting (considering the value chain), (2) retrospective and forwards-looking information (i.e., assessment of sustainability goals and indicators developed by companies and progress towards their achievement), and (3) consistency of standards with agreements, targets, and public policy regulations (EFRAG 2021). The overall goal will be to arrive at "advanced" standards over time, in accordance with EU sustainability policy changes. In the proposal of the EFRAG European Standard (2021), the environmental issues to be addressed are mentioned, which are those defined and required in the EU: climate change mitigation and adaptation, water and marine resources, circular economy (CE), pollution, biodiversity, and ecosystems. Companies will have to use more complex and consolidated tools to build a broader picture of environmental performance. Regarding climate-related information, the EC's guidelines (Comm. from the Commission 2019/C 209/01), which recommend the TCFD (Task Force on Climate-Related Financial Disclosures) and the NFRD, will be considered as references. Therefore, to assess GHG emissions, the GHG protocol must be used to estimate the total emissions with a view to the entire supply chain.

40.3 Methods

The following documents were analyzed for comparative analysis and to highlight the novelties of the new CSRD: the Directive of the European Parliament and of the Council 2014/95/EU on disclosure of non-financial and diversity information, the Proposal for a Directive of the European Parliament and of the Council as regards corporate sustainability reporting COM/2021/189 final, and the Proposals for a relevant and dynamic EU sustainability reporting standard setting (European Reporting LAB. EFRAG 2021).

40.4 Discussions

The new mandatory European reporting standards will undoubtedly lead to an increase in the amount of data and information that companies will have to report. However, how will the quality of the data improve? An initial examination of the proposals for the new EFRAG standards (Prop. for a Dir. 6292/22) shows that assessing environmental performance through a wide range of indicators and impacts will be necessary. CSRD is about climate change mitigation and adaptation, water and marine resources, CE, pollution, biodiversity, and ecosystems to assess the complete environmental footprint considering the entire supply chain throughout the life cycle. Thus, life cycle-based tools are certainly the most suitable for this purpose. In the CSRD proposal, reference is made to these tools. LCA (life cycle assessment) is the most widespread and consolidated tool for assessing the product, service, or process environmental impacts throughout its life cycle. On the other hand, sustainability reports are intended to inform about a company's overall environmental performance. Carrying out an LCA for just a few products might be a viable route. Different is the case for companies with an extensive product portfolio for which the LCA would entail a significant investment in money, time, and resources. Both O-LCA

(Organization Life Cycle Assessment) and OEF (Organization Environmental Footprint) can be used to provide information in sustainability reporting (Rimano et al. 2019).

For example, given the broadening of environmental parameters to be reported in reporting, O-LCA can provide a wide range of information on the supply chain about impact categories such as global warming, water consumption, ecosystem, and biodiversity damage and pollution, with a focus on data quality. O-LCA could be a suitable tool but is currently more methodologically complex, and the results cannot be used for comparisons between different companies (Blanco et al. 2015).

The OEF aims to analyze the environmental impacts of the entire value chain from a life cycle perspective, but in this case, the results can be used to compare performance between organizations in the same sector. This aspect improves non-financial reporting because, for example, it allows the reader to contextualize the data and analyze it against other values. In fact, comparability will be emphasized in the new Directive. Data and information reported must be related to the number of employees, turnover, size of production sites, or use of the functional unit parameter. These weight data would allow comparison of the performance of the same organization over different years and between different organizations.

Finally, by using life cycle thinking tools, non-financial reporting can benefit from the underlying methodological robustness.

The broadening of the list of environmental indicators to be reported within the future CSRD overcomes a critical issue highlighted by Raucci and Tarquinio (2020). They stated that organizations following the NFRD have restricted the number of environmental indicators compared to those analyzed prior to mandatory non-financial reporting. This is because they focus only on the indicators that are considered most relevant, as required by the NFRD, without further efforts. Furthermore, although GRI standards include some indicators in addition to GHG emissions, since the introduction of the Directive, emissions and energy aspects have been the main focus, generally leaving out aspects such as biodiversity and waste treatment (Posadas and Tarquinio 2021). Regarding the publication of the nonfinancial report in the same document as the Management Report, Caputo et al. (2021) claim that a single document may undermine transparency and thus the quality of environmental information. A separate report would allow the disclosure of nonfinancial information in more detail (Kiliç et al. 2015).

40.5 Conclusions and Prospects

Throughout 2022, the new CSRD will almost certainly be released. Based on the proposal released in 2021, the new provisions on nonfinancial reporting are expected to introduce some innovations compared to the current NFRD, such as broadening the scope of companies required to report and some improvements to increase the quality of the data. One of the most important innovations concerns the introduction of a broader range of environmental performance indicators in line with the current

EU policies. The aim is to demand an assessment of a more comprehensive environmental footprint. Life-cycle-based tools will undoubtedly play a significant role in providing information for sustainability reports. O-LCA and OEF have both strengths and weaknesses because they are based on a holistic view of the organization that is typical of these tools, and comparability is feasible in the case of OEF.

On the other hand, there is a problem with data availability and difficulty in categorizing the company's activity. Better comparability of data would allow a more thorough comparison of corporate performance over time and the performance of different companies in the same sector. The comparison would both help companies make strategic choices in the field of sustainability and allow stakeholders to make functional evaluations for their purposes.

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Chapter 41
ESG Indicators and SME: Towards a Simplified Framework for Sustainability Reporting

Andrea D'Angiò, Alessia Acampora, Roberto Merli, and Maria Claudia Lucchetti

Abstract The transparency of corporate disclosure represents one of the fundamental pillars of corporate governance. Sustainability reporting is a corporate practice of public reporting of company economic, environmental, and social impacts and of its contributions towards sustainable development. Sustainability reporting helps internal and external stakeholders to make informed decisions and to be aware of how the company approaches sustainable development. Alongside mandatory information, companies provide voluntary information with the aim of differentiating themselves from competitors and making themselves better known by investors. However, this practice is still uncommon for SMEs. This is understandable given the complexity of existing information frameworks – which combined offer more than 5000 KPIs – and competing data requests from customers and financial institutions. All of this makes the collection of sustainability data extremely difficult and costly for SMEs, which have limited financial and human resources for such spending. In this context, the need emerges for ESG (Environmental, Social, Governance) rating methodologies to be adapted to SMEs. In fact, although the main nonfinancial rating agencies are now focused on large companies, ESG criteria are entering the investment decisions of an increasing number of funds, and an increasing number of investors are called upon to apply these parameters to companies of smaller size. Small and medium-capitalization companies have peculiarities that require an ad hoc approach to be correctly represented by an ESG assessment. This work, therefore, aims to analyze the state of the art through a review of the scientific and grey literature on ESG criteria and their applicability to SMEs and to develop a conceptual model for identifying sustainability KPIs and ESG criteria for SMEs.

Keywords ESG · Sustainability · SME · Sustainability reporting · Non-financial disclosure

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41.1 Introduction

In recent years, in many countries, including Europe, the so-called sustainable finance has been developing, which is different from the traditional one because it has not only, and not primarily, the goal of achieving economic results but also the control and management of the social and environmental impacts produced by the investments themselves in a medium- and long-term perspective. Corporate disclosure is defined in the accounting literature as the communication to the public of corporate financial statements (Ağca and Önder 2007) or, more broadly, as the communication of economic, financial, and non-financial information, quantitative or related to the financial position and the corporate performance (Owusu-Ansah 1998). Sustainability reporting is a corporate practice of public reporting of its economic, environmental, and social impacts and its contributions to sustainable development. This practice helps internal and external stakeholders to make informed decisions and to be aware of how the company approaches sustainable development (Global Reporting Initiative 2016). Corporate disclosure is defined as mandatory when it consists of information disclosed to meet the minimum requirements imposed by laws and regulations; any information exceeding these limits is considered voluntary, taking the form of a free choice on the part of the company management to provide accounting and other information deemed relevant to the decision-making needs of the recipients of the company's annual reports (Meek et al. 1995). In recent years, the number of companies that voluntarily disclose information about their environmental commitment (mainly in terms of energy efficiency, recycling and waste, and renewable energy), their commitment to improving their relationships with internal and external stakeholders and related corporate governance has increased enormously. Companies are disclosing their efforts, as they believe that good corporate governance minimizes management and reputational risks and maximizes the profitability of capital in the medium and long term. At the heart of non-financial reporting are environmental, social, and governance (ESG) indicators. ESG reporting is a well-established concept in the financial sector as a basis for evaluating the sustainability of investments. The ESG criteria are now used in the financial sector to assess the sustainability of investments as a way to provide an overall assessment of a company that goes beyond purely economic results. In other words, it is increasingly common to consider performance against specific ESG criteria when assessing an investment, namely, the risk/return profile of portfolios. Experience shows that ESG criteria are distinctive characteristics of a company's quality in the long run. Companies that take ESG considerations more seriously are generally better managed, more sustainable, and forwards-looking. Companies with high ESG scores are better prepared to deal with crises and perform better on average than their competitors. The integration of ESG standards into investments aims to maximize the long-term return on the portfolio by better managing its risk exposure. ESG criteria used in sustainability reporting fall under both types of corporate disclosure, as they are in some cases mandatory, while they fall under voluntary reporting when they are applied by companies as a strategic choice towards sustainability. The application of ESG (Environmental, Social, Governance) rating methodologies to Small and Medium Enterprises (SMEs) is still largely unexplored today. Indeed, although the main nonfinancial rating agencies are now focused on large companies, ESG criteria are entering into investment decisions of an increasing number of funds, and increasingly more investors are called to apply these parameters to smaller companies. However, mid-low cap companies have peculiarities that require an ad hoc approach to be properly represented by an ESG assessment. To fill this research gap, this work will analyze the state of the art through a review of the scientific and grey literature on ESG criteria and their applicability to SMEs. The main aim is to develop a conceptual model for identifying sustainability KPIs and ESG criteria for SMEs.

41.2 Material and Methods

As a strategy to support sustainable development, this research tries to determine how to implement ESG criteria in SMEs. The objective of this paper is twofold: on the one hand, it seeks to contribute to the literature on ESG indicators, which is still developing a shared and common definition and practices; on the other hand, it seeks to be a useful and practical tool for the various stakeholders in the sector who want to improve their environmental, social, and economic performance and disclose their sustainability strategy. Through an extensive literature review, the paper explores the state of the art of the scientific literature and grey literature on ESG criteria and their applicability to SMEs and develops a conceptual model for identifying sustainability KPIs and ESG criteria for SMEs. The studies analyzed in this review were retrieved from the Scopus and Web of Science (WoS) databases. The search was performed in April 2022 using a Boolean search with the keywords “social*responsible mutual fund; social* responsible invest*; ESG; sustainab* invest*” OR “sustainab* financ*” OR “ethic* invest*” OR “responsible invest*.”

41.3 Results

41.3.1 The Non-financial Reporting Directive

Considering the legislative provisions in the European context, then from the mandatory reporting, the Directive 2014/95/EU (Non-Financial Reporting Directive) that was implemented in Italy with Legislative Decree N. 254 of 30 December 2016 with effect from 25 January 2017, sets minimum reporting standards for the ESG characteristics of companies in the European Union. The directive establishes the obligation for larger companies to report regularly on the company’s main ESG issues. Reporting on “nonfinancial” factors may be part of the regular financial statements or be published as a separate document, also subject to an external audit by an authorized auditing firm. The decree provides that the reporting contains information to the extent necessary to include the development, performance, position, and impact of the issuer's business on the five areas of information envisaged, namely, environmental, social and employee issues, respect for human rights and anti-corruption and bribery. With regard to the reference standard, it is possible to use reporting methodologies issued by authoritative supranational, international or national bodies of a public or private nature, or, alternatively, the use of autonomous evaluation methodologies is allowed if it is considered that the standard methodology is not suitable to correctly and clearly meet the information requirements required by the legislative decree and the Directive, provided that the adopted methodology is effectively justified and described (D. Lgs 245, 2016).

41.3.2 Corporate Sustainability Reporting Directive (CSRD)

In the wake of the EU Green Deal and the ambitious Sustainable Finance strategy, on 21 April 2021, the European Commission adopted its proposal for a Corporate Sustainability Reporting Directive ("CSRD"), which will review and extend the reporting requirements introduced by the Nonfinancial Reporting Directive ("NFRD"). Compared to the version of Directive 2014/95/EU that introduced for the first time the issue within the European Community legal system, the proposal presented the following: (1) it extends the requirement for sustainability reporting to all large companies (companies with more than 250 employees) and to all companies listed on regulated markets, including SMEs (with the sole exclusion of listed microenterprises, that are enterprises with less than ten employees and turnover or assets with a balance sheet of less than €2 million); (2) it requires the verification of the information provided by an independent third party (auditing firm) as already provided by Italian legislation; (3) it introduces more detailed reporting requirements aligned with the sustainability reporting standards that will be shared across the EU and that in the meantime will allow for international comparison; and (4) it imposes the obligation to include nonfinancial reporting in the document relating to the management report. Like the NFRD, the type of "sustainability information" to be disseminated will cover at least the following subjects: (i) environmental issues; (ii) social and labor issues; (iii) respect for human rights; and (iv) anti-corruption and bribery.

41.3.3 ESG Criteria for Nonfinancial Disclosure

Instruments of responsibility, including disclosure of information responding to environmental, social, and governance (ESG) issues, are pivotal to make visible the ethics of the company and its compliance with international standards to safeguard human rights, workers, and the environment. The integration of ESG criteria can therefore improve the risk/return profile of portfolios. These three ESG factors are essential to assess the sustainability and related risks of an investment position: (E) Environment means more attention to issues such as CO_2 emissions and climate change, population growth, biodiversity, and food security; (S) Social refers to concerns of companies about human rights, working conditions, child labor, and equality; (G) Governance is a criterion that mainly covers factors such as the quality and diversity of supervisory boards, the remuneration of managers, shareholders' rights, and the elimination of corruption. The international business environment offers many standards, guidelines, and reporting frameworks that entities can adopt when preparing a nonfinancial report. Companies considering the potential implementation of an ESG reporting framework should be aware of the variety of reporting standards that have been developed by standards managers around the world. As the various standards cover overlapping ESG topics but outline disparate reporting requirements, a continuous effort has been made to align standards with specific ESG reporting categories. For example, in terms of climate reporting, the Corporate Reporting Dialogue ("CRD"), a platform convened by the International Integrated Reporting Council, has been working on its "Better Alignment Project" since November 2018 to assess the alignment of the TCFD's disclosure principles between its participating standards makers, such as SASB, GRI, CDP (formerly Carbon Disclosure Project), the Climate Disclosure Standards Board ("CDSB"), and the International Integrated Reporting Council ("IIRC"). The goal is for these standards to help companies to better measure and manage their ESG risk exposures and become better corporate citizens by measuring, disseminating, and managing the environmental and social impacts they create.

41.4 Discussion and Conclusions

Although there is no legal obligation under the NFRD Directive for SMEs to disclose nonfinancial information, many of them are under increasing pressure from their parent companies to provide certain nonfinancial information to meet group reporting requirements (Steinhöfel et al. 2019). Key stakeholders, such as corporate customers who are introducing sustainability and transparency requirements into their supply chain, are also putting pressure in this field. All this, however, involves a considerable effort for SMEs that fail to meet these requests due to insufficient human and financial resources and are penalized in terms of access to the investment market or in difficulty with the requirements of the companies (Durst and Gerstlberger 2020). In fact, data from the Global Reporting Initiative (the most widely used among many voluntary sustainability reporting standards) show that only 10–15% of companies using its standards are SMEs. This is understandable, given the complexity of existing information frameworks – which combined propose more than 5000 KPIs – and competing data requests from clients and financial institutions (GRI and IOE 2020). Regarding the legislative requirements for SMEs in the European Union, the Commission, in view of these difficulties, has proposed that SMEs listed on regulated markets could use simpler reporting standards tailored to the ability of SMEs to comply with their legal reporting obligations, while nonlisted SMEs may decide voluntarily to use them. In addition, reporting obligations for SMEs would apply from 1 January 2026 so that they can better manage the transition phase, also considering the extra challenges faced following the COVID-19 emergency. To further address these issues, the European Commission plans to publish SME-specific sustainability reporting standards by 31 October 2023, taking into account the capabilities and characteristics of SMEs. These will also be addressed to SMEs outside the scope of sustainability reporting under the Accounting Directive. This standard will make it easier for SMEs to report on sustainability and reduce administrative costs. To achieve this, the standards should specify the key sustainability indicators that SMEs can reasonably report on and, most importantly, the methodologies and support tools that will allow them to be easily calculated. This relates in particular to greenhouse gas emissions; energy intensity; information on activities and resource use related to an increased risk of impact on climate, biodiversity, and deforestation; a clear guide to inform on climate transition plans and sustainable activities; due diligence on human rights; and meaningful labor indicators. The challenge, therefore, is to ensure that SMEs, in addition to aligning themselves with the various obligations, can exploit the opportunities relating to specific types of investment and the possibilities of increasing the "quality" of their actions by integrating ESG rating methodologies with traditional disclosure. From this point of view, in addition to the EU, other private entities and representative associations have made efforts in this direction. In particular, Confindustria recently published the "Guidelines for the sustainability reporting of SMEs" in collaboration with the GBS. The aim of this document is to provide a concrete framework to help SMEs approach sustainability reporting by providing simple and adaptable KPIs developed considering the different sizes of enterprises. This document is the first instrument, created specifically for SMEs, to approach this type of reporting through questions regarding governance and compliance, economic performance, circular economy, environmental management, people, working relationships and diversity, responsibility towards customers, suppliers and supply chain, local community and territory. The document also provides a list of indicators that can be used depending on the specific sector of the company. This approach highlights that the only way to ensure that SMEs can adapt to ESG-based reporting is by simplifying and clarifying the areas in which they operate. Indeed, providing clear documentation and identifying the useful KPI is, at the moment, the best way to solve the shortcoming for SMEs that emerged from the analysis.

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Chapter 42
Women Entrepreneurship and New Business Models for a Quality Production of Aloe Vera in Jordan

Daniela Tacconi, Leonardo Borsacchi, and Patrizia Pinelli

Abstract Aloe vera L. is a vegetal matrix of great interest. The gel obtained from its leaves is useful for the production of numerous items, even in different sectors, such as phytotherapy and cosmetics, thanks to its healthy and beneficial properties. This action research took place within the project "Promozione della filiera agribusiness dell'Aloe vera attraverso l'implementazione di un progetto pilota a sostegno delle cooperative di piccoli produttori nell'area di Karak in Giordania" (AID 11481), implemented by Jean Paul II Foundation and funded by the Italian Agency for Development Cooperation. The main objective of the project is to promote the A. vera chain in the Jordan Valley in Fifa, Karak region (Jordan). The project involved microenterprises owned by women with the purpose of providing training, materials, and equipment and designing a business model based on the cultivation, transformation, and sale of A. vera. This paper is structured in three parts: first, the methodology applied during the research is explained, then the core part focuses on some contextual factors and some common features observed among the target enterprises, and then the results regarding the definition of the business model and quality procedures.

Keywords Aloe vera L. · Sustainability · Cosmetics · Business model · Action research

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42.1 Introduction

Aloe vera L. is a well-known medicinal plant native to North Africa but is now widely distributed throughout the world for its ability to adapt and thrive in different climate conditions. In addition to being used as a medicinal plant worldwide (Sanchez-Manchado et al. 2017), A. vera has become one of the most important raw materials in different industrial sectors (e.g., food, cosmetic, herbal preparations) as an emerging source of bioactive components. The multifunctionality of Aloe vera L., and therefore, its possible use in different production sectors, must take into account qualitative, regulatory, and market requisites. The realization of semifinished or finished products for certain sectors must comply with vertical regulation and standards. On the other hand, Aloe vera L. is grown under specific pedoclimatic conditions, and agricultural inputs may be suitable for some production and not for others. This study took place within the project "Promozione della filiera agribusiness dell'Aloe vera attraverso l'implementazione di un progetto pilota a sostegno delle cooperative di piccoli produttori nell'area di Karak in Giordania" (AID 11481), implemented from 2019 to 2021 by the Jean Paul II Foundation and funded by the Italian Agency for Development Cooperation. The main objective of the project is to promote the Aloe vera L. agribusiness chain in the Jordan Valley in the region of Fifa (Jordan). According to the project, new Aloe vera L. crops have been planted in selected fields in the Karak region. Aloe vera L. is not in fact a native species of that region (Bartolini 2018).

The project involved in particular microenterprises owned by women with the purpose of providing them training, materials, and equipment. In addition, a business model based on the cultivation, transformation, and sale of Aloe vera L. has been designed. Such a business model aims to facilitate the planning and management of small farming and processing activities. It represents a flexible model applicable to both small-scale productive activities and more structured enterprises. Moreover, within the project, activities provided good manufacturing practices according to quality standards and regulations, especially to obtain traditional cosmetics (e.g., soaps) based on the gel of Aloe vera L. This paper presents the results of action research conducted by ARCO, a university action research center founded in 2008 at PIN S.c.r.l. (Polo Universitario "Città di Prato") – University of Florence. The paper is structured in three parts: first, the methodology applied during the research is explained, then the core part focuses on some contextual factors and common features observed among the target enterprises, and then the results regarding the definition of the business model and quality procedures.

42.2 Materials and Methods

This action research has adopted a methodology based on the active involvement of project stakeholders. In particular, the activities were carried out before and during a field mission: (a) Desk-based analysis of internal reports (e.g., previous field mission reports of the project partners) and literature. (b) Conduction of semistructured interviews and on-field visits. It should be noted that following the pandemic emergency, the activities carried out in the 2020–2021 period were conducted remotely (i.e., through online interviews and online evaluations of production sites). The development of the business model for the target enterprises has been generally based on data gathered through the conduction of semistructured interviews with farmers and associations. The model targeted four major women's associations in the area: Al Murjan, Al Jazzarah, Al Yusra, and Shabat Al Mustaqbal. For each of them, the production flows, the supply chain, and the potential destination market have been analyzed. This approach therefore combined commodity aspects with economic/financial aspects, with major implications for the supply chain (Biswas 2010). Once collected, data were processed to create average data representative of multiple local activities (ISMEA 2011). To facilitate comparisons, the exchange rate JOD/€ of January 2022 has been considered (€/JOD 1.2470) (www.cambioeuro.it).

42.3 Results and Discussions

The following flow diagram represents the main steps of the Aloe Vera production chain (from the field to semifinished products) in target enterprises (Fig. 42.1).

In accordance with Jordan regulation, the obtained gel can be directly used in traditional preparations (i.e., for making soaps). By adopting a business plan, it could be possible to facilitate the planning and management of small farming and processing activities of Aloe vera L. involved in the project. It represents a basic model, simple and flexible, that can be used by both small-scale productive activities and more structured companies. Moreover, the model aims to be replicable in different contexts and areas (Pandey and Singh 2016). In particular, it combines a dual function: (i) Through the analysis of costs and revenues in the long term, it describes and identifies the state of the art and business opportunities. The results outline technical and economic feasibility. (ii) Aiming at internal management control, it reports the unit cost analysis for each product. In addition, this business plan is structured to provide information on the cultivation phase and processing (Konstantinos 2022). For this reason, the tool could be used in a modular way according to the effective phases carried out by the enterprise.

The proposed model of the business plan is essentially composed of three parts:

1. Technical data: sheets called "Aloe farming," "Aloe processing," and "final products calculation." In these sections, technical data for cultivation and processing phases are identified (Samsai and Praveena 2016). Based on these, investment and annual costs were calculated. The sheet called "final products calculation" reports the number of finished products annually obtained based on the amount of raw materials used every month.

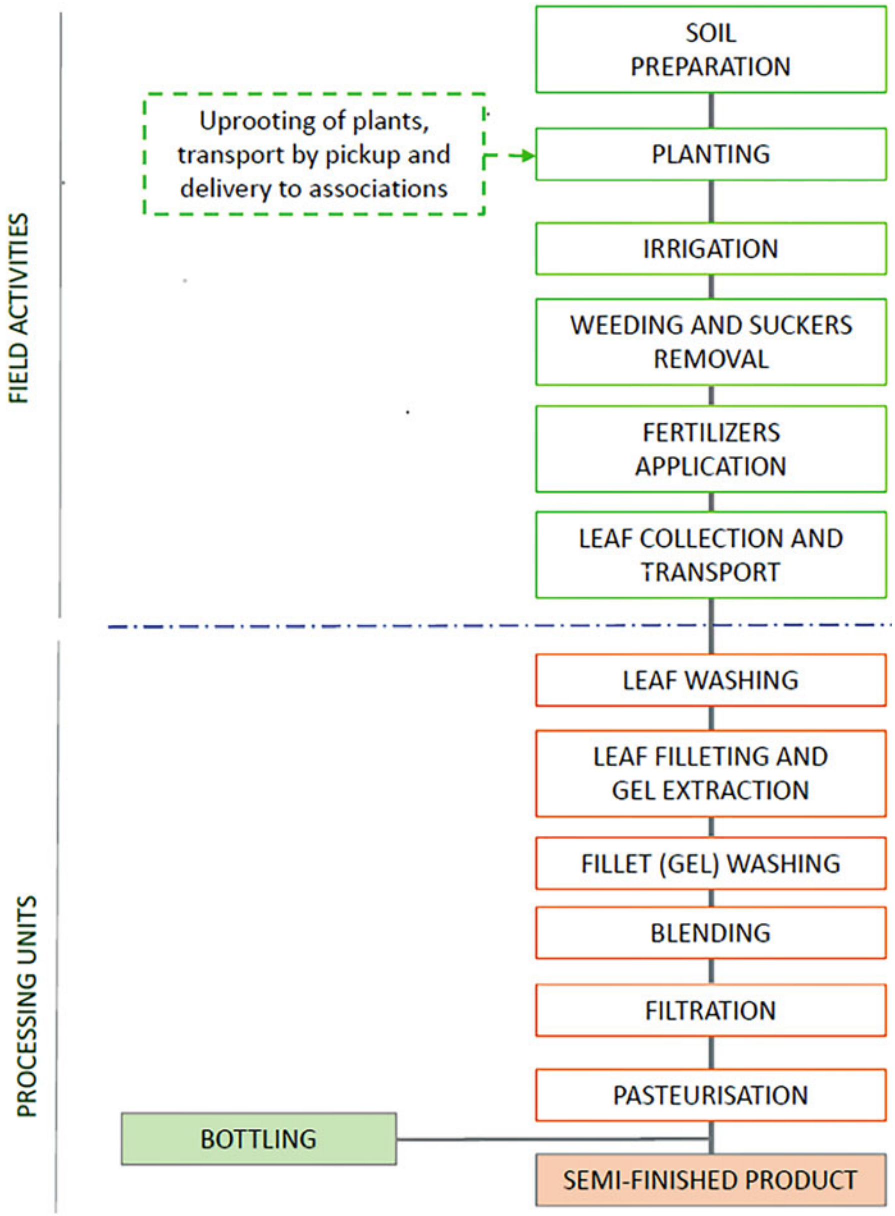

Fig. 42.1 Flow diagram of the Aloe vera chain within the project

2. Economic and financial evaluation: "costs", "revenues," and "loss and profits statement" sheets. All the annual costs and revenues are identified, classified, and analyzed to assess the net income (Brown et al. 2022).
3. Unit cost evaluation: "unit cost leaf" and "unit cost products." In these sections, the cost per unit (kg) is calculated for any final product. The aim is to analyze how the single cost items affect the total production cost to identify the right price (Liontakis et al. 2016, 2021).

The model considers an agricultural area of 0.5 donum (or 0.05 ha) with a cultivation of 475 plants and a production capacity of 10 leaves per year per plant, with a potential annual production of 4750. However, to consider a realistic scenario, we decided to consider a quantity of 45 leaves per month actually processed. Of these, 30 are sold as leaves (after a small pretreatment), and 15 are processed for gel extraction. In regard to the labor costs, an average hourly cost of € 2.03 was considered, with the involvement of two farmers for land preparation and one farmer for leaf collection and field management. At the leaf processing stage (for gel extraction and preparation of cosmetic products), a yield of 400 g per leaf was considered. Assuming to process 15 leaves per month, the estimated annual gel production is 72 kg (6 kg/month), but with a large potential increasing marge. The potential aloe-based finished products are anti-aging gel, aloe face cream, foot cream, hair oil, body lotion, hair spray, and aloe soap (Saiyem Abu Md et al. 2020). To evaluate the economic viability of aloe cultivation and processing, the annual costs and revenues were identified and analyzed. Investment costs (multiyear) and annual costs were identified for both the cultivation and processing phases. All the investment costs (necessary to conduct this type of activity) have been considered, even if they are not currently incurred by the associations as they are financed. As already mentioned, the objective is in fact to show how a company operating in this market should act and what the related challenges are. Annual costs, on the other hand, were further classified into direct and indirect costs. This classification of annual costs is used to assess the company's ability to produce profit and sustain fixed costs. Annual revenues were calculated considering current prices and assuming the sale of all the products obtained. In particular, the sale of 30 leaves per month was considered, together with the sale of aloe gel-based products obtained from the extraction of 6 kg of gel per month. As an economic result, with an initial investment of approximately € 7850.00, net profits are attractive from the first year.

Regarding economic and cash flow analysis, the main findings are as follows:

1. A Payback Period (PBP) of 6 months represents the amount of time required for cash inflows generated by the project to offset its initial cash outflow. Thus, in approximately 6 months, the initial investment might be recovered.
2. The break even point (BEP) turnover is the point where total revenues (from sales) equal total costs. Our BEP turnover is € 5778.00: above this figure, a profit is produced. Our revenues reach approximately € 25000.00 in the first year, so we are well over the profitability threshold.

Table 42.1 Economic and cash flow analysis

JOD currency	Number of years					
	0	1	3	5	8	10
Revenues		20,595	21,260	21,945	23,016	23,758
Direct costs		7907	8162	8426	8837	9122
Indirect operating costs		1617	2037	2102	2205	2276
Operational cash flow (EBITDA)		11,070	11,060	11,417	11,974	12,360
Amortization		1237	757	690	643	643
		9833	10,303	10,727	11,331	11,717
Financial management		0	0	0	0	0
Extraordinary management		0	0	0	0	0
Earning before tax (EBT)		9833	10,303	10,727	11,331	11,717
Jordan taxes		1967	2061	2145	2266	2434
NET INCOME (net profit)		7867	8243	8581	9065	9374
CASH FLOW						
Net cash flow	−6352	9104	9000	9272	9708	10,017
Discounted cash flow	−6352	8670	7774	7265	6571	6149

As it can be noticed from Table 42.1, the full application of the Business Plan model within the enterprises of the project shows the following findings:

- The initial investment is recovered in less than 1 year.
- The breakeven point turnover is approximately € 5700.00.

We can state that Aloe vera production represents an interesting business with considerable development potential. In addition, it could represent a good opportunity for young and women entrepreneurs, as it is a new market with a value chain that has yet to be fully established. Moreover, according to the available data, the production of oil, sprayers, and hand soap products is still uneconomic.

To improve the quality of production, along with the definition of a business plan model, a Technical Manual with procedures and good practices was developed. The newly developed technical manual consists of a set of practical instructions, operating rules, and organizational guidelines. It is inspired by the following standards: (i) HACCP, for food hygiene practices; (ii) ISO 9001, for management procedures; (iii) ISO 22716 standard concerning cosmetic manufacturing practices. The definition of standardized procedures and the adoption of quality procedures and good manufacturing practices (GMPs) helped to support the efficiency of processes, with consequent improvement of the quality and safety of productions. In particular, GMPs described in the manual are the following: GMP 01 Documentation; GMP 02 Records; GMP 03 Buildings and Facilities; GMP 04 Equipment; GMP 05 Personnel; GMP 06 Raw materials; GMP 07 Water; GMP 08 Production; GMP 09 Cleaning and sanitation; GMP 10 Analysis; GMP 11 Internal Audit and improvement; GMP 12 Complaints and recalls. The full application of the Technical Manual in the women's cooperatives implied a training activity.

42.4 Conclusions

This work focuses on the development of a business plan model and the implementation of quality procedures for small enterprises producing Aloe Vera in Jordan. The sector could represent a good opportunity for women entrepreneurs. The economic-financial analysis provided interesting data, especially in view of potential developments that could affect aloe production activities. In particular, we can observe that the initial investment is recovered in less than 1 year, with a Break Even Point Turnover is around 4600 JOD. Regarding the value of the finished products, it should be noted the composition of Aloe vera products is strongly influenced by the processing of the raw material; therefore, the optimization of production process is important to preserve the properties of aloe products. The production steps themselves, as well as the reference quality standards, are highly dependent on the type of product to be made, the target sector, and the target market. On the basis of this action-research, we can state that Aloe Vera production represents an interesting business with a considerable development potential in Jordan.

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Chapter 43
Sustainability Standards and Certifications for the Healthcare Sector: A Literature Review on Social, Economic, and Environmental Indicators

Carlotta D'Alessandro, Grazia Calabrò, and Giuseppe Ioppolo

Abstract Globally, the ever-increasing incidence of chronic diseases due to the current aging rates of the world population and the effects of climate change have made it necessary to develop a healthcare sector capable of holistically integrating the social, economic, and environmental aspects of sustainability. Indeed, it is increasingly oriented toward the principles of sustainability within the delivery processes and operations. Furthermore, the standardized use of indicators capable of measuring and evaluating the social, economic, and environmental performances of the health sector is a crucial strategic component for policymakers, managers, and planners. Despite this, the sustainability indicators capable of monitoring such social, economic, and environmental performances in a standardized manner are undertreated in the literature. For this reason, through a literature review of different international and national standards and certifications, the proposed study aims to fill this gap by exploring and analyzing a wide range of social, economic, and environmental indicators that characterize the healthcare sector. In terms of results, this analysis not only provides an innovative but also a clarifying perspective on the role of standardization and certification in healthcare sustainability.

Keywords Sustainable indicators · Healthcare sector · Standardization · Certification · ISO · Sustainability

43.1 Introduction

The health sector is continually evolving as feedback for emerging technologies, such as Blockchain, Internet of Things, or Artificial Intelligence, to address the needs of emerging countries, and to adapt to new policies characterizing public health,

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aimed at bolstering human wellness (Junaid et al. 2022). Developing a healthcare sector capable of integrating sustainability is growing due to its negative impact on the environment and climatic change; indeed, reducing greenhouse gas emissions can lead to significant enhancements in public health (Watts et al. 2017). Sustainability is understood as a combination of the environmental, economic, and social aspects of a system (Purvis et al. 2019). From this perspective, the introduction of sustainability can be considered a response to the troubles of the environment and society overall. Based on a United Nations (UN) survey, the world will be populated by 8.5 billion people in 2030, 9.7 billion people in 2050, and then 10.9 billion people in 2100, with global average life expectancy at birth of 72.6 years in 2019, showing an upgrading of over 8 years compared to 1990 (UN 2019). Population growth is taking place on an extraordinary magnitude around the world, and its externalities on the environment, economy, and society are palpable (Arbolino et al. 2017). The unexpected population growth due to the declining mortality rate, together with an aging population and socio-economic conversion, which causes many non-communicable diseases (Boutayeb and Boutayeb 2005), will likely create a constraint for the sustainable management of the healthcare sector. Moreover, the healthcare sector causes 4.4% of the total global greenhouse emissions (Karliner et al. 2020); health processes are responsible for the overproduction of nitrogen oxides, sulfur dioxide, and nitrogen runoff (Lenzen et al. 2020). In that sense, the literature assumes that all types of institutions can be the right items to support positive environmental policy (Ioppolo et al. 2016). For all these reasons, sustainability plays a key role in the healthcare sector in developed countries as well as in developing countries. The interconnected and synergistic so-called three pillars of sustainability that the health sector must consider – economic, social, and environmental sizes – are essential to improve the conservation of resources, and enhance human health, while considering the ecological and economic perspectives (Molero et al. 2021). Holistic integration of these three pillars is impossible without understanding how social actions impact the environment, as well as how today's decisions can affect future generations (Hutchins and Sutherland 2008). Along this line, globalization together with increasing economic stratification highlights the gap in the health conditions of several countries. Innovation and technology, reduction of costs, and the new provider-client relationship approach push for more attention to the quality and effectiveness of medical care. In this sense, organizations such as the International Organization for Standardization (ISO) furnish indicators to support the evolution toward a sustainable healthcare system. Nevertheless, sustainability indicators have been studied in several service sectors, to consider the grade of sustainability and establish mechanisms for checking advancement toward sustainable objectives (Abbasi et al. 2023); albeit, there is a gap in the research on the healthcare system. The purpose of the present paper is to compile a review of international and national standards and certifications suitable for the healthcare sector. The study aspires to analyze the contribution of international and national standards and certifications addressed to the healthcare sector. Following this introduction that develops a review of the theoretical literature for the healthcare sector, Sect. 43.2 reviews international standards, and Sect. 43.3 presents the methodology used. Finally, Sect. 43.4 discusses the findings and Sect. 43.5 concludes the paper.

43.2 Review of International Standards for the Healthcare Sector

Sustainability is a crucial aspect of the healthcare system since it can lead to yield advantages such as safeguarding health, cost savings, and efficiency while mitigating environmental hazards (WHO 2017). Sustainability has received considerable attention from researchers because it brings competitive advantage to healthcare facilities. Moreover, policymakers, managers, and planners are offered a broad spectrum of indicators and standards capable of assessing sustainability. Despite the significant number of grey literature, reports, and scientific articles on the sustainable healthcare sector, the most important indicators' standards come from the ISO. However, the selection of the proper indicators or certifications for achieving sustainability is a challenge for urban policymakers, managers, and planners. ISO 9001:2015 is an international standard that describes a process-oriented approach to performing a successful quality management system (ISO 2015a), suitable for all types of organizations. ISO 9001 helps the health system to ameliorate quality and patient satisfaction. ISO 9001:2015 requires healthcare organizations to fix their quality management systems based on changes in the regulatory background. The ISO 14001:2015 standard helps the healthcare sector handle environmental performance, becoming more responsible for the environmental pillar of sustainability (ISO 2015b). Thanks to the ISO 14001 Environmental Management System, it is possible to reduce the threat of environmental damage, making care organizations green and environmentally friendly. ISO 50001:2018 provides a pattern of continual improvement to assist policymakers in carrying out energy policies, in order to realize and support an energy management system (ISO 2018a). Implementing ISO 50001:2018 in healthcare organizations means being able to reduce greenhouse gas emissions; in that sense, the organizations will be greener and more sustainable. ISO 45001:2018 shows the requirements needed to ensure safe and healthy labor to improve the occupational health and safety (OH&S) management system (ISO 2018b). ISO/IEC 27001:2022 describes indicators to define, create, and sustain measures that furnish information security management systems (ISO 2022). Furthermore, ISO 13485:2016 outlines the criteria for a quality management system, establishing an organization's capacity to deliver medical devices and associated services in accordance with customer needs and relevant regulatory standards (ISO 2016). Finally, the ISO/IEC 17025 authorizes laboratories to certify the ability to produce lawful results (ISO 2017). Internationally, healthcare sustainability can be reached with different certifications. Moreover, the Leadership in Energy and Environmental Design (LEED) consists of performance standards mandatory to achieve certification (USGBC 2012). Obtaining LEED sustainability certification means having a healthcare facility committed to cutting toxic exposures to occupants and the environment. Further, by achieving BREEAM certification (Building Research Establishment's Environmental Assessment Method), healthcare structures give more emphasis on sustainability throughout building design, construction, and utilization phases (BRE Global Ltd 2014). In the end, JCI sustainability certification is in line with government policy to enhance harmony with international healthcare facilities. Achieving JCI accreditation is an indication to patients, it signifies that a healthcare organization has sustained thorough performance evaluation and has achieved a robust degree in patient safety and quality of care.

43.3 Methods

An analysis of the international standards and certifications relevant to the healthcare sector was initially carried out. To this end, a review of the relevant literature to provide the conceptual bases helpful for understanding the standards and certifications investigated was conducted. Therefore, the authors have disclosed a scheme to address the research question, integrating keywords and inclusion and exclusion criteria to determine sources relevant to the study. Regarding the research question, the proposed paper aims to analyze the contribution of international standards and certifications suitable for the healthcare sector. Mainly, using ScienceDirect, Google Scholar, and MDPI as databases, the following keywords were used to elaborate the literature: ("ISO for health") AND ("healthcare sustainability indicator" OR healthcare sustainability indicators") AND ("healthcare sustainability standard" OR "healthcare sustainability standards") AND ("industry 4.0 in health sector") AND ("sustainability in healthcare sector") AND ("healthcare system indicator" OR "healthcare system indicators") AND ("healthcare system standard" OR "healthcare system standards") AND ("healthcare sector certification" OR "healthcare sector certifications") AND ("standardization for healthcare sector"). This review generated a scenery of seven international standards and three certifications applicable to the healthcare sector, in line with the intention of the article. Therefore, with the purpose of consolidating the solidity of the study, the discovered sources were examined based on definite inclusion and exclusion criteria. More precisely, the inclusion criteria were (a) the authenticity and credibility of the resource; (b) using ISO or certifications in the field of healthcare; (c) effectiveness of international standards and certifications implementation on healthcare organization; (d) exposition of the requirements of international standards and certifications the requirements in healthcare organizations; (e) conformity with the forward-looking perspective of the study regarding sustainability for healthcare sector; and (f) published in English or Italian. Simultaneously, the exclusion criteria were (a) incompleteness of information and (b) inconsistency with the purpose of the study. Therefore, the study of international standards and certifications based on a qualitative analysis method was determined from the troubles of quantitatively delineating and specifying the data concerning the economic, environmental, and social aspects. In the following section, further details about the investigation of international standards and certifications suitable for the healthcare sector will be provided.

43.4 Results and Discussions

The integration of sustainability standards in the healthcare sector and the implementation of systems for the achievement of certifications not only preserve the consumption of money, energy, and water but also strengthen standardized processes among care facilities. For example, to be in line with ISO standards and certifications, healthcare facilities develop activities to minimize waste generation, chemical policy, or resort to the use of technology. The strategy of using indicators capable of measuring and evaluating the social, economic, and environmental performances, is crucial for a comprehensive approach to tackling sustainability challenges in healthcare, assisting managers and policymakers in devising strategies and setting improvement targets (Mehra and Sharma 2021). Nonetheless, the improvement of a forceful and standardized set of standards and certifications approach, aimed at quality betterment and able to increase environmental, social, and economic performance, as evaluating advancement, is necessary to ameliorate sustainability performance (Mortimer et al. 2018). Indeed, these standards are acknowledged as tools for assessing sustainability performance. The procedures should be standardized to provide valid confrontation; however, there lacks an internationally standardized approach (Sherman et al. 2019). Therefore, the review of international standards and certifications based on a qualitative analysis method is determined from the troubles of quantitatively delineating and specifying the data concerning the economic, environmental, and social aspects. The research attempts to define a preliminary ground useful for future quantitative analysis regarding the impacts of the healthcare sector. Thus, this must be realized by considering several aspects, such as healthcare providers, patient satisfaction, and family satisfaction. Moreover, different elements of sustainability in the healthcare sector are worthwhile specifically for patients, the healthcare facilities, and the family of the patients. More specifically, benefits resulting from the implementation of ISO standards and certifications could be the decrease in functioning and operational costs, the enhancement of overall energy and water efficacy, the control of consumption volumes, the limitation of emissions, and the management of waste treatment. In summary, greener environmentally friendly buildings and more efficient care provisions have superior capability in reducing greenhouse gas emissions compared to ordinary structures (Hafez et al. 2023). According to the literature, sustainability can be understood as the preservation of wellness over a prolonged, potentially unlimited timeframe (Kuhlman and Farrington 2010). Consequently, it is useful to support the implementation of standards and certifications considering the economic, social, and

Table 43.1 Review of advantages of international standards and certifications for the healthcare sector

	Healthcare organizations benefits	Patients benefits	Family benefits
ISO 9001: 2015	More versatility to better manage challenging	Best care for the patient	Ameliorate family's satisfaction
ISO 14001: 2015	EMS result in the hospital's perception as a deontological, and responsible organization	Enhancement of a quality of care for patient	Enhancement of quality of care for family
ISO 50001: 2008	Care facilities become more greener and more respectful of the environment	High-quality care to their patient's	Forceful image of ecological responsibility translates to family satisfaction
ISO 45001: 2018	Improve occupational health and safety, for a sustainable care facilities' reputation	Full employment involvement, means better quality of care for patients'	Patients' satisfaction induces family's satisfaction
ISO/IEC 27001: 2013	Protects the organization from cyber-attacks, improving its reputation	Safeguard confidential patient-identifiable data	Patient data protection translates into family's satisfaction
ISO 13485: 2016	High ability to achieve compliance with regulatory requirements	Reduce risks, rising quality for patients' satisfaction	Capacity to supply conform products, translates into family's safety
ISO/IEC 17025: 2017	It guarantees accurate and reliable results for specific tests by creating, establishing, and calibrating trust in the organization	Patient confidence in laboratory services	Family security in laboratory services
LEED certification	Creation of a good internal environmental quality	Focus on patient well-being	Family's relief due to focus on reduction of emissions
BREEAM certification	Mitigation of environmental burdens, for a greener hospitals' image	Focus on patient well-being	Family's satisfaction due to the focus on huge degrees of recovered materials
JCI certification	Ensures a safe healthcare environment	Constant efforts to reduce risks to patients	Family encouragement

environmental dimensions of sustainability, simultaneously considering stakeholders' and patients' needs (Table 43.1).

43.5 Conclusions

In this research, a fresh and original perspective on the role of standardization and certification in healthcare sustainability is proposed. The goal of this review is to shed light on what international standards and certifications are by placing them under the microscope to determine their focus and areas of action. Implementation of standards and certification in the healthcare sector can more effectively address sustainability issues. In this sense, international standards and certifications allow healthcare facilities to ameliorate their sustainability. In sum, the systematic and massive use of standards and certification for achievement is emphasized as a driver of care sustainability. The relevance of the ISO and certifications for healthcare sustainability is emphasized by the many international facilities that implement them, to actively collaborate on the social, environmental, and economic transition. By identifying and describing the relevant ISOs and certifications suitable for healthcare organizations, the study offers a comprehensive overview. In this direction, the intent of this paper is to promulgate the sustainability practices of the healthcare sector by analyzing different standards and certifications. In particular, the research illustrates that implementing ISO standards or certifications in care facilities can contribute to protecting the environment, improve social and economic efficiency, and enhance care's reputation. The employees and the patients of the healthcare organizations that will implement standards and certifications will be conducted toward sustainability. In brief, we underline the principal topic: (a) international standards and certifications suitable for the healthcare sector; (b) the development of sustainability necessitates standards and certifications capable of measuring and evaluating social, economic, and environmental performance; (c) the dynamic healthcare sector pushes policymakers to adopt those standards and certifications; (d) standards and certifications improve efficacy and quality of care; and (e) standards and certifications enhance environmental, social, and economic performance. Hence, the study and examination of standards and certifications suitable for the healthcare sector raise awareness of their possible contribution. Nonetheless, the review of the sustainability of the healthcare sector driven by the three pillars needs not just a qualitative approach, as suggested in this study. In this regard, the proposals for the next research aspire to supplement the formulated review with additional quantitative analyses to determine and assess the environmental, social, and economic effects of the healthcare sector and offer an over and exhaustive prospect for future research.

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Chapter 44
ISO 9001 Certification of the Specialization Schools of the Health Area of the University of Padova

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Abstract The project for the implementation and certification of Quality Management Systems of the Specialization Schools of the health area of the University of Padova was conceived, as a first hypothesis, at the end of 2016, anticipating the legislative provisions for the organization of the training and assistance activities of the schools of specialization in the health area. After the approval of the University's board of directors, in October 2017, the project was launched and extended to all the Specialization Schools of the health area of the University of Padua with access reserved for medical graduates (a total of 46 active schools) in which the final goal of obtaining ISO 9001 certification of the schools by December 2020 was achieved. The unitary approach and the participation of the medical residents in the implementation of quality management systems are distinctive elements of the project that allowed the achievement of the objectives on time with a progressive increase in efficiency also with reference to the compliance of the systems.

Keywords Specialization schools · Quality Management System · ISO 9001 · Health

44.1 Introduction

The project for the implementation and certification of the Quality Management Systems (QMS) of the Specialization Schools of the Health Area of University of Padua was conceived, as a first hypothesis, at the end of 2016, on the initiative of the "Osservatorio per la formazione specialistica post lauream," the pro-rector for

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postgraduate training, the area of teaching and student services of the university and the research center "Centro Studi Qualità Ambiente (CESQA)" of the Department of Engineering. The project, in its design phase, anticipates the subsequent legislative provisions of interministerial decree 402/2017 also concerning the "quality management and certification system," (Minstero Istruzione Università Ricerca – Ministero Salute 2017) taking advantage of the previous experience of the ISO 9001 certification obtained in 2008 by the Specialization School of Paediatrics of the University of Padova (Da Dalt et al. 2010). The project hypothesis, approved by the university's board of directors in October 2017, envisaged the implementation of QMS for the Specialization Schools of the Health Area of the University of Padua and the obtaining of ISO 9001 (ISO 2015b) certification by the end of 2020. The management of the project has been entrusted, from a technical point of view to Centro Studi Qualità Ambiente (CESQA), a university research center that, since the end of the 1990s, has been operating in the application of management systems, also providing support to various services of the university. The coordination of the activities has been entrusted to the "Ufficio Dottorato e post lauream – settore Scuole di Specializzazione," which, in its institutional role, provides support to Specialization Schools and resident doctors. As part of the project, the sector itself has embarked on a parallel path by implementing its own QMS that has led to the achievement of ISO 9001 certification. Finally, the strategic supervision of the progress of the activities was followed directly by the "Osservatorio per la formazione specialistica post lauream," a university body that deals with the evaluation, promotion, and monitoring of Specialization Schools.

44.2 Materials and Methods

44.2.1 Implementation of Quality Management Systems

All 46 Specialization Schools of the Health Area aimed at graduates from Medical Schools active – at the start date of the project – at the University of Padova were involved in the project (of these, the Specialization School in Paediatrics was already certified according to the ISO 9001 standard since 2008) in addition to the "Settore Scuole di Specializzazione," which, for uniformity of analysis, is excluded from this discussion. The Specialization Schools belong to seven university departments, as shown in Table 44.1.

Regarding the training offer, 15 schools provide a training course lasting 5 years, and 31 schools provide a training course lasting 4 years. For the implementation of the QMS in schools, a shared approach was adopted and developed in successive phases, defining intermediate milestones to allow for a gradual implementation of the QMS. In addition, the schools were divided into three "implementation groups" that started and completed the activities in different periods based on internal organizational needs.

Table 44.1 University departments and specialization schools involved in the project

Department	Afferent specialization schools
Medicine (DIMED)	Allergology and clinical immunology; Anatomic pathology; Intensive Care and Pain Therapy; Dermatology and venereology; Haematology; Endocrinology and metabolic diseases; Geriatrics; Emergency medicine; Sports medicine and exercise; Internal medicine; Nuclear medicine; Nephrology; Radio diagnosis; Radiotherapy; Rheumatology; Nutritional sciences
Surgery, Oncology and Gastroenterology (DISCOG)	General surgery; Digestive diseases; Oncology; Orthopaedics and traumatology; Urology
Molecular Medicine (DMM)	Infectious and Tropical Diseases; Microbiology and virology
Neuroscience (DNS)	Audiology and phoniatrics; Plastic, reconstructive and aesthetic surgery; Physical and rehabilitation medicine; Neurosurgery; Neurology; Ophthalmology; Otolaryngology; Psychiatry
Cardiac, Thoracic, Vascular Sciences and Public Health (DSCTV)	Cardiac surgery; Thoracic surgery; Vascular surgery; Preventive medicine and hygiene; Diseases of cardiovascular apparatus; Diseases of respiratory tract; Occupational medicine; Legal medicine
Biomedical Sciences (DSB)	Clinical pathology and clinical biochemistry
Women's and Children's Health (DSDB)	Paediatric surgery; Medical genetics; Gynaecology and obstetrics; Community medicine and primary care; Child Neuropsychiatry; Paediatrics

Specifically, the implementation phases are summarized below:

- General plenary training, aimed at all Specialization Schools and all personnel involved.
- Specific training relating to the methods of implementation of the QMS was carried out in subsequent moments for the various "implementation groups."
- Implementation of the QMS in the schools with specific deadlines for the different "implementation groups"; the activities were carried out by the staff of each school with the technical support of CESQA taking into consideration the reference legislative requirements (Minstero Istruzione Università Ricerca – Ministero Salute 2015, 2017), the applicable university regulations and applicable international standards (ISO 2015a, b).
- Internal audit carried out at each school by the qualified technical staff of CESQA.
- Management review carried out by each school.
- Certification process for each school implemented by an accredited certification body (QCB Italia, now part of the TÜV Austria group).

44.2.2 Project Highlights

Two elements of the project are emphasized, functional to achieving the objectives and increasing the efficiency in the implementation process of the QMS. First, the unitary and shared approach and the involvement of all the schools allow the development of synergies between the staff employed in the activities and stimulating dialogue between the subjects to seek the most efficient solutions for achieving the goals. All the actors of the project (including the research center that supported the activities and with the obvious exception of the certification body) were selected within the University of Padua to further stimulate synergies and unity during the implementation process, both from a strategic and technical point of view. Second, medical residents were involved in all operational phases of the project, from the first general training activities to the implementation of the QMSs and audit. The participation residents, on a voluntary basis, had the dual objective of making the implementation process more efficient while guaranteeing maximum transparency towards the main recipients of the service offered by the schools. Table 44.2 shows the data relating to the staff of the schools and to medical residents who actively participated in the implementation of the QMS. The data (average number per school) relate to all 46 certified schools, divided into four groups based on the total number of attending residents (data updated in April 2022 and provided by the dottorato e postlauream office of university).

The very high-attendance group includes only schools that provide for 5 years of training; in the group with the lowest attendance, only schools with 4 years of training.

The staff who actively participated in the implementation of the QMS included the following:

- Structured university staff (school directors, professors, researchers) for a total of 87 people.
- Technical-administrative staff employed by the schools or departments for a total of 48 people;
- Residents for a total of 47 medics.

Table 44.2 People (average number per school) actively involved in the project

School groups by attendance	n. of schools in the group	Attending residents	Structured university staff involved	Technical-administrative staff involved	Residents involved
Group 1 $\geq$100 attending	6	155.67	1.83	1.17	1.83
Group 2 $50 \leq$ attending < 100	10	70.80	1.90	1.20	0.70
Group 3 $20 \leq$ attending < 50	21	30.48	1.90	0.95	0.95
Group 4 $<$20 attending	9	13.67	1.89	1.00	1.00

Analyzing the data, it can be seen that, while the average number of structured and technical-administrative staff who participate in the implementation of the QMS is almost uniform among the groups, the average number of participating residents is higher for very high-attendance schools (group 1: number of attending residents $\geq$ 100).

44.3 Results and Discussions

Regarding the achievement of the project objectives, excluding the already certified School of Paediatrics, 7 schools obtained certification in 2019 (certification group 1), 13 schools obtained certification in the period May-September 2020 (certification group 2), and 25 schools obtained certification in the period October-December 2020 (certification group 3) in compliance with the general deadlines set by the project. It is noted that the certification group 1 does not include very high-attendance schools ($\geq$100 attending residents) as evidence of how the number of attending residents influences the organizational complexity also requiring, in general, a longer path for the implementation of the QMS. As indicators of efficiency, it is useful to take into consideration the results of the internal and external audits conducted (to date, all schools have completed at least the external certification and first maintenance audit as well as two internal audits for a total of four audits for each). The total number of findings issued in the four considered audits (including the School of Paediatrics) was 844, with an average of 18.35 per school. The findings mainly concern the control of documented information, the control of service provision, and process monitoring. Regarding the classification of findings, these are mainly comments (833 in total). Only 11 findings classified as nonconformities were issued during the precertification internal audit; considering this result, in the rest of the discussion, the findings are considered without distinction of classification. Considering the schools in which at least one resident has participated in the implementation of the QMS (in total 33 schools), the average of the findings per school is equal to 17.61; for the remaining 13 schools in which no resident has participated in the implementation of the QMS, the average of the findings per school is equal to 20.23; this result highlights how the active participation of residents also has positive effects in terms of compliance with the QMS. Table 44.3 shows the data relating to findings

Table 44.3 Audit results: findings issued (average number per school per audit)

Certification groups	n. of schools in the group	Precertification internal audit	Certification external audit	Prefirst maintenance internal audit	First maintenance external audit
Group 1	7	10.29	4.14	6.14	2.29
Group 2	13	7.46	3.69	4.00	2.08
Group 3	25	8.32	3.32	4.12	2.00

(average number per school) issued during the four considered audits (data provided by QCB Italia and CESQA).

It is noted that the findings issued in the internal audit (precertification and prefirst maintenance) are greater in number than those issued in the external audit and that, for the schools in group 1 (schools that first completed the implementation), a higher average number of findings was issued in all audit with respect to the schools that concluded the activities subsequently; the result testifies to the validity of the unitary and shared approach adopted for the implementation and the effectiveness of the progressive transfer of know-how between schools.

44.4 Conclusions and Future Perspectives

The objectives of the project were achieved within the established time frame by obtaining the ISO 9001 certification of all the Specialization Schools of the Health area of the University of Padua (the only university in Italy to date to have achieved such a result). The unitary development of the project and the shared and phased approach made it possible to efficiently tackle the activities, also allowing a progressive improvement of the audit results, as seen from the analysis of the number of findings. The participation of medical residents, a peculiar element of the project, was useful in the implementation phase (especially for schools with greater complexity in terms of the number of course years and number of attending residents) and led to positive results in terms of compliance with the QMS, as emerges from the analysis of the findings issued in the audit. With regard to future developments, a further study of the project results is hoped for at the end of the first 3-year certification period for all schools (December 2022). Following the important results achieved and the positive effects for the management of the Specialization Schools, the University of Padova has decided to promote and launch a further project for the certification of other Specialization Schools relating to various scientific fields.

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Chapter 45
European University Alliances and Good Quality Assurance Practice

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Abstract In Europe, the higher education scenario is changing towards the structuring of alliances of institutions, sharing resources, skills, and long-term strategies. This vision aims to foster the emergence of supranational universities that promote the ideals and characteristics of the European Union (EU), revolutionize the approach and competitiveness and give students a degree as a result of a combination of studies from different EU countries. Currently, the 41 Alliances of European Universities involve approximately 280 higher education institutions. This contribution aims to identify the best practices in place among the Alliances that specifically involve Italian universities through the research and examination of some pilot projects. The experience of the Alliance partners in cross-border, intra-European, and international cooperation has in many cases encouraged a collaborative environment useful for the creation of a supranational university, characterized by joint education and virtual campuses. The real challenges, however, are the construction of effective new governance characterized by existing resources and structures, the legal and financial autonomy of the virtual university, and operational and bureaucratic constraints that will have to be able in a limited time to define the central role of the EU in the near future.

Keywords European University · Higher education · Quality assurance

45.1 Introduction

In recent years, in the modern context of the Bologna Process, learning and teaching have emerged as topics of interest and priority, both in the institutional and political fields. In the political field, with the Yerevan communiqué of 2015, a renewed vision

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on the future of the EHEA (European Higher Education Area) emerges, whose main mission is represented by the improvement of the quality and the importance of learning and teaching (Klemenčič 2018). In a clearer and more detailed way, the Paris Communiqué of 2018 emphasizes continuous transformation in terms of teaching and learning, concretized in the development of participatory and collaborative approaches with all stakeholders. In detail, individual countries need to work to improve three key areas in their higher education system: recognition, quality assurance, and the three-cycle system. In the context of EU policies, at the Göteborg Summit in 2017, the European Commission proposed the creation of a European education area by 2025, focused on three pillars: the creation of a formal network of European Universities; the automatic mutual recognition of diplomas; and the European Student Card allowing the electronic identification and registration of the student to higher education institutions (HEIs) within the EU in case of mobility for study purposes. The focus of this renewed agenda is the creation of a European education area "based on trust, mutual recognition, cooperation and exchange of best practices, mobility and growth" (EU Commission 2017a, b; Gunn 2020). In addition, the European Commission published "A Renewed EU agenda for higher education" in 2017 and "A Renewed European Agenda for Research and Innovation – Europe's chance to shape its future" in 2018. In the institutional field, the Trends 2018 report of the European University Association (EUA), which is based on an extensive survey of learning and teaching in HEIs, has shown that different advances and interesting experiences are underway (Gaebel and Zhang 2018; Gaebel et al. 2020). There is evidence that changes and transformations stem from implemented learning and teaching practices, while such transformations are sustainable and successful through strategies and institutional support. This is stated in the Paris Communiqué, underlining how exchanges and collaborations between European universities serve to a large extent to stimulate and encourage change, concretizing itself in the European Learning and Teaching Forum of the EUA. In light of this, the analysis of our study focuses on identifying the best practices in place among the alliances that specifically involve Italian universities through the research and examination of some pilot projects. Case studies will then be presented, selected on the basis of their specific objectives and the best strategies put in place to achieve them. The paper is structured as follows: Sect. 45.2 presents a background on the European University Alliances; Sect. 45.3 explains the methodological approach, and Sect. 45.4 illustrates the results and the discussion of our study. Finally, Sect. 45.5 provides conclusions.

45.2 European Universities

The European Universities initiative can be placed in a context of increased collaboration. With President Macron's speech on 26 September 2017 at Sorbonne University in Paris, the nature of European policies in the field of higher education was reshaped. A new vision accepted and translated into the Strengthening European

Identity through Education and Culture report was presented by the European Commission to EU leaders at their meeting in Göteborg on 17 November 2017. In detail, the report recommended "creating world-class European Universities that can work seamlessly together across borders" (EU Commission 2017a). In addition, potential initiatives have been identified in the report, including the creation of a European university network "to reinforce and structure cooperation among higher education institutions," mainly through the creation of university networks and the provision of joint study programs, due to the adoption of tools that allow distance learning (EU Commission 2017b). This position was then consolidated by the Education Committee of the Council, which met on 22 May 2018, affirming the importance and role of "European Universities" in the creation of a European education area (EU Council 2018). European universities are alliances between different HEIs that promote European values and identity and revolutionize the quality and competitiveness of the higher education scene in Europe. To achieve this objective, the European Commission promotes and tests collaboration among European universities within the Erasmus+ program. These alliances include all types of HEIs, ensuring wide geographical coverage across Europe; they will be based on a long-term strategy in which the design of joint study programs is shared by all partners. In addition, the study programs offered will be joint and student-centered, developing and promoting mobility at every level of study (bachelor's, master's and doctoral level).

45.3 Material and Methods

This study is based on a literature review and an analysis of the available documentation on the European alliances' projects in which Italian universities are involved, starting from the implemented practices. The information was extracted from official channels, mainly from the Erasmus+ database of funded projects and from the documentation published by each Alliance. The contribution focuses on educational initiatives dedicated exclusively to students; therefore, all actions carried out in the field of research have been excluded. This decision was dictated in large part by the fact that in many cases the financings turned to such initiatives are different and consequently also the organizational structure and the name itself of the project.

45.4 Alliance and Initiative Overview

At the moment, the European Commission has launched two calls for proposals to finance the European Universities initiative. In 2019, 54 proposals were received, from which 17 were selected; in 2020, 62 proposals were sent, and the number of selected alliances rose to 24 (Table 45.1). The large number of participating

Table 45.1 No. of submitted proposals, selected initiatives, participating countries, and institutions for call for proposal

Call	Proposals sent	Selected initiatives	No. of participating countries	No. of participating institutions
2019	54	17	24	114
2020	62	24	26	165
Total	116	41	50	279

Source: Authors' elaboration from EU Commission

Table 45.2 No. of initiatives, total and Italian institutions for call for proposal

Call	Initiatives	No. of total institutions	No. of Italian institutions
2019	11	85	12
2020	11	79	12
Total	22	164	24

Source: Authors' elaboration from EU Commission

institutions, amounting to 279, gives a perfect idea of how far this initiative is extended in the European area.

Moreover, with the recent publication of the new call, this number will certainly tend to increase even more. In total, there are currently 41 active Alliances of European Universities, each of which has obtained substantial funding (between 4 and 5 million euros) to implement its projects over a 3-year period. Italy is currently a member of 22 Alliances with the participation of 24 Institutions. Our country is part of a very extensive network that includes 164 universities from 29 different countries (Table 45.2).

In one case, an Italian institution is also the project leader. The nation most represented among the coordinating countries is France, with ten coordinated projects, followed by Germany, which is the leader of eight alliances. Spain and the Netherlands participate in five initiatives as coordinators, while Portugal and Austria and Belgium are leaders of three and two projects, respectively. Going into the merits of the projects of which Italy is part, in Table 45.3, there is the list of Alliances with the coordinating institutions and the respective country and the name of the Italian institution that is part of it. It is interesting to note that the leading country for most of the initiatives is Germany, with seven projects, followed by France, which coordinates four; the Netherlands and Spain both participate in three alliances as leaders, while the remaining nations (Belgium, Hungary, Poland, and Portugal) coordinate one project.

The extent of the network of nations with which our country is working is well understood by the distribution of partner nations according to the territorial classification of the UN. In most cases, the partner countries are part of the western part of Europe (56), but there is also a good presence of northern countries (34); from the southern and eastern part of Europe come 24 institutions and two partners extra-EU (i.e., Turkey and Cyprus) are present.

Table 45.3 List of Alliances, coordinating organization name, coordinator's country, and Italian institutions

Alliance	Coordinating organization name	Coordinator's country	Italian institution
ATHENA	Instituto Politecnico Do Porto	Portugal	Università "Niccolò Cusano"
Aurora Alliance	Stichting Vu	Netherlands	Università di Napoli "Federico II"
EC2U	Universite De Poitiers	France	Università degli studi di Pavia
EELISA	Universidad Politecnica De Madrid	Spain	Scuola normale superiore di Pisa Scuola Superiore Sant'Anna di Pisa
ENGAGE. EU	Universitaet Mannheim	Germany	Università LUISS di Roma
ENHANCE	Technische Universitat Berlin	Germany	Politecnico di Milano
EUNICE	Politechnika Poznanska	Poland	Università degli studi di Catania
EUniWell	Universitaet Zu Koeln	Germany	Università degli studi di Firenze
T4E	Universitat Des Saarlandes	Germany	Università degli studi di Trieste
ULYSSEUS	Universidad De Sevilla	Spain	Università degli studi di Genova
UNITA	Universita Degli Studi Di Torino	Italy	Università degli studi di Torino
1EUROPE	Katholieke Universiteit Leuven	Belgium	Alma mater studiorum Università di Bologna
4EU+	Sorbonne Universite	France	Università degli studi di Milano
ARQUS	Universidad De Granada	Spain	Università degli studi di Padova
CIVICA	Institut D'etudes Politiques De Paris	France	Università Bocconi di Milano European University Institute
CIVIS	Universite D'aix Marseille	France	Università degli studi di Roma La Sapienza
EDUC	Universitaet Potsdam	Germany	Università degli studi di Cagliari
EU4ART	Magyar Kepzomuveszeti Egyetem	Hungary	Accademia delle belle arti di Roma
FORTHEM	Johannes Gutenberg-Universitat Mainz	Germany	Università degli studi di Palermo
UNITE!	Technische Universitat Darmstadt	Germany	Politecnico di Torino
ECIU	Universiteit Twente	Netherlands	Università degli studi di Trento
YUFE	Universiteit Maastricht	Netherlands	Università degli studi di Roma Tor Vergata

For Italian higher education institutions, the majority are located in northern Italy, seven in the northwest and four in the northeast; nine universities are located in the center, while the remaining four are located in the south and the islands. There is also a certain variety in the type of Italian institution participating in the projects. Although almost all is represented by state universities (19), two nonstate institutions, an academy operating in the AFAM sector, a telematic university and an international institution, are involved in these alliances. The heterogeneity of the characteristics of Italian universities and foreign partners highlights the strong will of the European Commission to involve the largest number of actors and entities operating in the field of higher education to achieve the objective set. The plurality of organizations translates into a strong focus on several topics relevant to the achievement of European goals. The core values that lead the actions of the projects, based on the analysis of the descriptions in the Erasmus+ database, refer to topics such as society and citizenship, societal and cultural transformation, digitalization, well-being and health heritage new economy, science, sustainability, environment and climate change. These core values represent the disciplinary frameworks within the Alliances that must implement the initiatives aimed at students, with a view to making them become future European citizens aware and competent. In practice, this results in various types of educational activities. Even if none of the alliances is still concluded in the first 3 years of the pilot phase, the launched initiatives are already very numerous: 11 winter, summer or spring schools have been organized, and 9 alliances are already engaged in providing a large number of tracks (at the bachelor's and/or master's level), namely, packages of courses that outline a disciplinary path for students composed of between 16 and 24 ECTS. However, the main challenge for the Alliance is to offer students joint programs organized and delivered by all partner institutions and making full use of mobility among nations. At the moment, two alliances have completed the initial accreditation procedures for a joint program that will start in the 2022/2023 academic year: 1EUROPE and EC2U. The EC2U Alliance has managed to organize three joint master's degrees in the fields of well-being and ageing, cultural and social diversity and the environment, energy, and urban planning. According to Alliance's progress report (EC2U 2021), to open these programs, each university underwent the initial accreditation procedure according to national legislation. The 1EUROPE Alliance, however, has managed to launch a joint bachelor program in European studies. The Alliance's organizational structure is certainly configured as a best practice within the European Universities, also considering the greater difficulty of obtaining accreditation for a first-level course. According to the EUniQ evaluation report, although it is a young project, the results achieved are impressive. The implemented QA system had undoubtedly been of great support. There are two internal bodies responsible for the QA issues of the Alliance: The Quality Assurance Cluster (QAC) and the Quality Assurance Board (QAB). The QAB also includes external stakeholders and carries out quality control of actions and results. Together with the QAC, they have the dual role of ongoing evaluation of the QA internal system and sharing of QA-related expertise within the Alliance. Moreover, a considerable number of academics and professional staff, as well as individual institution governance, are regularly involved in all phases of the pilots.

45.5 Conclusions

In the higher education landscape, alliances represent a long-standing distinctive element that can take many forms and come from different territorial scales (Gunn 2020). The joint internationalization strategies implemented by higher education institutions represent a "new set of actors, logics and relations between and beyond institutions of higher education and research" (Tadaki and Tremewan 2013). Gunn (2020) identifies the main factors that have enabled the overcoming of political and operational obstacles that in previous years have represented barriers to the attempt to build a supranational university. They can be summarized as follows: innovative 'network of networks' approach; the structural and governance changes that have taken place within the universities themselves, following the establishment of the EHEA and the Bologna Process (Maassen and Stensaker 2019); greater institutional and financial autonomy; adoption of internationalization strategies across Europe (De Wit et al. 2015; Seeber and Lepori 2014); and pursuit of Excellence-Driven Policies and Initiatives (Froumin and Lisyutkin 2015). Nevertheless, a clear and effective organizational structure makes achieving the desired results a more easily reachable objective. Moreover, the provision of a good internal QA system aimed at monitoring and controlling quality and achieving results, as in the case of 1EUROPE, is certainly a good practice that current and future alliances can be inspired by. However, major obstacles remain to the creation of joint programs at the European level: the impossibility of applying the European Approach for Quality Assurance of Joint Programmes throughout the EHEA, starting from countries such as Italy. This procedure aims to facilitate the evaluation of the QA system of joint programs without the application of additional national criteria and by facilitating the creation of integrated QA systems of the programs. However, regulatory constraints remain in some countries that limit its applicability to a still too narrow context of European universities, complicating the procedures for the accreditation of joint programs.

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Chapter 46
The Inclusion of Gender Diversity in Italian Universities: Main Priorities and Critical Issues

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Abstract The policies for gender integration represent one of the most important on the European social agenda in the awareness that the promotion of equal opportunities is a necessary and priority condition for the achievement of the objectives of the European Union in terms of growth, employment, and social cohesion. Gender permeates all aspects of our individual and collective, private and public life, defines opportunities, and shapes identities. In Italy, gender inequalities, exacerbated by the COVID-19 emergency, can be multiple ambitious processes, such as the labor market, women's participation in decision-making, education, and access to health. The same National Recovery and Resilience Plan (PNRR) has identified measures that can act directly or directly to the elimination of gender inequalities. The purpose of the work is to analyze the issue of gender equality in Italian universities in light of the initiatives undertaken in recent decades and of the changes that have also occurred following the spread of the COVID-19 pandemic in the management of daily lifetimes regarding family commitments and all professional responsibilities. In particular, the innovative tools at the University of Salerno see wellness devices as a fundamental element for the affirmation of a model of human resources, culture, and business processes, with a view to equal opportunities. The University of Salerno has recently adopted a plan for gender equality, which outlines a series of concrete actions aimed at ensuring the full participation of men and women in scientific research and the organizational life of the university. An initiative that ensures equal opportunities improves people's well-being and, finally, yet importantly, makes the University of Salerno a model of "best practices" on a national and European level.

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Keywords Gender equality · Organizational well-being · Diversity management · Social inclusion

46.1 Introduction

Gender equality represents a fundamental value, sanctioned by the Constitution and by the international charters dedicated to the rights of the person. It is an essential condition for combating discrimination and prevarication and for promoting inclusive environments, in which differences are valued and individual, social, and organizational well-being is promoted. In Italy, the legislator has intervened in an articulated and complex way to affirm and implement the principle of gender equality, introducing many changes in social policies. However, the disparity between men and women continues to persist because the traditional family vision of reference has not been significantly changed, which entrusts to women, making them visibly invisible, the care of family members and the carrying out of domestic activities (Lombardo and Del Giorgio 2013). The third annual report on the labor market in Italy states that "gender gaps remain high: half of the women of working age do not work and almost one in five would like to work but cannot find a job" (Ministry of Labour and Policies Social, Istat, Inps, Inail and Anpal 2020). Furthermore, according to the EU gender equality index (EIGE 2021), gender inequalities are more pronounced in the sectors of power, time, and work in Italy than in other EU countries. The scores related to money and knowledge are less distant and, in any case, lower. Processes of segregation and gender bias also occur in the scientific and academic context. Within Italian universities, the female component is still significantly underrepresented: compared to 12,303 full professors, there are 2952 full professors. There are 19,676 associate professors and 7575 colleagues (Ubbiali 2021); the presence of women at the top of universities is extremely scarce, not only in Italy but also at the European level. Data from the European University Association show that in 2020, among the 28 EU Member States, only 15% were governing (from 9.5% in 2010 to 13% in 2013 and 14.3% in 2019). On a national level, the directors are only in eight Italian universities. In some areas, such as in some scientific departments, the gap is vast: women – professors and researchers – are less than a third of the total. The scientific literature includes among the occupational segregation factors, not only ideological beliefs and persistent stereotypes about the attitudes of the two sexes but also unconscious prejudices and/or implicit prejudices practiced by people of both sexes (Pettit 2021; Prandini 2012; Solera and Bettio 2013; Supino and Malandrino 2016). The purpose of this work is to analyze the issue of gender equality in Italian universities in light of the initiatives undertaken in recent decades and the changes that have also occurred following the spread of the COVID-19 pandemic in the management of daily lifetimes concerning family commitments and professional responsibilities. In particular, the commitment of the University of Salerno (UniSa) sees welfare devices as a fundamental element for the affirmation of an innovative model of management of human resources, culture, and business processes, with a view to equal opportunities. While aware of the need for work-life reconciliation policies to go beyond the narrow channel of the female universe, we cannot overlook the powerful contribution they can make to resolving the gender gap. The University of Salerno has recently adopted a Gender Equality Plan that outlines a series of concrete actions aimed at guaranteeing the full participation of men and women in scientific research and the organizational life of the university. An initiative that guarantees equal opportunities improves people's well-being and, finally, but above all, makes the University of Salerno a model of "best practices" at the national and European levels.

46.2 The Path of Equal Opportunities in the University of Salerno

The University of Salerno has always promoted policies in support of equality and equal opportunities, from the establishment of the Equal Opportunities Committee (in 1999) to the appointment of the first Rector's Delegate for equal opportunities (in 2000) to the establishment of an Interdepartmental Observatory for Gender Studies and Equal Opportunities (OGEPO) in 2011, whose Board created the basis for the establishment, in 2014, of the CUG (Single Guarantee Committee). In recent years, the university has implemented and planned multiple positive actions aimed at involving all social actors to direct the attention of the latter to the "value" generated by diversity. The planning of educational courses for the affirmation of a gender culture that gives full citizenship to differences and eliminates all forms of violence and discrimination has been particularly active in recent years. The strategic path undertaken by the university is aimed not only at highlighting the cultural changes taking place but also, above all, at attenuating the differences between men and women in terms of needs, conditions, life, work, and life opportunities, participation in decision-making processes, as well as demonstrating that policies are not gender neutral but, on the contrary, have a differentiated impact on men and women. In this context, an important role is played by the Gender Budget, which the University of Salerno has endowed with, which represents an important tool for promoting and disseminating gender culture. The document, supported by the logic of numbers, highlights the areas of imbalance still present, even if much has been done to overcome them, and reveals many lights, under the strong commitment made in pursuing objectives of equality and equality in training, in research and work. In the face of graduates quantitatively and qualitatively higher than their male colleagues, the gap gradually decreases in the first levels of the academic career up to the reversal of positions to the advantage of male staff in the role of associate professor and, in particular, in that of full professor (this situation is also shared at the international level, as confirmed by the latest surveys). UniSa, starting from the critical issues highlighted in the previous BdG, has tried to overcome them both through the creation of a network of organizations, structures, and services aimed at combating all forms of discrimination and through the implementation of the Positive Action

Plan and the Gender Equality Plan (GEP). The latter – approved, in 2018, within the two most important decision-making bodies of the university (Academic Senate and the Board of Directors) – outlines a series of concrete actions aimed at ensuring the full participation of men and women in scientific research and the organizational life of the university. The effectiveness of the GEP is widely recognized as a strategic and operational tool to facilitate the identification of the most suitable legal, organizational, economic, and social framework for implementing gender mainstreaming in practice. The UniSa GEP was developed as part of the Horizon 2020 Project "R&I Peers – Pilot experiences for improving gender equality in research organizations," of which the University, supported by OGEPO, is the leader of a Consortium made up of ten research organizations (EU-Cordis 2019). The GEP aims to address the challenges still present in achieving gender equality, in particular the obstacles and lasting limitations to the recruitment, advancement, and mobility of women, especially in the STEM area, where women receive fewer opportunities as students, researchers, and leaders. It also takes into account the low presence of women in top positions and the limited integration of the gender dimension in research programs, which hampers research excellence and full innovation potential. Thanks to the initiatives undertaken by the university, important results have already been achieved in terms of integrating the gender dimension into research perspectives. However, despite the considerable commitment made, from the study conducted thus far, new and important challenges emerge for UniSa to achieve a real transition towards more widespread and institutionalized adoption of welfare programs. Challenges that UniSa is ready to take on through new and more ambitious objectives aimed at combining and enhancing different needs, inclusiveness, and organizational flexibility to implement profound social and cultural change and offer a solution to the gender gap.

46.3 Conclusions and Future Perspectives

Over the last few years, the strong commitment made by the university to promoting inclusive cultural and organizational processes has enabled the achievement of some of the many objectives set in the field of equality and equality in training, research, and work. The governance of UniSa has activated important synergies with the academic community based on forms of sharing values, mutual trust, and the search for organizational well-being. This, in a context such as the current one, is characterized by profound transformations both in the traditional structure of work and in family units but also by strong economic and social criticalities. Many and varied positive actions have been implemented to promote the implementation of the principles of equality and equal opportunities between men and women in the workplace in academic career paths through forms and tools for reconciling life and work times. A substantial gender balance has been achieved in terms of participation in the academic path up to graduation and any attendance of specialization and/or doctoral courses. There was an increase in the percentage of women, albeit modest, present in the scientific-technological disciplines (i.e., STEM) in various study paths. This important result was achieved thanks to the orientation actions dedicated to final-year high school students and the awareness and information actions that involved all students. In addition, the policies undertaken by the university in recent years have also led to an increase in graduates, PhD students, PhDs, and research fellows in some scientific-technological disciplines that may have important implications in the academic career paths in the coming years. In recent years, educational programs have been designed for the affirmation of a gender culture that gives full citizenship to differences and eliminates all forms of violence and discrimination; courses on gender studies were advertised and promoted, which could be included in the curriculum of all students of the university. In general, there was wide involvement and active participation of the academic community in gender-related initiatives promoted by the university. UniSa has also strengthened the territorial network with industries and stakeholders for the promotion and dissemination of gender culture and, more generally, a gender culture even beyond the binary perspective to develop heterogeneous skills and abilities as well as carry out synergistic actions and activate organizational and social innovation processes. The cooperative dimension is, moreover, a strong point that facilitates the involvement of competent and motivated human resources who are often little used in the area. The establishment of a territorial network also allows the dissemination of valid practices to inspire cultural and mental changes and to spread a culture of equality and equality that, while respecting differences, includes their specificities. The trend lines followed by the University will increasingly go towards an increase in economic resources to promote gender equality in the field of scientific research, an objective to which the group of scholars belonging to OGEPO is committed, as well as in the implementation of good practices in line with the CUG Positive Action Plan. The challenges that UniSa will have to pursue will not be limited, however, only to achieving gender balance, but will be aimed at adopting diversity management measures. The benefit of diversity management arises precisely from the possibility of the uniqueness of the human being who can develop and apply, within the organization, a broad and integrated spectrum of skills that reflects their background and experience. Only in this way will the university, by internally reflecting the social and economic landscape, be able to respond more easily to the even latent needs of the area in which it operates, investing in a management approach oriented towards the enhancement of human resources at a professional and personal level.

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Chapter 47
Patent Box as a Tax Relief Tool for Companies Operating in a Circular Economy Context

Federico Mertoli, Sergio Arfò, Antonio Zerbo, and Agata Matarazzo

Abstract The patent box is a tool for tax reduction for companies that own trademarks and industrial patents but also apps and software and that allow third parties to exploit the economy. It is therefore an optional scheme that facilitates, by partially discounting them, income from the exploitation of assets, known as "intangible assets." The aim of this tool is to encourage investment in Research and Development, which, in line with the Recovery and Resilience Plan, will focus on the creation of tools and intangible assets aimed at reducing the environmental impact, both during and at the end of the operating processes of Italian companies. Fiscal Decree 146/2021, linked to budget law 2022, contains important innovations in the field of patent boxes; the rule has established the elimination of the eligibility of know-how as an intangible asset. The considered case study shows the implementation of this innovative tool in a company located in Gela, Sicily, which produces items designed with particular attention to quality, functionality, durability, and aesthetics; these supplies use plastics derived from recycling in the framework of the circular economy. In addition to the significant direct economic advantages deriving from the implementation of patent boxes, there are also several indirect advantages linked to the introduction of R&D projects that allow the production of economically exploitable intangible assets. Actually, this tool allows the inventing company to achieve tax benefits and, through their exploitation by third parties, better efficiency of production processes and reduction of environmental impacts and waste.

Keywords Patent box · Tax benefits · Circular economy · Ecodesign

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47.1 Introduction

More than 2.5 billion tons of waste are produced annually in the European Union, which is why, after the Action Plane issued in 2015, the European Commission presented in March 2020, through the European Green Deal, the Action Plan for a New Circular Economy including different proposals on the design of more sustainable products, waste reduction, and empowering citizens, such as through the "right to redress." The transition to a resource-efficient, low-carbon and climate-resilient economy is a renewed global challenge to achieving sustainable and inclusive growth (Astarita 2017). The circular economy, in fact, is nothing more than a model of production and consumption involving sharing, lending, reuse, repair, reconditioning, and recycling of existing materials and products for as long as possible (Kirchherr et al. 2017). This extends the life cycle of products, helping to minimize waste (Horbach et al. 2015). Once the product has finished its function, the materials it is made of are in fact reintroduced, where possible, in the economic cycle. In this way, they can be continuously reused within the production cycle, generating additional value. The principles of the circular economy contrast with the traditional linear economic model, based instead on the typical scheme "extract, produce, use and throw."

The issue of the circular economy has been addressed numerous times in national and international forums, and to date, it is one of the main priorities of the European Union (Finkbeiner et al. 2010). The objective is environmental protection, with an average annual reduction in emissions of 617 million tons of CO_2 equivalent, with a positive impact on employment, through the creation of 500 thousand jobs, and on the economy of the euro area encouraging, according to estimates by the European Parliament, GDP growth up to 7% more by 2035. There are three models for making circular systems. The first refers to the development of industrial symbiosis districts and follows a line from below, as it is not derived from a previous project but originates through agreements between companies. The second concerns industrial parks, industrial networks that require state intervention because of their complexity. The third model is related to the creation of networks that connect operators and experts for the implementation of symbiotic systems. The paradigm shift and the beginning of the transition will surely lead to high costs (Chertow 2012). Nevertheless, at the same time, at the European level, it is an opportunity to stimulate growth, investment, and employment in light of the ambitious objectives set out in the Europe 2020 Strategy. In this framework, Patent Box, developed in a circular economy context, allows for an effective reduction in taxable income for inventing companies and could be a useful tool for the economic exploitation of intangible assets by third parties, also significantly reducing the environmental impact (Gaiani 2018). After a review of the main legal sources and the way to compute the tax breaks (Sect. 47.2), the case study will be briefly discussed (Sect. 47.3). Therefore, the main results will be discussed (Sect. 47.4), and some final considerations conclude the paper (Sect. 47.5).

47.2 Review of Regulatory Items and Computation Method

Currently, companies need more liquidity, and in light of the increasing importance of intangible assets in the creation of added value, it has been necessary for the Italian government to set up tax incentives. In particular, the Patent Box plays a major role, as well as a system of preferential taxation, which protects intellectual property and stimulates innovation. The application of this scheme also has the objective of encouraging and maintaining the production of such goods in Italian territory, avoiding relocation abroad, which occurred very frequently in the past. In addition, this scheme aims to encourage investment in the research and development activities of Italian companies. The system is in continuity with the models gradually introduced in other Member States of the European Community (Belgium, France, Great Britain, Luxembourg, Netherlands, and Spain) and is in accordance with the principles developed within the OECD with regard to fiscal discipline for the taxation of income from the use of intangible assets. The decree "Patent Box" of 28 November 2017, issued in agreement with the Minister of Economy and Finance, containing the proposals of revision of the previous decree of 30 July 2015, was adopted in the implementation of art. 1, paragraphs 37–43, of the Law of 23 December 2014, n. 190 (Stability Law 2015), as amended by Decree-Law 24 January 2015, n. 3 (Investment Compact, 2015), converted, with amendments, by Law 24 March 2015, n. 33, and by Decree-Law 24 April 2017, n. 50, converted, with amendments, by Law no. 96 of 21 June 2017 (Decree- Law, 2017). Further proposals on the subject are provided in Article 4 of Decree-Law 30 April 2019 n.34 (Growth), converted into law, with amendments, by art. 1, paragraph 1, L. 28 June 2019, n. 58.

The patent box regime covers the following:

- Income from the use of these intangible assets to third parties through indirect use
- The hypothesis of direct use of the same

The discounted income is equal to the income attributable to the exploitation of the intangible asset multiplied by a coefficient equal to the ratio between (Art. 9 of DM 30.7.2015):

- Research and development costs incurred for the maintenance, enhancement, and development of the intangible asset (numerator) and
- The total costs incurred to produce and develop this asset (denominator)

This method of calculation responds to the need to comply with the so-called nexus approach required by the OECD Guidelines, which allows us to facilitate only income derived from costs incurred in the territory of the state (Rotondaro and Sabbatini 2021).

The explanatory report to DM 30.7.2015 clarifies that the costs to be included in the numerator and denominator are those incurred during the reference period, regardless of the tax regime and the accounting treatment. The DM specifies that the calculation of the percentage must be made referring to the data of the previous 3 years. In particular, for the calculation of the percentage for 2020, the costs to be considered are those incurred in the years 2018 to 2020.

The costs to be put in the numerator include:

- Those supported by beneficiaries.
- Those charged to beneficiaries by universities, research organizations, equivalent bodies, and companies. Additionally, innovative start-ups, which are not part of the group of enterprises to which the taxpayer belongs.
- The costs incurred by companies' part of the same group in relation to research and development activities outsourced to third parties. Alternatively, the costs are incurred by the taxpayer himself under a cost-sharing agreement with other companies in the group (Gaiani 2018).

The costs to the numerator can finally be increased for an amount equal to the difference between the numerator and denominator for a maximum value equal to 30% of the same numerator.

For example, if the costs to the numerator are equal to 100 and the denominator is equal to 150, an additional 30% can be added to the numerator:

- 30% of 100 = 30
- 150 – 100 = 50 > 30

At the denominator, instead, will be included:

- All costs entered in the numerator
- Costs related to outsourcing data research and development services to companies that are part of the same group
- The costs related to the acquisition of the intangible asset subject to the facility (or part thereof), including by means of a concession licence in use

After determining the subsidized income, it is necessary to determine the portion of it on which the exemption will be applied.

Qualified costs are research and development expenditure and expenditure on the improvement and enhancement of the value of intellectual property.

The total costs are represented by the sum of the qualified costs and the cost to acquire intellectual property.

(Share of subsidized income = qualified costs/total costs * subsidized income)

The calculation of the subsidized share of income, therefore, depends largely on the weight (that is, the percentage) of research and development expenditure incurred to create the intellectual property in relation to which the exemption is sought.

47.3 Material and Methods

According to ISTAT data, urban waste increased in 2020, while the recycling rate in Europe remained stable. Data released by Eurostat show a slight increase in 2020, with an average on the continent of 505 kg of per capita waste produced. The increase is 4 kg in 2019 (+1%) and 38 kg more than in 1995 (+14%). In absolute terms, 225.7 million tonnes of municipal waste ended up in EU bins in the year of the outbreak of the pandemic. Values that see Italy perfectly in line with the European average, at 505 kilos each, even if for Italy the data stop at 2019. Compared to 1995, when we produced 454 kg, the increase is substantial but still below the average of the other countries: +10.1% (ISTAT report 2015). Considering these statistics, the start of a transition towards the circular economy represents a strategic input of great importance with the transition from a "necessity" (efficiency in the use of resources, rational waste management) to an "opportunity," that is, designing products in such a way that what is now intended to be waste becomes a resource for a new production cycle. The company considered in this study, Ecoplast, is a company located in Gela (Sicily) and operating in the field of the manufacture of plastic products, specialized in the production of plastic household items, offering a set of products that, over time, has been refined not only from the point of view of quality but also with a focus on quality, functionality, durability, and aesthetics. Ecoplast products stand out on the market for their excellent value for money, design, and eco-sustainability. Each line and collection have been designed to meet the needs of customers with excellent quality products. Plastic is a "plural material" with multiple applications; here are the ones chosen by Ecoplast thus far. As part of its activities, the company is committed to adopting constantly updated methodologies and technologies that have allowed the company to develop over the years a know-how, hitherto characterized by the lack of awareness and accessibility and the accurate combination of the elements that constitute it. The know-how owned by the company is managerial, organizational, and technical, contributing to a part of the activity carried out by the company, which consists of products manufactured by the company and the purchase and resale of products manufactured by other suppliers (so called made on a third-party account), as specified below. By orienting new investment in research and development, Eco sustainability is pursued by Ecoplast, with a view to circular economy, through the use of recycled plastic; the recovery of postproduction waste; the generation of renewable energy by waste; the use of machinery and electric vehicles; the minimization of water consumption and its reuse. These are strategic actions aimed at making the production process more efficient and at significantly reducing carbon emissions and the release of nonbiodegradable substances on the planet.

47.4 Results and Discussions

The results of the exemplary analysis show how the company, in addition to performing high added value functions related to the development, maintenance, and enhancement of know-how, is also engaged in so-called routine functions. These kinds of activities do not require the performance and/or use of high value-added assets and/or unique assets of significant value and economic impact, respectively (Munda and Matarazzo 2020). Because of these considerations, the determination of the economic contribution of the intangible assets was carried out through the

Table 47.1 Calculation of the tax benefit

Ecoplast Company	Year 2020
Income (loss) NET attributable to intangibles (Nexus Ratio 100%)	€ 493,764
Discounted income FY 2020 (50%)	€ 246,882
Decrease due to self-liquidation (1/3)	€ 82,294

application of the transactional profit split method. As a result of this analysis, a total amount of net subsidized income of Euro 493,764 was determined for the company. For this purpose, as required by the Patent Box legislation, the income from the use of fiscal incomes as described above will be facilitated on the basis of the percentages available for the tax period in question, which for 2020 is equal to 50%. It is also added that, as provided for in the Provision, with respect to the benefit connected with the possibility of proceeding directly to the direct calculation of the subsidized income, the decrease determined in this way should be divided into three equal annual instalments, or in the income tax refund and IRAP relating to the period in which the option is exercised and the next two. Therefore, Table 47.1 is an outline of the decreases in income of the considered company, with the purpose of the self-assessment of the benefit provided by this provision.

In light of the foregoing considerations, Ecoplast Company, in reference to the determination of the economic contribution for the purpose of the auto liquidation provided by the Order, has determined, for the tax year 2020, a value of the taxable income of Euro 246,882. Consequently, the decrease in taxable income due to application of the Patent Box for 2020 is equal to Euro 82,294.

47.5 Conclusions and Future Perspectives

The dichotomy between the production process and environmental safeguards is gradually being reduced. These two needs are more connected than previously thought. Proof of this assumption is the fact that, for example, green energy consumers are supported in their final costs by European Union economic incentives. The use of renewable sources, indeed, favors a series of significant funding and facilities related to the use of this type of resource. In line with these guidelines, measures have recently been taken to facilitate the transition towards a circular economy model. These measures aimed at stimulating research and development fall within this framework. In particular, patentable inventions are stimulated, granting tax incentives to companies that obtain the recognition of patents aimed at reducing environmental impact. Note that this kind of incentive is intended for all companies that incur costs related to the research and development of intangible assets that can be economically exploited. A considerable part of these costs can be deducted from corporate income, with a significant reduction in the tax burden, as shown in the short presented in this study. This example shows how Patent Box allows for an effective reduction in taxable income for the company, and it is actually a useful tool for the economic exploitation of intangible assets, also significantly reducing the environmental impact. From this perspective, it might be interesting to encourage access to this tax system with a more efficient and rational group structure and organization with respect to the company that intends to join. Companies organized with vertical integration and/or symbiosis of companies could more effectively enjoy the advantages offered by this tax incentive.

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Chapter 48
Industrial Symbiosis in Sicily: Perspectives and Criticalities

Agata Matarazzo, Roberta Ternullo, Sergio Arfò, Laura Cutaia, Antonella Luciano, Ludovica Olivieri, Diego D'Urso, and Ferdinando Chiacchio

Abstract The principles of the circular economy present a production and consumption model that involves sharing, reuse, repair, reconditioning, and recycling of materials and resources. They are closely related to the phenomenon of industrial symbiosis, a process in which a company's waste products and byproducts become raw materials for another company or for another production process, which in turn creates interdependence between companies in which energy and waste circulate uninterruptedly without refusing products. This study is based on the assessment of the degree of circularity of the economy, inspired by the new UNI 1608856 standard and on the analysis of Sicilian good practices, according to the provisions of UNI 1608977, by the definition and measurement of appropriate indicators. The paper aims to analyze and collect data relating to the Sicilian eco-industrial framework, analyzing the critical issues and opportunities of the industrial symbiosis system within Sicilian companies. To achieve this goal, a questionnaire developed in collaboration with ENEA was administered. The questionnaire investigates the successes and failures of causes related to the implementation of a path of industrial symbiosis within companies. By processing the results, it was possible to observe how Sicilian companies relate to the system of industrial symbiosis.

Keywords Industrial symbiosis · Circular economy · Environmental sustainability · Production cycles · Materials recycling

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48.1 Introduction

The growing demand and the limited supply of resources, especially for some raw materials that are becoming increasingly rare, force companies to take into account the risk of dependency on a few suppliers and the increase in production costs. Moreover, the supply of some raw materials often has very high environmental impacts, and the search for new sources can also be uneconomical. Inspired by living systems, the circular economy is a production and consumption model that, unlike the linear economy approach, allows an enhancement of the product life cycle by becoming a second raw material where product components are kept within the economy wherever they are productively useful to create additional value (Deselnicu et al. 2018). The circular economy entails reusing, repairing, recycling, leasing, and sharing running materials and products as long as possible, together with the use of energy from renewable sources, so that waste can be reduced to the minimum and the goods of today become the resources of tomorrow. The reason why we need to abandon the take-make-dispose model lies in the scarcity of raw materials. In fact, since the industrial revolution brought innovations that allowed us to have access to various products at affordable prices from all over the world, at the expense of the natural environment, we have taken part in a comfortable yet unsustainable finite supply chain of resources that cannot work in the long term (MacArthur 2019). In addition, energy consumption has dramatically increased, negatively impacting our environmental ecosystem in terms of greenhouse gas emissions and biodiversity loss. Moreover, the fact that raw materials are limited implies rising costs for countries that depend on other countries to supply their natural economic resources (MacArthur 2019). In general, terms, the European Union noted that the enhancement of the circular economy would encourage the sustainability and competitiveness of businesses in the long term, helping to preserve resources, including some that are becoming increasingly scarce or subject to price fluctuation; save costs for industries; unlock new business opportunities; build a new generation of innovative, resource-efficient businesses; create local low- and high-skilled jobs; and create opportunities for social integration and cohesion. The benefits of the circular economy are numerous: reports indicate that CO_2 emissions could be reduced by up to 70% and create new jobs and report success stories of numerous entrepreneurs who are making an impact on the development of the circular economy and creating collaborations that use circular business models from which “circular start-ups” were born (Veleva and Bodkin 2018). There are several ways to achieve a circular economy: design aimed at reducing waste and internal reuse of waste, using materials that can be easily disposed of or reused, producing and designing goods that can be repaired, or the flow of goods able to come back from consumers to manufacturing companies (reverse logistics). Since a company is not always able to reuse its waste internally, which can be transformed into second raw materials for another industry, in this paper, we will consider the *industrial symbiosis* that, according to (Chertow 2000), is the interaction between different industrial plants, grouped in districts or at a distance that still makes the operation feasible to maximize the reuse of resources (normally considered waste) and the sharing of knowledge and skills between companies (Henry et al. 2020). The term "symbiosis" derives from the observation of biological and symbiotic connections that normally take place in nature. Here, materials, reserves, and energy are related to a concept of mutual support in a reciprocally beneficial way (Veleva and Bodkin 2018). These kinds of resources—material, energetic, and water—represent a priceless raw material to manufacturing lines of companies, which try to reduce production waste and process effluents. Symbiosis between companies mainly takes place through three actions:

1. Utilizing scraps or byproducts in place of commercial products or raw materials.
2. Sharing utilities and plants to use and manage resources, such as steam, energy, water, and waste.
3. Supplying services aimed to satisfy common needs such as security, hygiene, transport, and the management of refuse.

However, it must be observed that many of the approaches and strategies mentioned here, while being typical of the circular economy, had historically originated in other fields of study, particularly industrial ecology. In this paper, we present the results of a survey conducted about the spread of industrial symbiosis in Sicily and the initiative created to promote it. Afterwards, we propose new research concerning a data collection system (questionnaire and database) and some possible feasible tools for data analysis that can operationally support operators to achieve industrial symbiosis (VV. AA. 2014).

The paper is organized as follows. After a short review of the specific literature, a brief mention of the questionnaire analyzed in the study is made. The main results of this survey are then analyzed and discussed in the next section. The last section contains some final considerations and indicates a new line for future research.

48.2 Review of the Literature

The traditional Italian sustainable system is always more adopted and implemented in Italian companies, but it is necessary to enhance it to make it even more efficient according to territorial features (VV. AA. 2015). Actually, industrial symbiosis is an interaction with which many companies work together to improve the land itself. ENEA, the National Agency for new technologies, energy and economic sustainable development, keeps looking at the Italian circular framework through R&D allocations and expenses (Wijkman and Skanberg 2015). The aim of this paper consists of analyzing how Italy, and especially Sicily, can use industrial symbiosis policies together, analyzing the data obtained from a study developed by ENEA and distributed to many Sicilian companies. The survey examines successful and unsuccessful cases related to the implementation of an industrial symbiosis itinerary inside companies. In particular, it evaluates what motivates companies to choose this kind of itinerary; the features of resources (classification, provenance and target sector, etc.); The number of parties involved; Advantages and effects; The economic value of the good; The legal status of the good at the moment of trade; If the industrial symbiosis itinerary was interrupted or is still ongoing; Elements of facilitation and obstacles which were rediscovered along the way; If the practice used is innovative or consolidated with the potential annexed conditions for replication or expansion; Last, data of organization and compiling's representative. The summary of the paper is the following: outline of ENEA's history and the successive development of the SUN net; presentation and discussion of the survey; analysis of three specific case studies; and, finally, the main economic and environmental benefits found. This study allows us to acquire essential information about available resources recyclable inside companies: waste materials, refuse, skills, and services (Munda and Matarazzo 2020). These results were obtained first thanks to the compilation of suitable input–output tables and, later, through the proposal of efficient synergies between companies (Van Buren et al. (2016). According to this approach, therefore, the industrial symbiosis realization goes through the following:

- Interconnection between traditionally separated interlocutors (net).
- Knowing the chances present in the territory through data bank analysis. These can be of two types: georeferenced, GIS-based (Geographic Information System (Ramadoss 2018), or not.
- The availability of expert skills able to take and offer solutions of industrial symbiosis.
- The platform was designed for Sicily, but it can be used for all of Italy, and the territorial extension of the application would be greater, stimulating opportunities for encounters between the supply and demand of resources (Elia et al. 2020).

In July 2015, the paper "The experience of the first industrial symbiosis platform in Italy" was published in the Environmental Engineering and Management Journal, reporting the first approach to the implementation of the Industrial Symbiosis platform promoted by ENEA (Pollitt et al. 2015). The objectives of the project are to provide a methodology and a tool for the implementation of industrial symbiosis on a regional scale and to implement an IS platform as support for SMEs to identify opportunities in the region (MacArthur 2013). Therefore, the organizational and executive approach replies on network activation (McDonough and Braungart 2002); planning and implementation of the platform architecture; analysis of the Sicilian production sectors and related data collection (Matarazzo et al. 2018); and involvement of companies (Ghisellini et al. 2016).

48.3 Materials and Methods

The survey distributed in 2022 by the Italian Network of Industrial Symbiosis SUN to various Sicilian companies was aimed at analyzing and verifying the Sicilian eco-industrial framework. It is important to examine how Sicily stands towards the industrial symbiosis system to understand how many steps it has made and how many more it will have to do to improve its approach to industrial ecology. In fact,

Fig. 48.1 The sectors interviewed with the questionnaire

constant research and data collection are necessary tools to be aware of facilitating elements and eliminating barriers (Henry et al. 2020). The sample interviewed includes 21 Sicilian companies, both small and medium-small. The response, as seen from Fig. 48.1, comes mainly from 76% of the agricultural sector, followed by textile, electronic, wood-furniture, port, and industrial services. Furthermore, the legal sites of the companies interviewed are located in the provinces of Catania, Syracuse, Enna, and Ragusa. The questionnaire is mainly formed by multiple-choice questions (10), but there are also questions that require open answers to better specify, for example, the details of the production process or the results found by Sicilian companies. The questionnaire was then elaborated and analyzed by the authors, the main results of which are reported below. The sample interviewed includes 21 Sicilian companies, both small and medium-small in size. The questionnaire consists mostly of multiple-choice questions, but there are also questions that require open answers to more adequately specify, for example, the characteristics of the resources, the details of the production process or the results found by Sicilian companies. The first questions are mainly focused on the motivation of wanting to start a process of industrial symbiosis within your company and on the characteristics of the asset sold or acquired. Then, there are questions related to the quantity of subjects involved in the symbiotic business interaction, the tools used for the qualitative and quantitative measurement of benefits and repercussions and, finally, the economic value and legal status of the asset. Finally, questions are included relating to the state of the path of industrial symbiosis, the relative benefits and limits found, the type of practice and the related conditions for replicability or expansion, depending on whether it is, respectively, an innovative practiced or consolidated.

48.4 Results and Discussions

It is well known that the gap between northern and southern Italy, in terms of industrial resources, human capital and economic efficiency, is also evident in the ability to respond and innovate in the environmental field. Among the 432,000 Italian industrial and service companies that invested in green products and technologies in the 2015–2018 period, 215,495 were active in the north. This means that in the five-year period under consideration, 29.3% of the companies located in the north invested in a green way, including 28.7% only in Piedmont, compared to 26.1% of the companies in the central regions and 24% of companies in the south. The companies that invest in the green economy are also companies more suited to exports (51% increase exports versus 38% of others), which leads to more innovation (76% versus 61%) that grows in terms of employment (19% versus l'8%) and that expects an increase in turnover (26% versus 18%). Employees committed to activities classified as "green jobs" in 2018 grew to 3,100,000 units, representing 13.4% of total employment (in 2017, it was 13.0%). Additionally, in this case, and to a significant extent, there is a concentration in the northern regions: 56.3% of green jobs, compared to 51% of total employees. The data on recycling indicate the exceptional level of environmental management of waste now reached in many regions, especially in northern Italy. However, the most relevant data for the circular economy is the strong concentration of industrial recycling capacity in the northern regions. Sixty-seven percent of the total waste sent to Italy for material recovery is treated and managed in the northern regions, which produce 59% of the total waste. The survey analyzed in this study is aimed at monitoring the state of the present industrial symbiosis in Sicily, with the consequent general picture of the Sicilian sustainable framework. From the first data acquired, it can be seen how, among the Sicilian companies interviewed, 48% have successfully undertaken industrial symbiosis itineraries, achieving excellent results. Nine percent attempted to start a symbiosis policy for the enhancement of their own residues or for the use of byproducts from other activities, but without being able to complete these initiatives. Forty-three percent of the companies interviewed did not try symbiosis paths for various reasons, such as:

- Not being aware of the phenomenon of industrial symbiosis (43%).
- Internally reusing all waste and residual production resources, without the need to exploit corporate interdependence (47%).
- Owning certain assets that cannot be treated as byproducts due to presumed regulatory problems (10%).

Among the successful cases, as shown in Fig. 48.2, the agricultural sector triumphs once again, followed by the textile, electronic, wood-furniture, and services (port and industrial) sectors (Basile et al. 2020). The cultivation of cereals, although belonging to the agricultural sector, has been considered separately for its great importance within the agricultural sector in Sicily. The reasons that push 48% of companies to choose an industrial ecological path are essentially focused on respect for the environment, on the enhancement of local resources and, finally, on the desired enjoyment of competitive advantages. With regard to the residual resource, it can been seen that the most exploited resource belongs to the material classification with the presence of only one case instead of the energy classification. Second, compared to the 30% of companies that choose to acquire the resource as an input and implement it in their production process, it can be seen from Fig. 3 how the cases in Sicily are connected to the transfer of the residual output to other companies.

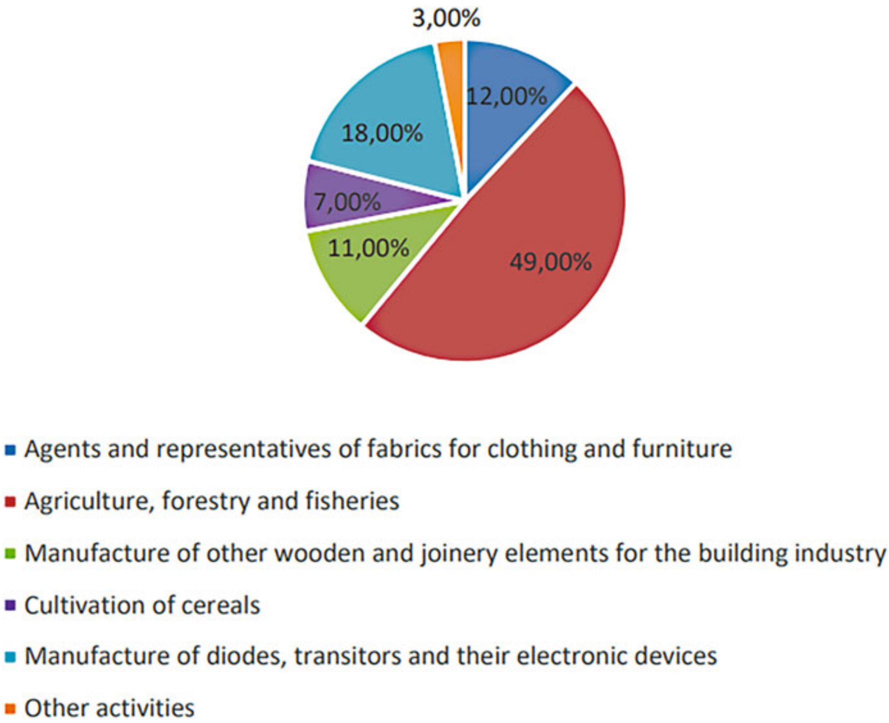

Fig. 48.2 Sectors of origin of resources from waste

The sectors of origin of residual resources, the protagonist of the Sicilian system of industrial symbiosis, is the agricultural one, followed by textile sectors for clothing and furnishings, electronics, those dedicated to the cultivation of cereals and manufacturing and carpentry for construction and, finally, from the tertiary sector.

On the other hand, the target sectors include activities such as breeding, manufacturing of wood products and cosmetics, tailoring, production of nondistilled fermented beverages and fresh confectionery, retail trade, treatment and disposal of hazardous waste. The exchange of resources for most Sicilian companies takes place through an economic enhancement in favor of the producer for 50% of the cases, an improvement that evidently testifies to the multiple economic advantages deriving from industrial symbiosis. Forty percent of the companies interviewed choose the alternative for which, instead, it is the user who bears the burden, while the remaining 10% faces the exchange without any economic enhancement.

The transport of the goods and cost of reaching the destination sector may depend on the manufacturer, the user or third parties' advantages. It is noted that in Sicily, most companies prefer to place this type of burden on the manufacturer, although the difference with the burden borne by the user is minimal. At the time of the exchange, the preponderant legal status is that of 40% of the secondary raw material, with the remaining 60% being divided equally between byproducts and waste. The facilitating elements found by companies along their itinerary of industrial ecological implementation certainly reflect the conditions for which the circular process is both simple and rapid, and an important behavioral change derives from the realization of this project. Entrepreneurs are more aware of waste and want to make a more efficient use of resources. In contrast, if for some companies there are neither barriers nor criticalities, a good percentage of companies still require solutions to specific problems. The difficulties found mostly derive from the lack of harmonization of EU legislation, consistent incentives, and real circular regulation. In addition, both limits dictated by distance between the companies and the presence of quality problems during the production cycle still do not fully reconcile the desire of Sicilian companies to blend with the reality of industrial symbiosis (MacArthur 2013). The analysis tool associated with this last chapter, namely, the processing of the data relating to the survey, was able to underline, in the concrete business reality of Sicily, the advantages deriving from the adoption of this circular process (Fichera et al. 2020). In fact, by reconstructing testimonies of the various companies involved in the test, it is shown how industrial symbiosis can reduce environmental waste; ensure a lower consumption of raw materials, obtaining, thanks to recycling, a lower environmental impact; enhance the waste, transforming it into a resource; cancel the cost of waste disposal; enhance the local territory and its resources; benefit from competitive advantages, thus placing companies in a privileged position compared to others; implement sustainable innovative actions in sectors where there is an uncontrollable waste of resources; facilitate sectors of resource destination, especially when the exchange of the asset does not involve an economic enhancement; allow the addition of a new line of products, moreover natural; facilitate initially low investments; and change the attitude of entrepreneurs, who are increasingly aware of the need for a production system and a country-system inspired by environmental principles. In summary, the production residue, which must submit all the legal requirements to be managed as a byproduct, can be transferred as a "resource" from one company to another with significant economic advantages:

- For the assignor company → reduction of annual waste management costs and increasing income in the event of an exchange with economic enhancement.
- For the company that uses the byproducts → a reduction in production costs.
- Creation of new business networks and new market opportunities.
- Improvement of business relations with external parties.

From an environmental perspective, instead, the efficient use of natural resources in production processes reduces the demand for ecosystemic goods and services and lowers the impact of production activities through the containment of emissions into water and the atmosphere, the prevention and reduction of waste and subsequent disposal in landfills, etc. From the social point of view, an aspect not yet considered in the section, the management of some residues as byproducts produces new occupations and professional figures or the retraining of the existing workforce;

the reduction of health and social costs related to waste disposal; and a cultural change within society that favors the meeting of various interested interlocutors (Oliveri et al. 2022). Therefore, the implementation of this business model creates important advantages for both the business system and the community, thanks to the increase in the overall competitiveness and efficiency of local production systems, the reduction of pressure on ecosystem services and on the biodiversity of the territory and, finally, to the improvement in the quality of life of communities.

48.5 Conclusions and Future Perspectives

Despite the variety of economic, environmental, competitive, and commercial benefits, the gap between the regions of northern Italy and Sicily is very large, as noted above, and Sicily still has to advance and seize opportunities in the circular economy and sustainable development. Without a doubt, entrepreneurs are increasingly aware of what is currently needed inside and outside companies. In fact, Sicilian companies are gradually moving towards the industrial ecological front, bringing home excellent results and thrilling not only the market but also citizens, who are proud of the progress of their region. In any case, the road still seems long and troubled. Indeed, Sicilian companies complain of the lack of a real circular regulation consistent with EU legislation of facilitating the construction of infrastructures. Moreover, in some cases, specific difficulties have also been encountered in accessing relevant information and assessments. Therefore, regulatory and economic facilitation can only increase Sicily's approach to an important system such as that of industrial symbiosis. For the future, Sicilian companies will benefit from a greater expansion of networks, platforms, and infrastructures, which facilitate contact between suppliers and receivers in their sector, and from greater territorial cohesion. The results analyzed show how almost half of the sample of considered companies has already successfully implemented an industrial symbiosis system based on the recovery of production waste and on the exchange of waste with other companies. However, of course, much remains to be done to obtain an increasingly widespread success of the practice under consideration and to seize the great opportunity still present in southern Italy. In future research, we will try to verify the progress of the industrial symbiosis in Sicily by preparing new appropriate questionnaires and by direct investigations in the field.

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Appendix

List of the 29 Commodity Science congresses that were held from 1962 to 2020; the 30th was the one held in March 2022 whose proceedings are contained in this Springer volume.

1962 – "Convegno sul tema: Progresso tecnologico e miglioramento della qualità", Bari, 12–13 settembre 1962. Atti in: Quaderni di Merceologia (Bari), 1, 1, Bari, Editore Cressati

1963 – "Secondo convegno nazionale sulla Qualità", Roma, 27–28 maggio 1963. A cura del prof. Elvio Cianetti. Riassunti delle relazioni e comunicazioni in: Rassegna Chimica, 15, (3), 127,132 (maggio.-giugno 1963)

1964 – "III Convegno sulla Qualità, Perugia, 25–27 maggio 1964". "Atti del III Convegno sulla qualità", Istituto di Merceologia, Università di Perugia, 1964

1965 – "Convegno nazionale della Qualità, Trieste 11–12 settembre 1965". "Atti del I convegno regionale dell'alimentazione e del IV Convegno Nazionale della Qualità", Regione Autonoma Friuli-Venezia Giulia, Assessorato dell'Igiene e della Sanità, Trieste, 1965

1966 – "V Convegno della qualità, Messina, 10–12 settembre 1966", Atti in: "Annali della Facoltà di Economia e commercio di Messina, IV, (2), 1966

1967 – "VI Congresso della Qualità, Genova, 11–13 settembre 1967. Atti del VI Convegno della Qualità, Istituto di Merceologia Università degli Studi, Genova,

1971 – VII Convegno internazionale della Qualità, "Difesa dei beni naturali e valorizzazione della produzione", Cagliari-Sassari 17–22 maggio 1971, "Atti del VII Convegno Internazionale della Qualità", Istituto di Merceologia, Università di Cagliari, 1971

1976 – VIII Convegno sulla qualità Perugia, 11–13 ottobre 1976. Atti in: "Annali della Facoltà di Economia e Commercio dell'Università degli studi di Perugia", N.S., n. 3, Anno Accademico 1975–76, Perugia,

G. Lagioia et al. (eds.), *Innovation, Quality and Sustainability for a Resilient Circular Economy*, Circular Economy and Sustainability,
https://doi.org/10.1007/978-3-031-55206-9

1977 – IX Congresso di Merceologia sul tema: “I contributi della Merceologia alla risoluzione dei problemi tecnici, economici e sociali”, Bologna, 30 settembre – 1ottobre 1977. Atti in: Quaderni di Merceologia (Bologna), 16, (III), settembre dicembre 1977, Clueb, Bologna

1982 – X Congresso Nazionale di Merceologia sul tema: “Classificazione e caratterizzazione delle merci”, Palermo, 14–17 ottobre 1982. Atti in: Atti del X Congresso Nazionale di Merceologia, Università degli Studi di Palermo, 1982

1984 – XI Congresso Nazionale di Merceologia sul tema: “Ruolo della merceologia nell’ambito dello sviluppo tecnologico”, Napoli, 2–5 ottobre 1984, Miccoli Editore, Napoli, 1984

1986 – XII Congresso Nazionale di Merceologia sul tema: “Contributo delle Scienze Merceologiche allo sviluppo delle regioni”, Torino, 22–25 settembre 1986, Atti del XII Congresso Nazionale di Merceologia, Istituto di Merceologia e Università di Torino, 1986

1988 – XIII Congresso Nazionale di Merceologia sul tema: “Le merci.: produzione, distribuzione, consumo ed. impatto ambientale”, Messina – Taormina, 10–13 ottobre 1988, Istituto di Merceologia – Facoltà di Economia e Commercio, Università di Messina

1990 – XIV Congresso Nazionale di merceologia sul tema: “Qualità e sicurezza degli alimenti nell’Europa degli anni ‘90″, Pescara, 27–30 settembre 1990

1992 – XV Congresso di Merceologia (in collaborazione con S.I.M. e I.G.W.T.) sul tema: “Libera circolazione e qualità dei prodotti nel mercato unico Europeo”, Roma 24–26 settembre 1992, Università degli Studi “La Sapienza”, Istituto di Merceologia, Ed: KAPPA, Roma 1994

1994 – XVI Congresso Nazionale di Merceologia sul tema: “Innovazioni tecnologiche, qualità e ambiente”, Pavia, 1–3 settembre 1994, Atti del XVI Congresso Nazionale di Merceologia, Università degli Studi di Pavia e Società Italiana di Merceologia, Pragma, Pavia, 1994

1996 – XVII Congresso Nazionale di Merceologia sul tema: “Merci e cicli produttivi nel settore agroindustriale alle soglie del 21° secolo”, Atti del XVII Congresso Nazionale di merceologia. Lecce 3–5 ottobre 1996, Adriatica Salentina, Lecce, 1996

1998 – XVIII Congresso Nazionale di Merceologia sul tema “Qualità verso il 2000. Contributi dalla Scienza Merceologica”, Verona, 1–3 ottobre 1998, Atti del XVIII Congresso nazionale di Merceologia, Università degli Studi di Verona – SIM, Verona 1998

2000 – XIX Congresso Nazionale di Merceologia sul tema “La sfida per il terzo millennio: tecnologia, innovazione, qualità e ambiente” Sassari-Alghero, 27–29 settembre 2000

2002 – XX Congresso Nazionale di Merceologia, Euroconference on University and Enterprise” – Università “La Sapienza” di Roma, 26–28 settembre 2002

2004 – XXI Congresso Nazionale di Merceologia sul tema “Risorse naturali e sviluppo economico sociale. Contributi delle scienze merceologiche”, Foggia, 22–24 settembre 2004

2006 – XXII Congresso Nazionale delle Scienze Merceologiche: “La qualità dei prodotti per la competitività delle imprese e la tutela dei consumatori”, Roma, Università Roma Tre, 2–4 marzo 2006

2007 – XXIII Congresso Nazionale delle Scienze Merceologiche sul tema: “Qualità, ambiente e valorizzazione delle risorse territoriali”, Atti del Convegno, Fossanova – Terracina – Fondi, 26–28 settembre 2007

2009 –XXIV Congresso Nazionale delle Scienze Merceologiche sul tema: “Ambiente, Internazionalizzazione, Sistemi, Merci, Energia”, Torino–Alba, 23–25 giugno 2009

2011 – XXV Congresso nazionale di Scienze Merceologiche sul tema “Contributo delle scienze Merceologiche per un mondo sostenibile”. Trieste-Udine, 26–28 settembre 2011

2014 – XXVI Congresso Nazionale di Scienze Merceologiche sul tema “Innovazione, Sostenibilità e Tutela dei Consumatori: L’Evoluzione delle Scienze Merceologiche per la Creazione di Valore e Competitività”. Pisa, 13–15 febbraio 2014

2016 – XXVII Congresso Nazionale di Scienze Merceologiche “Qualità & Innovazione per una Economia Circolare ed. un Futuro Sostenibile”. Viterbo 2–4 marzo 2016

2018 –XXVIII Congresso Nazionale di Scienze Merceologiche Firenze 21–23 febbraio

2020 – XXIX Congresso Nazionale di Scienze Merceologiche- Le scienze merceologiche nell’era 4.0 Salerno 13–14 febbraio