

## Article

# Feasibility and Local Perceptions About Treated Wastewater Reuse for Irrigation: Insights from the Prato Circular City Framework (Italy)

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## Abstract

The reuse of treated wastewater for agricultural irrigation is increasingly considered a strategic response to water scarcity and climate change, particularly in Mediterranean regions. This study examines the local feasibility and social acceptance of water reuse within the framework of Regulation (EU) 2020/741, focusing on its implementation in Italy. The research combines policy analysis, technical assessment of effluent quality from the GIDA wastewater treatment plant (Prato, Tuscany), GIS-based spatial evaluation, and a mixed-method survey of local agri-food producers. Results show substantial compliance with EU minimum quality requirements, alongside additional constraints arising from national regulatory thresholds. Survey findings reveal cautious but tangible openness among farmers toward reclaimed water use, particularly in response to increasing climate-related pressures. The case of Prato is further analysed within the Prato Circular City and local food policy frameworks, highlighting the role of participatory governance and multi-actor engagement in supporting reuse initiatives. The study contributes empirical evidence on the interaction between EU regulation, national implementation measures, and local socio-institutional conditions shaping peri-urban water reuse systems. Furthermore, it serves as a preliminary framework for future economic feasibility studies and the subsequent regulatory and permitting phases required to operationalize this practice.

**Keywords:** treated wastewater reuse; water policy; circular economy; local farming



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## 1. Introduction

Climate change and increasing freshwater scarcity are posing major challenges to global food production systems, particularly in Mediterranean regions where water stress is already acute. Water use for irrigation and food production represents a critical global challenge, especially considering that agriculture accounts for over 70% of global freshwater withdrawals, and up to 90% in some rapidly growing economies [1]. In today's context, in which climate change is altering natural balances and future forecasts estimate a global population growth of up to 10 billion individuals by 2050 [2], we are witnessing the construction of a time horizon in which pressure on food production will increase

exponentially, burdening water resources, the environment and the economy [3]. While non-European countries have widely adopted water reuse practices, uptake within the EU remains limited, primarily because of stricter regulatory requirements for industrial effluent reuse compared to urban wastewater, the absence (until recently) of harmonized minimum quality standards across reuse applications, and persistent perceptions that reused water is inferior to conventional freshwater sources [4]. Indeed, over the past decade, growing attention has been paid to the regulatory and operational conditions required to implement safe and acceptable water reuse systems in agriculture. In the European Union, a comprehensive regulatory framework was finally introduced with the adoption of Regulation (EU) 2020/741, which defines quality standards and monitoring requirements for the reuse of treated urban wastewater. Its national implementation, however, remains complex and uneven across Member States. In this context, the reuse of treated wastewater for agricultural purposes is gaining strategic relevance as a sustainable water management solution. This practice not only alleviates pressure on freshwater resources but also contributes to the circular economy by recovering valuable water and nutrients from wastewater streams. In fact, this approach promotes the circular treatment of wastewater and sludge, converting them into valuable resources, including reclaimed water, energy, and materials recovered from sludge [5]. Recent regulatory updates and technological developments have also renewed Italy's interest in scaling up these systems, particularly in urban and peri-urban settings where water demands and wastewater production co-exist. Increasing treated wastewater reuse can alleviate pressure on surface and groundwater resources, safeguarding the ecosystem services they provide and ensuring a stable summer water supply for agriculture [6]. Achieving this objective, however, requires an integrated management approach that links water supply, wastewater treatment, and drainage systems in a coherent framework. Such an approach ensures not only environmental protection but also safeguards public health and enhances overall community well-being. Embracing circular water management contributes to building more resilient, inclusive, and livable cities, in line with global sustainability goals. In addition to technical and regulatory concerns, it is important to consider how local communities and stakeholders view wastewater use in production. Although its benefits are clear, development may be limited by technical and financial challenges, particularly without sufficient government or local support, which can increase costs for farmers.

In addition to technical and economic constraints, socio-behavioral factors are equally important, since farmers who are better informed about treatment processes and associated health and environmental risks tend to be more supportive of wastewater reuse, while low trust in responsible institutions raises concerns about hygiene standards and discourages its adoption [7]. One major psychological barrier is the "disgust factor," highlighted in global surveys. Many farmers express strong aversion to using treated wastewater, as shown in Menegaki et al.'s research [8] which shows that about 33% of Greek farmers surveyed identified disgust as the main reason for rejection. On the other hand, many farmers also recognise concrete advantages in the reuse of wastewater, such as the supply of nutrients to the soil (nitrogen, phosphorus, etc.) that reduce the use of chemical fertilizers and the increased reliability of the resource under climatic stress conditions [7]. Indeed, EU Regulation 2020/741 aims to boost data and process transparency by involving stakeholders. Projects like "water citizen science," where stakeholders monitor irrigation water themselves, can help build trust in reuse practices. While many Europeans are open to eating produce irrigated with purified wastewater, concerns about hygiene and health persist despite better information or education [9]. This requires an interdisciplinary approach that integrates social sciences, public policy and environmental health, in addition to the

technical health assessment. It is therefore essential to promote information campaigns and to involve citizens in the governance of reuse, as suggested by EU 2020/741 itself.

Italy ranks second in Europe, after Spain, with over 2.4 million ha of irrigated land (excluding protected crops and household gardens). Irrigated land makes up about 19% of Italy's utilised agricultural area, similar to Greece and just behind Malta, Cyprus, and Greece. Nationally, 65.6% of technically irrigable land is irrigated, representing 19.3% of total UAA. The average volume of water applied per hectare of irrigated land amounts to 4666.1 m<sup>3</sup>, according to the 6th Agricultural Water Census conducted by ISTAT [10]. Irrigation practices vary significantly across regions and crops, resulting in a highly heterogeneous national landscape in terms of water use and efficiency. Although still limited in scope, the reuse of treated wastewater in agriculture, especially for high-demanding crops could play a significant role in promoting sustainable water use. When combined with good agricultural practices, the adoption of reclaimed water for irrigation may contribute substantially to water conservation efforts, with positive implications for hydrogeological stability and the mitigation of desertification processes.

To address the current research gap regarding the local application of EU Regulation 2020/741, this study adopts a multi-dimensional approach by investigating the Prato (Tuscany) district as a strategic case study. The methodology integrates policy analysis, technical assessments of GIDA SPA effluent quality, GIS-based spatial evaluations, and stakeholder engagement via Living Labs. It is important to note that the present work specifically focuses on assessing spatial and social readiness; consequently, detailed infrastructure cost-benefit analyses and engineering feasibility studies for the 'last-mile' distribution network are excluded from the current scope and are identified as the necessary next steps for future research.

## 2. Materials and Methods

This paper adopted a mixed-methods approach, combining document analysis, geographic mapping using GIS-based software (QGIS version 3.40.12), and a quali-quantitative field survey targeting local agri-food producers in the Prato area. The research aimed to explore both the technical feasibility and the socio-institutional acceptability of reclaimed water reuse for irrigation. The research was developed within the framework of the Prato Circular City (PCC) program, which integrates urban metabolism strategies with circular economy principles [11]. PCC follows the Living Lab model, integrating research, experimentation, and co-creation with multiple stakeholders to develop and test sustainable solutions in real-world settings [12]. The study engaged specialists in commodity science, environmental engineering, urban planning, social innovation, and agricultural systems, thereby ensuring a comprehensive transdisciplinary perspective. The methodological process was structured in the following four steps:

- (i) Stakeholder engagement and Living Labs: Informed by the principles of social innovation and living lab methodologies [13,14], a series of multi-stakeholder workshops [15] within the framework of PCC [16] were organized to explore the social acceptability, perceived risks, and governance conditions associated with the reuse of treated wastewater for irrigation. These Living Labs brought together representatives from local government, agricultural associations, research institutions, and civil society. The Living Lab process, implemented during 2023 and 2024, within the framework of Prato Circular City, comprised seven workshops. Participation included a consistent core group of at least 15 individuals per session, representing various stakeholder categories such as local authorities (Municipality of Prato), academic entities, and representatives of prominent local agricultural and trade organizations, as well as farmers. Data collection was conducted using a qualitative methodology, whereby meeting

minutes were systematically analysed. These qualitative findings were then assessed through a SWOT-based framework, facilitating the identification of socio-institutional synergies and conflicts.

- (ii) **Survey:** A field survey was carried out using a targeted selection of farms near the Prato treatment plant to gather local agricultural data. Therefore, structured interviews were carried out through in-person visits to collect data on current water sources, irrigation practices, openness to the use of reclaimed water, and the conditions required for its acceptance. Open-ended questions were included to capture qualitative insights into perceived benefits and barriers [17,18]. The complete structure of the questionnaire, including sections on company profiles, water resource management, and attitudes toward reclaimed water reuse, is provided in Appendix A.
- (iii) **Spatial analysis:** A GIS-based spatial representation was developed to identify the treatment plant's potential area of influence and to map nearby agricultural plots and irrigation infrastructures. This geospatial analysis was used to assess logistical feasibility, potential environmental impacts, and future technological options for reclaimed water distribution [19,20].
- (iv) **SWOT analysis and definition of policy guidelines for the territory:** the outputs of the regulatory review, stakeholder consultations, field survey, and spatial analysis were triangulated to develop a systemic understanding of the technical, institutional, and social dimensions of water reuse in the local context.

In addition to assessing the technical and regulatory feasibility of reclaimed water reuse, this paper aims to demonstrate the relevance of participatory, multi-actor engagement processes in informing and shaping local policy frameworks. The case study focuses on the GIDA S.p.A. wastewater treatment plant, located in the industrial area of Prato, Tuscany. The plant serves both domestic and industrial users and has the technical capacity to produce treated water compliant with agricultural reuse standards. Its proximity to agricultural plots makes it a suitable candidate for potential reuse schemes. A mapping of nearby farms was carried out using land-use data and municipal databases. A purposive sample of 14 farmers was selected based on proximity to the plant, irrigation needs, and type of production (e.g., horticulture, vineyards, cereals). A structured questionnaire was developed to gather detailed information on various aspects of agricultural water use and stakeholders' attitudes toward the reuse of treated wastewater. The instrument explored current water sources and irrigation practices, as well as respondents' perceptions and willingness to adopt reclaimed water for agricultural purposes. Particular attention was given to the conditions under which such reuse would be considered acceptable, including factors such as water quality, supply reliability, and cost. The questionnaire also addressed perceived risks and concerns associated with the use of treated wastewater. Data collection was conducted through a combination of face-to-face interviews and online surveys administered between January and April 2025. Quantitative responses were analyzed using descriptive statistics and cross-tabulations. Open-ended responses were coded thematically to identify key perceptions, concerns, and enablers. For the sake of data transparency and methodological clarity, the composition of the sample and the reference population require specification. A total of 15 farms were interviewed: 14 located in the Municipality of Prato and 1 in the Municipality of Carmignano. Of these, 14 out of 15 are registered in the ARTEA database (Regional Agency for Agricultural Payments in Tuscany). ARTEA records indicate that twenty-nine farms have their legal headquarters located within the Municipality of Prato, specifically within the boundaries of the "Parco Agricolo della Piana" (PAP). Consequently, these farms are regarded as part of the reference population. Among these, 13 farms can be confidently identified as included in the interview sample. If the population is defined as farms registered in ARTEA within the Municipality of

Prato, a sample of 13 units represents a substantial proportion of the total (approximately 45%). However, this criterion introduces certain limitations. While cadastral data for these 13 farms indicate a total area of approximately 91 ha, this figure should be considered a conservative estimate. In the peri-urban context of Prato, agricultural land tenure is characterized by high fragmentation and informal arrangements. Official databases often fail to record lands managed through gratuitous loans or informal verbal agreements, which are common in areas where agriculture is not the predominant land use. Consequently, this research adopts an exploratory case study approach, prioritizing qualitative depth and direct stakeholder input over large-scale statistical inference. Indeed, this purposive sampling ensures that the findings reflect the real operational conditions and perceptions of the actors who will be the primary end-users of reclaimed water, regardless of the limitations found in official land registries.

The framework is organised around a systemic logic. Climate resilience operates as both the external driver of the study and the intended outcome, namely the enhanced adaptive capacity of the local agri-food system. Circular economy provides the strategic and normative frame: the closing of water cycle is the goal of the proposed intervention, anchored in the Prato Circular City (PCC) programme and in the existing GIDA closed-loop textile water reuse infrastructure. Governance defines the institutional feasibility corridor across three scales—EU regulation (2020/741), national implementation (D.M. 185/2003), and local authorities. The Living Lab is the operative mechanism that brings the other three pillars into empirical interaction.

### 3. Results and Discussion

The methodological design explicitly incorporates the use of Living Labs, conceived as an open, collaborative, and iterative environment in which stakeholders can jointly explore problems, co-produce knowledge, and formulate actionable policy recommendations.

In this context, the Living Labs function as a social innovation instrument [14,15] enabling the integration of experiential knowledge from farmers, public authorities, water utilities, research institutions, and civil society actors. Such participatory mechanisms are increasingly recognized as essential for addressing complex sustainability challenges, particularly those involving resource management, environmental risks, and socio-technical transitions, where traditional top-down decision-making often proves insufficient [21].

Through a sequence of guided workshops, thematic discussions, and co-design sessions, stakeholders contributed to the identification of key barriers, opportunities, and priorities related to treated wastewater reuse. This process not only facilitated the collection of qualitative insights but also enhanced the legitimacy, robustness, and local ownership of the resulting policy proposals. By embedding stakeholder deliberation within the broader methodological framework, the study illustrates how participatory approaches can support evidence-based policy design and strengthen the alignment between municipal strategies, such as the PCC framework, and the practical needs and expectations of end-users.

#### 3.1. GIDA Wastewater Treatment Plant

Prato is one of the largest textile districts in Europe, with over 7200 SMEs. Since 1981, the city's centralized wastewater treatment system, managed by GIDA S.p.A., has exemplified a closed-loop model integrating industrial and domestic wastewater treatment. GIDA was established in response to Italian Law 319/76, which required wastewater treatment for industrial facilities. Instead of obliging each textile company to build its own treatment plant, local authorities and industry leaders jointly created a centralized plant, generating economies of scale and environmental benefits. GIDA's Baciacavallo wastewater treatment plant (WTP) processes a mix of domestic and industrial wastewater. It serves

around 400 textile SMEs through a 75 km industrial aqueduct, one of Italy's largest, covering 1.5 million m<sup>2</sup>. Treated water is returned to textile factories for reuse, effectively closing the water loop. The plant includes two water lines and operates in several phases: (i) Pre-treatment: Wastewater undergoes coarse and fine screening, solid removal (EWC 19.08.01), and grit separation in four 50 m<sup>3</sup> sand traps. (ii) Primary treatment: Coagulation (with ferric chloride and anionic polymer) and sedimentation take place in mixing and settling tanks. Separated sludge is extracted and thickened. (iii) Biological (secondary) treatment: The effluent enters four oxidation/nitrification tanks with surface aerators, followed by sedimentation. Sludge is partially recycled or sent for further thickening. (iv) Tertiary treatment: Includes chemical treatment (aluminum trichloride and polymers), followed by ozonation to reduce color and residual surfactants. Ozone is produced on-site from liquid oxygen via high-voltage discharge, then injected through porous disks into contact basins. (v) Sludge treatment: Excess sludge from all stages is thickened, dewatered (to 25–27% dry matter), and either incinerated on-site or transported offsite. The incinerator operates with a 100 t/day capacity and includes post-combustion, a scrubber, and continuous emission monitoring (e.g., CO, TOC, SO<sub>2</sub>, NO<sub>2</sub>, dust).

To evaluate the suitability of reclaimed water from the GIDA treatment plant for agricultural reuse, we compared the annual average values obtained from monthly chemical analyses conducted in 2023 with the threshold limits established for the four reuse classes (A to D) under Regulation (EU) 2020/741, as summarized in Table 1.

**Table 1.** Comparison between the 2023 annual average chemical parameters of reclaimed water from the GIDA treatment plant and the threshold limits for agricultural reuse classes (A–D) established under Regulation (EU) 2020/741.

	Quality Class A (Limits)	Quality Class B (Limits)	Quality Class C (Limits)	Quality Class D (Limits)	GIDA (Average Value)
<i>E. coli</i> (cfu/100 mL)	≤10	≤100	≤1000	≤10,000	0
BOD <sub>5</sub> (mg O <sub>2</sub> /L)	≤10	≤25	≤25	≤25	<5
TSS (mg/L)	≤10	≤35	≤35	≤35	<10
Total phosphorus (mg P/L)	2–10	2–10	2–10	2–10	0.94
Total nitrogen (mg N/L)	15–35	15–35	15–35	15–35	15.5
Ammonium nitrogen (mg NH <sub>4</sub> <sup>+</sup> /L)	2	2	2	2	1.1

The GIDA effluent demonstrates good performance across most monitored parameters. Specifically, *E. coli* levels are consistently non-detectable (0 cfu/100 mL), significantly below the Class A threshold of ≤10 cfu/100 mL, indicating a high level of microbiological safety. Similarly, values for Biochemical Oxygen Demand (BOD<sub>5</sub>) and Total Suspended Solids (TSS) fall well within Class A limits, with readings of <5 mg/L and <10 mg/L respectively.

Nutrient parameters also show favorable results: Total phosphorus is 0.94 mg/L, and Total nitrogen is 15.5 mg/L, both values aligned with the permissible range for all classes. The temporal pattern of total phosphorus exhibits values at or close to the detection limit (<0.1 mg/L) during the winter and early spring (January–March), followed by sporadic increases in late spring and summer (e.g., 0.68 mg/L in May, 0.84 mg/L in July). The highest concentrations occur in early autumn (2.30–2.39 mg/L in October), before stabilizing again around lower values toward December. Regarding total nitrogen, the variance, calculated at 16.80, and the standard deviation of 4.10 mg/L, demonstrate that its measurements exhibited greater fluctuation compared to phosphorus. The minimum total nitrogen concentration observed was 7.89 mg/L in April, while the maximum reached 26.4 mg/L in June. Notable features of the data include

relatively high concentrations during winter months, ranging from 12 to 19 mg/L. A pronounced peak was recorded in early summer, with June showing the highest value (26.4 mg/L), which may be associated with increased industrial activity or reduced nitrification efficiency due to temperature stress. Additionally, a secondary peak occurred in July, with levels at 22.2 mg/L. Toward late autumn and early winter, concentrations tended to stabilize, remaining within the range of 13 to 16 mg/L. Overall, the GIDA effluent complies with all mandatory minimum parameters established under Annex I of Regulation (EU) 2020/741. In particular, *E. coli*, BOD<sub>5</sub>, and TSS values meet the thresholds required for Class A reuse, while total nitrogen and total phosphorus concentrations fall within acceptable ranges for agricultural application. A marked temporal variability is observed in ammonium nitrogen (NH<sub>4</sub><sup>+</sup>) concentrations. Although the annual mean value (1.10 mg/L) remains below the 2 mg/L threshold established under Italian national legislation (D.M. 185/2003), several episodic peaks exceeding 5 mg/L were recorded during specific months. It is important to clarify that ammonium nitrogen is not included among the mandatory minimum quality parameters listed in Annex I of Regulation (EU) 2020/741. The 2 mg/L threshold is therefore derived from the Italian regulatory framework, which complements EU minimum requirements with additional national constraints. These exceedances do not affect compliance with the core EU minimum standards but may have implications within national authorization and risk management procedures. From a policy and planning perspective, this case illustrates the multi-level regulatory context in which water reuse operates, where EU minimum requirements coexist with pre-existing national thresholds. Ensuring compliance under both frameworks may require enhanced monitoring and potential optimization of nitrification processes. It also underscores the need for targeted investments and technical upgrades if the goal is to expand the role of reclaimed water in supporting local food systems, as envisioned within the PCC framework.

### 3.2. Prato Circular City Framework

The city of Prato has adopted an ambitious vision for sustainability, positioning the circular economy not only as a strategy for efficient waste management but as a transformative paradigm for urban development. The PCC Framework encompasses various interrelated domains, including modular and flexible building design, renewable and resilient energy systems, sustainable urban mobility, urban bioeconomy, and production systems oriented towards resource efficiency, reuse, recycling, and recovery. Circularity is placed at the core of the city's innovation and development policies, embedded in a broader integrated planning framework based on digital and ecological transitions, economic development support, and inclusive urban policies. The framework was launched in July 2020 and shaped as a permanent living lab involving local stakeholders. The initiative seeks to overcome the main barriers to the circular transition by pursuing three complementary directions: Better Regulation, Better Funding, and Better Knowledge. These pillars aim respectively to influence regulatory frameworks at regional, national, and EU levels; to mobilize appropriate financial resources and partnerships; and to strengthen awareness and knowledge across all levels of society. Its operational focus revolves around four interconnected domains: the textile and apparel district, urban resource management, circular consumption, and sustainable urban agriculture [16].

The methodological approach is structured around thematic working groups composed of relevant stakeholders. Each working group follows a step-by-step process that includes stakeholder identification, topic selection, collaborative discussion, proposal drafting, external feedback, and the development of an operational action plan. The process also incorporates an initial diagnostic phase in which participants identify ex-

isting initiatives, good practices, regulatory frameworks, and funding opportunities. This is used to assess feasibility and relevance through a decision tree, allowing the group to select and refine actions that are both meaningful and implementable. Overall, the incorporation of a living-lab methodology demonstrates that policy relevance and feasibility are significantly enhanced when technical assessments are coupled with participatory governance processes, ultimately contributing to the development of more adaptive, context-sensitive, and socially accepted solutions for circular water management. As of April 2024, the PCC has held 64 meetings, with 17 specifically dedicated to urban agriculture. The Living Labs referenced in this study were conducted through seven workshops in 2023 and 2024. Each workshop focused on short supply chains and included at least 15 participants from local authorities, academia, agricultural and trade organizations, and farmers. During these sessions, stakeholders raised concerns about the implementation of Regulation (EU) 2020/741, particularly noting that insufficient last-mile connections between the GIDA treatment plant and individual plots constituted a significant physical bottleneck. Additionally, involving local key stakeholders in discussions around this issue may present opportunities for establishing a short circular irrigation chain. On the other hand, principal threats stem from the disconnect between institutional procedural timelines and the immediate operational requirements of agricultural enterprises. The bureaucratic intricacies associated with authorization processes, along with unresolved questions regarding future governance and maintenance of new infrastructure, pose significant challenges. Participants stressed that without a definitive governance structure for long-term network management, the sustainability of the system may be jeopardized. Findings have been integrated into Table 2.

**Table 2.** SWOT analysis based on empirical evidence from farmers’ interviews and Living Labs activities within PCC.

Dimension	Evidence from Farmers’ Survey and Living Labs	Link with Prato Circular City Framework	Link with Prato Urban Food Policy Framework
Strengths	High awareness of climate change impacts on agriculture. General openness to reclaimed water reuse if quality and safety are guaranteed. Familiarity with GIDA and existing textile water reuse practices.	Reinforces Better knowledge through shared learning and co-design. Living Labs function as a stable arena for dialogue and experimentation. Builds on Prato’s consolidated experience in circular water management in textile.	Short supply chains enhance trust. Local, traceable, seasonal food production supports acceptance of sustainable practices. Prato Urban Food Policy framework can facilitate communication on water reuse.
Weaknesses	Limited technical knowledge of agricultural water reuse experiences. Economic concerns regarding water pricing and investment costs. Uncertainty about supply continuity and infrastructure reliability.	Indicates the need for targeted capacity building under Better knowledge. Highlights economic barriers to be addressed via Better funding.	Weather-related variability affects market participation and planning. Fear of negative consumer perception regarding food safety.

Table 2. Cont.

Dimension	Evidence from Farmers’ Survey and Living Labs	Link with Prato Circular City Framework	Link with Prato Urban Food Policy Framework
Opportunities	Regulation (EU) 2020/741 provides harmonized minimum requirements at the EU level, reducing legal uncertainty for plant operators. Increasing drought frequency strengthens the need for alternative irrigation sources.	Supports integrated water–food–urban strategies.	Urban food policies provide a platform to link water reuse with food security and resilience. Proximity to peri-urban agricultural areas and the PAP.
Threats	Regulatory complexity and authorization procedures. Uncertainty about long-term governance and maintenance of reuse infrastructure. Misalignment between institutional timelines and farmers’ needs.	Highlights economic barriers to be addressed via Better funding.	Increasing climate extremes threaten agricultural continuity. Risk of declining institutional support for local food systems and farmers.

### 3.3. Local Farming

The PAP covers approximately 8000 ha in the peri-urban area between Florence and Prato, encompassing eight municipalities and serving a population of over 720,000 residents [22]. Historically devoted to intensive agriculture, the area supports traditional crops (cereals, vegetables, fruit trees, olives, and vines) mapped by ARTEA, which in 2023 recorded some 3900 ha of agricultural land and 327 enterprises benefiting from Regional rural development funds [23]. Established by Tuscan Regional Resolution No. 161 of 16 July 2014, the PAP is intended to function as an “organizing element” for the protection and regeneration of peri-urban rural zones [21]. In 2018, it was also designated as an Integrated Territorial Project for biodiversity measures, climate adaptation, and sustainable resource management [24]. Although the PAP has been in place since 2007, the adoption of agroecological practices remains patchy, and farms, often small in scale, report logistical and regulatory barriers to accessing innovative irrigation technologies [25].

Due to data constraints, it is not possible to precisely determine the actual spatial distribution of cultivated plots in relation to the PAP’s perimeter. Concerning crop typologies, ARTEA data present inconsistencies in classification and terminology, which limits their reliability for detailed sectoral analysis. Among the 14 farms examined for this paper, cereals and arable crops are most common (14 farms), with horticulture following (7 farms). Livestock farming and forage crops each account for 3 farms, while viticulture and olive cultivation each represent 2 farms. Smaller shares are recorded for nursery production, textile crops such as flax and hemp, legumes, oilseed crops, and apiculture. Overall, despite certain data limitations, the sample provides a meaningful representation of the agricultural activities formally registered within the PAP area and offers a sufficiently robust basis for qualitative and exploratory quantitative analysis.

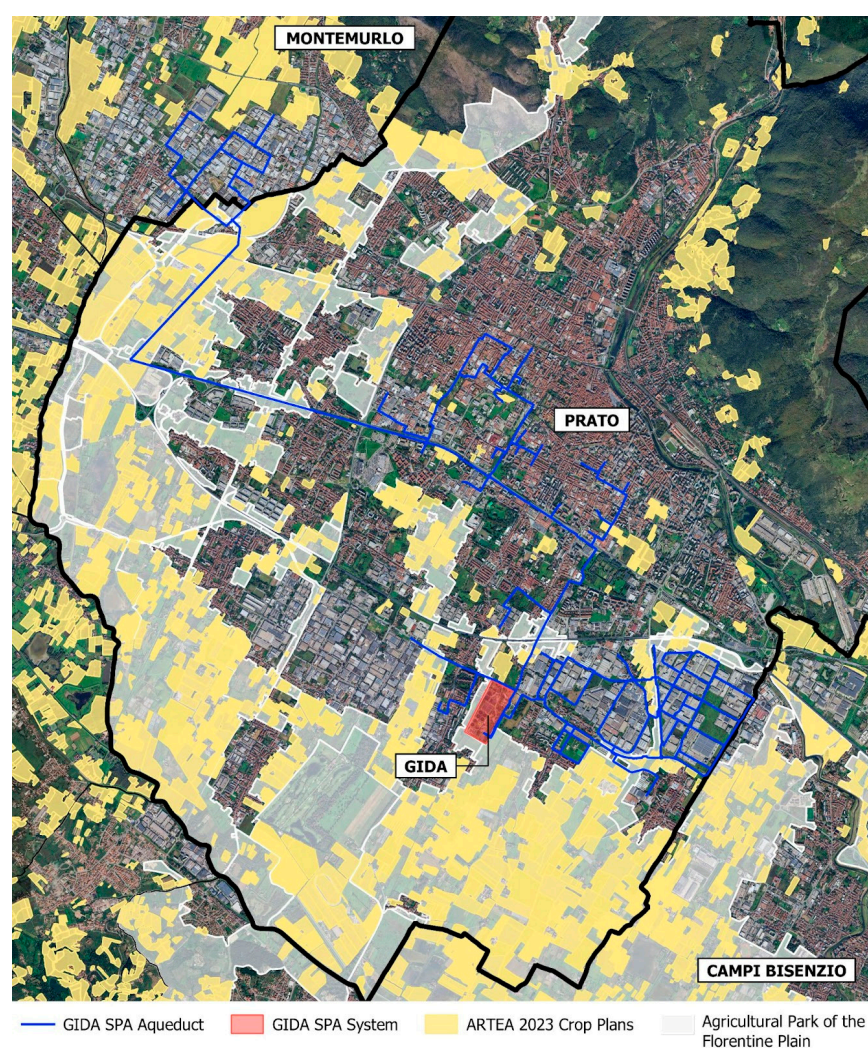
### 3.4. Perceptions of Reclaimed Water in Irrigation

The survey highlights a farming system under increasing climatic pressure, characterized by cautious adaptation strategies, strong local embeddedness, and growing awareness of environmental challenges. These conditions provide fertile ground for introducing alternative water sources, such as treated wastewater, provided that economic, technical, and governance concerns are adequately addressed through participatory and policy-integrated

approaches. Most examined farms are affiliated with a farmers' association. Approximately 80% of respondents are members of a professional organization. Only 20% report no current membership, often motivated by dissatisfaction with the availability or effectiveness of technical support. This high level of association membership suggests a generally good level of institutional embeddedness and access to collective services, which may facilitate information dissemination and policy engagement. About 53% of the examined farms participate in local markets or short food supply chains. The remaining 47% mainly sell through intermediaries or wholesale channels, especially cereal producers. Farms engaged in direct sales show greater proximity to consumers and stronger links to local food systems, potentially enhancing acceptance of sustainability-oriented practices, including reclaimed water reuse. The agricultural system in the study area is highly diversified. Approximately half of the farms are primarily engaged in horticultural production, often combined with fruit trees and olives, while around one third focus mainly on cereal crops and fodder, frequently under rainfed conditions. A smaller number specialize in ornamental plants or mixed systems. Crop rotation is widely practiced, and several farmers highlight adaptive strategies in response to climate stress, such as reducing maize cultivation due to drought-related yield losses and mycotoxin risks. The majority of respondents (about 80%) report no substantial change in cropping systems over the last five years. When changes occurred, they were mainly driven by climatic constraints, particularly water scarcity and heat stress, rather than by market incentives or policy measures. This indicates a relatively conservative production structure, with adaptation occurring incrementally rather than through radical shifts. Only a small minority of farms (approximately 15–20%) report planned changes in cropping systems in the coming years. Proposed changes include experimentation with alternative crops (e.g., hemp or flax) or minor adjustments within existing rotations. Overall, uncertainty related to climate conditions and economic returns discourages proactive transformation, reinforcing the need for supportive policies and risk-sharing mechanisms. Yield reductions have been widely experienced. Ten farmers reported that they had experienced periods of reduced production in recent years. These events are mainly associated with summer droughts, prolonged heatwaves, floods, and pest outbreaks. The temporal concentration of production losses between June and October underscores the vulnerability of local agriculture to seasonal water stress. Extreme weather impacts are even more pronounced. More than 70% of respondents report having suffered significant crop damage due to anomalous meteorological events, including floods and prolonged droughts. In several cases, damages reached near-total crop losses (up to 100%) or resulted in substantial economic losses (up to tens of thousands of euros). These findings confirm the increasing exposure of peri-urban agriculture to climate-related risks. Knowledge of the PAP is relatively widespread. About 67% of respondents are aware of the initiative, often through previous projects, institutional roles, or professional networks. However, awareness does not necessarily translate into active involvement, suggesting untapped potential for stronger integration between agricultural policies, territorial planning, and circular economy initiatives. Irrigation practices are heterogeneous. Around 53% of farms use groundwater wells, a third rely on rainfed agriculture, and some combine other water sources like harvesting, tanks, surface water, or municipal supplies. Drip irrigation is common, showing a trend toward efficient technology. About 40% report seasonal water shortages in summer; others face soil and fertility issues from heat. Interestingly, some farms face the opposite problem (excess water and flooding) emphasizing the dual challenge of water scarcity and water surplus in the local context.

Figure 1 illustrates the agricultural land registered within the PAP located inside the administrative boundaries of the Municipality of Prato. Parcels that both fall within the PAP perimeter and are listed in the ARTEA database are highlighted in yellow. The map

shows that the main wastewater treatment plant of Baciacavallo, operated by GIDA, is situated in close proximity to, and largely surrounded by, PAP agricultural land. The water distribution network depicted in blue corresponds to the so-called “separate sewer system”. Thus, in the industrial district east of the GIDA treatment plant, where textile companies are predominantly located, this network is used to redistribute treated wastewater back to industrial users, operating within a circular economy framework. By contrast, the aqueduct extending across the rest of the urban area toward the western boundary of Prato is currently employed primarily for non-potable purposes, such as supplying water for street-level fire prevention systems. Notably, the branch of the network reaching the western sector, characterized by a significant belt of agricultural land, could potentially be upgraded to enable the distribution of treated wastewater for irrigation purposes. Such an intervention would require relatively limited infrastructural modifications and may therefore be technically feasible from an engineering and planning perspective.



**Figure 1.** Agricultural land in Prato (source: authors’). Note: The black line marks the boundaries of the municipality of Prato. Figure generated using QGIS. Background satellite imagery was sourced via the QuickMapServices plugin (e.g., Google Satellite), while other elements are vector datasets processed by the authors: GIDA SPA Aqueduct (linear .shp, georeferenced from PDF documentation), GIDA SPA System (polygonal .shp, outlining the wastewater treatment plant), ARTEA 2023 Crop Plans (polygonal .shp, provided by ARTEA), and PAP (polygonal .shp, downloaded from the Tuscany Region’s Geoscopio portal). All data were organized in QGIS layers and georeferenced with EPSG:3003.

The following SWOT analysis integrates empirical evidence from farmers' interviews and Living Labs activities within the PCC initiative and aligns them with the emerging local food policy framework of the Municipality of Prato. It should be noted that the open-ended questions included in the survey (see Appendix A) were designed to capture qualitative nuances regarding perceived risks and long-term expectations. Data from these qualitative responses, as well as from the Living Lab sessions, were analyzed to categorize recurring concerns and proposals into the SWOT framework presented in Table 2.

#### 4. Conclusions

This study examined the feasibility and social acceptability of treated wastewater reuse for irrigation within the framework of Regulation (EU) 2020/741, using the Prato case as an empirical testbed. The findings indicate cautious but tangible openness among local farmers, particularly in response to increasing climatic pressures and seasonal water scarcity. While economic and organizational conditions remain critical, reclaimed water is not perceived as inherently problematic, provided that quality standards, supply continuity, and institutional support are clearly ensured.

From a regulatory perspective, the case also highlights the layered nature of water reuse governance in Italy. Regulation (EU) 2020/741 establishes harmonized minimum quality requirements for agricultural reuse (Annex I), defining quality classes (A–D) primarily based on microbiological and organic parameters. Ammonium nitrogen is not included among the mandatory EU minimum parameters. However, Italian national legislation (D.M. 185/2003) introduces an additional threshold of 2 mg/L for ammonium nitrogen in reclaimed water. While the GIDA treatment plant complies with all mandatory EU minimum requirements and meets Class A standards for *E. coli*, BOD<sub>5</sub>, and TSS, episodic exceedances of ammonium under the national threshold illustrate how pre-existing domestic regulations may impose stricter technical constraints. In a peri-urban context such as Prato, this regulatory layering has practical implications for authorization procedures, risk management planning, and infrastructure optimization. The interaction between EU harmonization objectives and national implementation measures therefore plays a crucial role in determining the effective feasibility of reuse schemes at the local level.

Farmers express cautious optimism toward water reuse. They see reclaimed water as a solution to climate-related shortages but emphasize the need for coordination, risk management, and economic feasibility. However, fragmented responsibilities, unclear regulations, and infrastructure gaps present major challenges.

The GIS-based spatial analysis identified as a potential strategic asset an existing pipeline managed by GIDA SPA that traverses the western agricultural areas of Prato. The proximity of this infrastructure to the target fields significantly lowers the geographical barriers for water distribution. While this study establishes the spatial and regulatory foundation for reuse, it does not include a detailed infrastructure cost estimation or formal distance analysis thresholds. Such technical and economic assessments are planned as a subsequent phase of this research. Currently, the presence of the existing western pipeline serves as a 'proof of concept' for the physical feasibility of the system.

Beyond technical compliance, the study underscores the importance of participatory governance mechanisms. The Living Lab approach adopted within the Prato Circular City framework proved instrumental in fostering dialogue among farmers, water utility managers, researchers, and public authorities. Such multi-actor engagement processes contributed to reframing treated wastewater from a residual output into a potential circular resource embedded within local development strategies.

The Prato case illustrates how reclaimed water reuse can be integrated into broader urban and food policy frameworks, linking water management, agricultural resilience,

and circular economy objectives. However, regulatory complexity, fragmented responsibilities, infrastructure adaptations, and long-term governance arrangements remain key challenges. Addressing these dimensions requires coordinated action across institutional levels, financial support mechanisms, and continued stakeholder involvement.

Overall, this research contributes empirical evidence on the local implementation of EU water reuse regulation in a peri-urban context. It highlights that the transition toward circular water systems is not solely a technical matter, but a socio-institutional process in which regulatory alignment, infrastructural capacity, and social trust must evolve simultaneously. Indeed, effective water reuse requires collaboration among utilities, municipalities, farm groups, and regional authorities to transition beyond pilot programs.

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## Abbreviations

The following abbreviations are used in this manuscript:

PAP Parco Agricolo della Piana  
 PCC Prato Circular City  
 WTP Water Treatment Plant

## Appendix A

Survey on Agricultural Water Use

### 1. Company Information

1.1. Company Name:

1.2. Address:

1.3. Legal Representative:

1.4. Number of Employees:

1.5. Years in Operation:

1.6. Production Type:  Conventional  Organic

1.7. Agricultural Land: Are the cultivated fields contiguous? If not, please specify their location.

1.8. Total Hectares:

1.9. Address:

1.10. Tenure:  Owned  Rented  Gratuitous Loan

1.11. Land Parcel Details: Plot | Area (ha) | Cadastral ID | Tenure (Owned/Rented/Loan) |

### 2. Respondent Information

2.1. Name & Surname:

2.2. Email/Phone:

2.3. Age:

2.4. Role:

### 3. Evaluation and Crop Information

3.1. Do you belong to a trade association?  Yes  No (Reason:)

3.2. Do you participate in local markets?  Yes  No (Reason:)

3.3. Current Production (Year 2024): Plot (Coordinates) | Area (ha) | Cadastral ID | Crop Type | Annual Qty | Water Req. | Irrigation Type |

3.4. Has the cropping system changed in the last five years? If yes, please specify years and crops.

3.5. Do you plan to maintain the same cropping system? If not, what would you adopt?

3.6. Have you experienced production shortfalls?  Yes  No (Year/Period:)

3.7. Have recent anomalous weather events caused damage?  Yes (\_\_\_%)  No

3.8. Are you aware of the “Parco Agricolo della Piana Fiorentina”?  Yes  No  I have heard of it.

### 4. Water Requirements and Source

4.1. Estimated annual water requirement (m<sup>3</sup>):

4.2. Irrigation Method:  Drip  Surface/Flood  Sprinkler  Other:

4.3. Main water source for irrigation:

Public Aqueduct

Well (If selected, skip Q4.7–4.9)

River/Surface water

Rainwater harvesting

No irrigation used

4.4. Do you experience water scarcity periods?  Yes  No

4.4.1. If Yes, Months: (Jan–Dec)

4.4.2. If Yes, Causes:  Drought  Flooding  High water prices  Inadequate infrastructure  Poor water quality  Other:

4.4.3. If Yes, Consequences:  Reduced production  Plant water stress  Increased irrigation needs  Other:

4.4.4. If Yes, Adaptation measures:  Reducing irrigated area  Drought-resistant crops  Rainwater collection  Efficient irrigation systems  Other:

4.5. Have you considered rainwater harvesting systems?  Yes  No (Reason:)

4.6. Have you considered alternative water supply systems?  Yes  No (Reason:)

4.7. Have weather anomalies influenced water costs?  Yes  No

4.8. How do you rate the average cost of irrigation water?  High  Adequate  Low

4.9. Suggested tariff changes for efficiency:  Seasonal rates  Incentives for efficient systems  Waste penalties  Wastewater treatment and reuse  Other:

### 5. Reclaimed Water Perception

5.1. Are you concerned about environmental and climate issues (Drought/Floods)?  Yes  No

5.2. Is your future water supply guaranteed?  Yes  No

5.3. Importance of environmental sustainability:  Very  Neutral  Low

5.4. Are you aware of treated wastewater reuse in other countries (e.g., USA, Middle East)?  Yes  No

5.5. Could treated wastewater reuse be a solution in Italy?  Yes  No  Don't know

5.6. Would you consider using treated wastewater for irrigation?  Yes  No

5.7. Conditions:  Price parity  Competitive price  Guaranteed availability during drought

5.8. Infrastructure: Would you collaborate on pipeline construction?  Yes  Only with incentives  No (Reason:)

- 5.9. Are you familiar with the G.I.D.A. treatment plant? [ ] Yes [ ] No
- 5.10. If G.I.D.A. ensures regulatory quality standards in the future, would you use their water? [ ] Yes [ ] Under certain conditions [ ] No
- 5.11. Interest in regional/EU funding for wastewater reuse? [ ] Yes [ ] Already participated [ ] Only if supported with documentation [ ] No
6. Open Discussion
- 6.1. Treated wastewater is the solution to water scarcity in this territory?
- 6.2. Costs of ecological transition should not fall entirely on farms?
- 6.3. Collaboration (Farmers, Institutions, University) may enhance competitiveness?

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