Effects of Wastewater Regulation Policies on Italian Agriculture: A georeferenced approach using the SIMPLE-G framework

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Abstract

In the face of rising water demand and climate change, sustainable water use is a growing concern for agriculture in Mediterranean countries like Italy. Although only 20.6% of Italy's agricultural land is irrigated, it accounts for nearly 40% of total crop output, with strong regional disparities. Emilia-Romagna, for instance, heavily depends on irrigation for water-intensive crops. In this context, the reuse of treated wastewater emerges as a key strategy for circular economy and sustainable agriculture. While the EU only regulated its use in 2020 (Reg. 2020/741), Italy anticipated this with early legislation and transposed EU rules in 2023. However, local-level analyses of its impact remain limited. This paper uses the gridded version of the SIMPLE-G model adapted for to evaluate the potential effects of wastewater reuse policies, focusing on Emilia-Romagna. After building a 2017 georeferenced agricultural database, we simulate a baseline to 2030 under increasing demand, a climate change scenario with localized productivity shocks, and three wastewater reuse policy scenarios, assuming 30%, 47%, and 70% increases in surface water availability. Results quantify impacts on crop production, input use, and prices, offering insight into the role of wastewater in supporting climate-resilient and resource-efficient agriculture in Italy.

Keywords: wastewater, SIMPLE-G Italy, agrifood, water sustainability

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1. Introduction

In the context of growing demand and climate change, agriculture faces significant challenges related to sustainable water management, especially in EU Mediterranean countries. As a critical natural resource, the availability and quality of water directly influence agricultural productivity and pose significant challenges to the economic resilience of the agrifood sector (World Bank, 2022; EU, 2021). The constant temperature increase, in tandem with the growing frequency and intensity of extreme climatic events, underscores the urgent need for a well-defined strategy to ensure sustainable water management and safeguard food security. In the future, new irrigation strategies and water sources will be crucial to support the economic competitiveness of local agrifood systems and farmers' income (EC, 2025; Vaquero-Pineiro et al., 2025). Strategic policy interventions are, in fact, one of the channels through which efficient and harmonized regional/national water distribution services can be established, making them resilient to water shocks and stresses at different levels. In this context, particular emphasis has been placed on the possibility of extending the reuse of wastewater in agriculture to guarantee extra input volumes and reduce other input expenditures. The use of reclaimed water for agriculture is, in fact, a strategic measure to implement circular economic strategies and achieve the transition towards more sustainable agrifood production systems (e.g., SDG No.6 and No. 12, Eurostat, 2024).

As anticipated in 2015: "*The [EU] Commission will take a series of actions to facilitate water reuse; this will include a legislative proposal on minimum requirements for reused water, e.g. for irrigation and groundwater recharge.*"[1] In June 2020, the EU approved the new Water Reuse Regulation (Reg. (EU) No. 2020/741), which applied in all EU member stated since June 2023, with the aim of fostering water reuse agricultural irrigation in the European Union.[2]
With this objective, the EU established common quality standards which shall facilitate the uptake of water reuse in economic activities, while ensuring the safety of human health and the environment (Tuomisto et al., 2014). The EU encourages to reuse water for agriculture irrigation, encouraging the reuse of treated urban wastewater, identifying it as an additional water source, particularly in areas affected by water stress.[3] Some Member States had already regulated wastewater purification, such as Italy that regulated the use of reclaimed water since 2006.[4] Given a leading role in water purification culture, only 4.6% of the agricultural land is irrigated by this non-conventional type of water, leaving, at least in principle, a huge potential for improvement. The latest data available, shows that of the 30 billion m3 of water withdrawn yearly in Italy, 41% is dedicated to agriculture. The share of

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[1] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the loop - An EU action plan for the Circular Economy. COM(2015) 614 final.

[2] Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse. The regulation adds to the existing EU legislation about water and environment, such as the Wastewater Treatment Directive (91/271/EWG), the Water Framework Directive (2000/60/EG), the Groundwater Directive (2006/118/EG amended by 2014/80/EU), the Nitrate Directive (91/676/EWG) as well as the legislation related to food safety (EC) No 178/2002, (EC) No 852/2004, (EC) No 2073/2005 and (EC) No 1881/2006.

[3] Commission Notice. Guidelines to support the application of Regulation 2020/741 on minimum requirements for water reuse. (2022/C 298/01).

[4] La Direttiva 91/271/CEE concernente il trattamento delle acque reflue urbane, recepita in Italia nella Parte III del Dlgs n. 152/2006.

irrigated land on irrigable land was 62%, while the share on the Utilized Agricultural Area was 19% (ISTAT, 2024). Yearly, the amount of wastewater treated is 7 billion m3. In this context, the new EU regulation is expected to have significant additional implications in this country at both local and national levels, influencing water pricing and availability, the volume and cost of agricultural production and irrigation sustainability (Farabegoli, 2023; Duong & Saphores, 2015).

Some efficient pilot cases of management wastewater for agriculture already exist (ISPRA, 2012). Among them, the Emilia Romagna region in 2023 established a strategic plan to manage water availability up to 2030 following the EU regulation (*Piano di tutela delle acque 2030, Documento Strategico*) (Ercoli et al., 2023). Within this regulative framework, for instance, the plant of Cesena for depuration is expected to supply approximately 6 million m3 of treated wastewater per irrigation season, intended for agricultural and environmental use.[5]

Academic literature on whether and to what extent using wastewater for agriculture is controversial, even if a general optimism emerges from the studies (Hristov et al., 2021). However, so far, we are far from a political, or scientific consensus, on the real potential of reclaimed water for irrigation, especially under the current climate change scenario. This uncertainty could be partially explained by severe data limitations and, consequently, the lack of comprehensive analysis. At the EU level a database with a data on wastewater does not exist. In Italy, for example, the official national datasets about water do not contain information about this type of unconventional source of water.[6] Some information is collected from the authorities managing each treatment plants, but, even in this case, data are not harmonised and are not public available. To address this issues, academic papers are often based on case studies (Manganiello et al., 2024), with data collected directly from the authorise responsible of the infrastructure, or at national level using AQUASTAT data from FAO.

Studies evaluating the effects at sub-national level are, therefore, missing, but this issue is never more relevant than before due to the critical water scarcity challenge the agriculture sector faces. The need to develop a quantitative tool that allows us to measure, and simulate, its implication at sub-national levels becomes evident.

In this context, this paper aims to simulate the impacts of implementing wastewater regulation policies, and the related additional reclaimed water availability for agriculture, on the following economic outcomes: crop production, prices, and inputs use. [7]

We focus on Italy, starting from a region that is particularly relevant not only due to its economic role for the agricultural sector, but also for its role as a pioneer of wastewater

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[5] More information available at: https://www.gruppohera.it/gruppo/attivita/acqua/i-nostri-impianti

[6] Some of the official datasets are the Sigrian (National information System for the management of water resources in agriculture) that collects all the information of nature management, infrastructural and agronomic related to collective irrigation at national level, Dania (National information systems for irrigation investments), Italian Farm Accountancy Data Network, with data on the total amount of water used by farms.

[7] Due to model structure, in this paper we do not distinguish between direct and indirect reuse of water. Accordingly, to the European Environmental Agency, treated wastewater can be indirectly reused when it is discharged into a watercourse, diluted, and used again downstream. Direct reuse means the direct supply of treated effluent from the treatment plant to the user.

regulator: the Emilia-Romagna region. Italy is the EU country with the strictest regulations on wastewater reuse and the highest potential for reusable wastewater (Ercoli et al, 2023; Maffettone and Gawlik, 2022).

Methodologically, we adopt the gridded version of the Simplified International Model of Agricultural Prices, Land Use, and Environment (SIMPLE-G), which has been *ad-hoc* extended for Italy. SIMPLE-G is a multi-scale partial equilibrium model that accounts for 17 world regions plus Italy divided in into 5-arc-minute grids (Liu et al., 2017, Baldos et al., 2020). So far, versions of SIMPLE-G have been constructed for the U.S. (Baldos et al., 2020); China (Wang et al., 2020) and Brazil (Wang et al.,2022).

Two are the main strengths of adopting a local (gridded) model, such as SIMPLE-G. The first one is methodological as grids are designed to capture heterogeneity in data and parameters while remaining small enough to ensure that commodity prices can be treated as exogenous. The second one is mainly conceptual and linked to the nature of the new EU regulation wastewater reuse (Reg. (EU) No. 2020/741). It moves away from a "fit-for-all" approach and adopts, for the first time, a "*fit for purpose*" approach, meaning that, in addition to minimum quality requirements (Tuomisto et al., 2014), local authorities have a level of legislative autonomy based on their agriculture specialization and geographical conditions. In details, "[...] *the various parties involved in the water reclamation process should [...] [set] up reclamation treatment procedures in accordance with the requirements for specific uses, and in order to be able to plan the supply of reclaimed water in line with demand from end-users*" (Reg. 741/2020, art. 18). This allows each Member State to decide that the reuse of water for agricultural irrigation is, or not, appropriate in some of its territories (i.e., river basin or part of them), based on their geographical conditions, local water stress and costs. As a result, the adoption rate of this innovative approach varies across territories. In this context, a local-based model is therefore essential to efficiently, and correctly, capture the effects.

Hence, using SIMPLE-G as framework, we simulate the effects of three different policy scenarios which account for an additional percentage of water availability thanks to the reclaimed water.

This paper adds to the existing literature in three main ways. First, it provides first insights into the future effects of using treated wastewater for local irrigation systems at regional, national and international levels. Second, by extending the SIMPLE-G model to Italy, the paper contributes to the recent literature on the application of this model for investigating water issues. It presents the first application of the SIMPLE-G-IT with the water module demonstrating how this model is a valid approach to simulate the impacts of regional interventions at the local and global levels. Lastly, the paper contributes to the current policy debate on the economic impact of irrigation for farmers' resilience (Vaquero-Pineiro et al., 2025) and the relevance of investing to guarantee water availability event through non-conventional source of water (EC, 2025).

The rest of the paper I structured as follows. Section 2 presents the contextual framework and the literature review, Section 3 introduces the simulation setting, while results are presented in Section 4. In Section 5, we draw final remarks and conclusions.

2. Contextual framework and literature review

2.1 Agriculture water in Italy

From the economic perspective, even if with cycle dynamics, agriculture in Italy still plays a role in the national economy, accounting for 1.95% of the GDP and 1.4% of total exports in 2023, according to ISTAT and WITS data. However, agriculture is the productive sector that use water the most: agricultural production depends on water availability and irrigation offers multiple benefits to farmers, such as increased crop resilience, yield and quality (Vaquero-Pineiro et al., 2025; EU, 2021). Also in response to climate change, in Italy agricultural land artificially irrigated is constantly increasing (+7% in 10 years reaching the 19% of the Italian SAU in 2020), with arable crops account for the higher share of irrigated land (68.5%) and some permanent crops experienced a particularly high growth rate over the last decade (e.g., grape + 27%) (CREA, 2024). The share of irrigated production varies significantly across regions. The Nord-Ovest regions is the area with the highest number of irrigated hectares, while Central regions account for the lowest number. This heterogeneity reflects on the one hand, the territorial differences in crop specialization (e,g, rice in the Nord-Ovest), and on the other hand, different climate conditions. In Emilia-Romagna, where arable crops and water intensity fruit permanent crops (e.g., kiwi) are the main productions, 61% of total crop production is achieved through artificial irrigation. Regarding management services, the collective system is the most common supply source (60%). In Italy, the governance of agricultural water is historically managed by different institutional bodies across territories (e.g., *Land Reclamation and Irrigation Consortia*) which adopt heterogeneous governance strategies (e.g., collective *vs* self-supply irrigation) that are often with lower degrees of freedom for individual decisions. While climate change is constantly increasing water demand (EU, 2021), this heterogeneity raises doubts about the actual impact of firms' digitalization adoption on water consumption, as individual choices have limited room for intervention due to restricted degrees of freedom. In this context, the adoption of wastewater could be determinant to increase the availability of surface water for irrigation and to continue satisfying agriculture water needs.

From the scientific academic perspective, papers debating on the consequences of the use of wastewater policies for irrigation exist. The first group involves reviews of legal documents and the nature of policies and regulations (Farabegoli, 2023; Berbel et al., 2023). Most of this study discuss the different legislative approaches and the effects of the different regulations' reforms. Hamam et al. (2024) proposed a very clear SWOT analysis of agricultural wastewater reuse in Italy.

A second group includes papers evaluating the ex-post benefits and related problems of using wastewater in agriculture, concluding that, without efficient management and a strategic governance, reclaimed water does not constitute a solution.[8] Most of these studies are limited to the analysis of a very specific case studies.

Conversely, few studies adopt ex-ante simulation analysis and all of them focus on simulating quantity availability for irrigation from treated water. An example is Hristov et al. (2021) that, by using CAPRI model updated with water module at the NUTS2 level,

[8] Papers looking at other destination of treated wastewater (e.g., industrial processes) are out of the focus of this paper.

investigated whether water reuse is a viable alternative to mitigate water scarcity across the EU and to reduce the risk of water shortages for irrigation. Very little attention has been paid so far to conduct ex-ante simulations aiming at evaluating the potential economic consequences of wastewater regulations at different territorial levels. The JRC Report (Pistocchi et al., 2017) is one of the rare exceptions, but the model is still implemented at the NUTS2 level. They estimated the distribution of costs of reclaiming and transporting treated wastewater for reuse in agricultural irrigation across EU regions.

2.2 Simple-G framework for water issues

There is a growing body of literature who has implemented the SIMPLE-G model so as to examine how different drivers impact crop production, prices and resource use at a local level. More specifically, within SIMPLE-G literature a group of studies focus on the implications of various water management policies.

At a global scale, Liu et al. (2017) developed the first global version of SIMPLE-G to examine the impacts of reducing unsustainable irrigation on food security, land use, and carbon emissions, considering inter-basin water transfers and market integration. Later, Baldos et al. (2020) first developed an application of the model for the U.S with a higher resolution based on a more detailed database specific to that country. Even though these applications used the model to study the implication of water related scenarios, they lacked a detailed representation of water as an input of production.

In this respect, Haqiqi et al. (2023a) worked on the previous U.S. model and introduced a distinction between rainfed and irrigated crop production. Additionally, within the irrigated production function, ground and surface water demand is also accounted for at a local level. This framework was used to study future population growth and groundwater policies' effects on local crop production and demand. Similarly, Zuidema et al. (2023) explores how a U.S. climate policy raising carbon prices improves water quality by reducing fertilizer use and nitrate runoff with added benefits from wetland restoration.

Haqiqi et al (2023b) incorporated the crop production functions at a global scale. This framework was later used to evaluate what would have happened to the world's crop production if the COVID-19 pandemic had coexisted with regional droughts. Even though this model represents an important step in terms of modelling water demand for agriculture at a global level, the dataset used may not reflect accurate estimates for some specific countries such as Italy.

Further applications of SIMPLE-G were also made for Brazil and China. Wang et al. (2022) studied how irrigation expansion as an adaptation measure for Brazil could impact crop and livestock production. Wang et al. (2020) calibrated a model for China to explore the consequences of promoting biofuel demand within the country. Their findings highlighted substantial spatial heterogeneity in the impacts on food, land, and water systems, underscoring the necessity for region-specific policy formulations to address the challenges of energy transition while safeguarding food security. Wang and Liu (2021a) elaborated on this extension to evaluate the local impacts on cropland, production and irrigation water use of the introduction of the South-North water transfer project (SNWTP) intended to transfer water from the main rivers located in the southern part of the country towards the northern regions. However, even though this study employed the SIMPLE-G framework as a basis, their methodology does not include a distinction of rainfed and irrigated crops such as the one used by Haqiqi et al. (2023a) and Haqiqi et al. (2023b).

Given the literature, the paper aims at developing a SIMPLE-G application for Italy with a detailed representation of both rainfed and irrigated crop production distinguishing between surface and groundwater withdrawals. This model will not only contribute to the existing SIMPLE-G literature but also present a suitable framework to evaluate the effects of water availability policies, both conventional and non-conventional, on economic outcomes.

3. Simulation setting

3.1 Simple-G-IT

SIMPLE-G is a multi-scale partial equilibrium framework integrating economic principles with biophysical characteristics (Hertel & Haqiqi, 2024).[9] It enhances the original SIMPLE model (developed by Hertel & Baldos, 2013) by a more granular, location-specific analysis of crop production. In this framework, production is modelled at the grid level, spatial units whose size varies with latitude, larger near the equator and smaller toward the poles. The georeferenced nature of SIMPLE-G allows for a detailed representation of inputs like land type, water use (differentiating between surface and groundwater), and fertilizer application rates, providing a more precise understanding of agricultural production processes.

The model is designed to capture how human systems adapt to environmental change, reflecting shifts in food consumption, crop production, land use, and water use in response to changes in market prices. A key advantage of the model is its capacity to account for market-mediated spillovers across regions, enabling the analysis of feedback between economic and environmental systems.

Its multi-scale structure also allows for seamless integration of local and global dynamics. At the grid level, variations in crop choices reflect local conditions. These outputs are then aggregated to produce national and global figures, based on assumptions about crop substitutability. Importantly, regions with more diverse crop mixes exhibit lower substitution elasticities. In this framework, agricultural output can either be consumed domestically or traded internationally, depending on factors like relative prices and production costs.

The implementation of the SIMPLE-G model for Italy required to single out the country from the broader EU region embedded in the original model structure and disaggregating it into 5 arc-minute grid cells. This spatial refinement enables the assessment of localized impacts within Italy, which is not feasible using the original SIMPLE-G database.

The previously discussed features of the model make it particularly well-suited to analyze the impacts of implementing wastewater regulation policies and the associated increase in reclaimed water availability for agricultural use. Its spatial resolution enables a detailed analysis of the impacts of wastewater reuse in the Emilia-Romagna region and its spillovers. This advantage is further enhanced by the model's integrated water module, which not only accounts for water use but also differentiates between water sources and captures how producers substitute among them.

[9] Multi-scale refers at models local-global-local analysis that have territories aggregated at different spatial levels (e.g., national, world regions, local) included in the same model.

3.2 Data

The SIMPLE-G dataset for Italy has been created ad-hoc collecting data from different sources. In concrete terms, satellite imagery was used from various data sources (USGS, GCWM, and Earthstat) and reconciled with world data sources at an aggregate level (FAOSTAT) and specific agricultural databases from Italy such as Italian FADN, CREA database about land, ISMEA Mercati for prices and ISTAT datasets. The result is a consistent and complete database for Italy 2017 with 3,745 grids.

Table 1. Data sources used.

Dataset	**Geographical Dimension**	**Links**
FAOSTAT	Country level	https://www.fao.org/faostat/es/#data
Earthstat	10km x10 km	http://www.earthstat.org/
AQUASTAT	10 km x 10 km	https://www.fao.org/aquastat/en/
USGS and GFSAD	30 m x 30 m	https://www.usgs.gov/
GCWM	10 km x 10 km	https://www.uni-frankfurt.de/45217988/Global_Crop_Water_Model__GCWM
ISMEA Mercati	Italian regional level	https://www.ismea.it/mercati
Italian Farm Accountancy Data Network (FADN) Rete di Informazione Contabile Agricola (RICA)	Italian provincial level	https://rica.crea.gov.it/
Indagine Mercato Fondiario - CREA	Italian regional level	https://www.crea.gov.it/web/politiche-e-bioeconomia/-/indagine-mercato-fondiario

Source: Own elaboration.

To construct the SIMPLE-G model tailored to the Italian context, a combination of national and geospatial data sources was used. While FAOSTAT served as the primary source for national agricultural statistics, its lack of georeferenced data necessitated the integration of the Earthstat database, which provides spatially explicit information on cropland distribution, production, and input use at a 5 arc-minute resolution. For water-related variables, we relied on AQUASTAT, which offers data on water availability and usage for agriculture, as well as the Global Crop Water Model (GCWM), which distinguishes between irrigated and rainfed cultivation at the same spatial scale.

To capture economic aspects, information on farm-level prices and values of irrigated versus non-irrigated production was drawn from the Italian Farm Accountancy Data Network (FADN), complemented by local market price data from ISMEA. Additionally, land market values were obtained from the Council for Agricultural Research and Economics (CREA) to establish regional and national benchmarks for farmland valuation.

Combining these datasets with estimated grid-level elasticities (income, price, and substitution), we were able to develop a spatially explicit version of the SIMPLE-G model for Italy. The year 2017 was selected as the baseline due to the availability and consistency of data across sources, allowing for a coherent and representative starting point for simulation.

3.3 Simulation design

As a starting point, a baseline scenario is designed to 2030 where both Italy and the world's agricultural sector face increasing crop demand driven by population growth, rising per capita incomes, and biofuel requirements. Population estimates were derived using the population projections developed by Samir & Lutz (2017), while GDP per capita estimates were based on projections by Crespo Cuaresma (2017). These projections follow the intermediate Shared Socioeconomic Pathway (SSP2) the International Institute for Applied Systems Analysis (IIASA) created. As far as future biofuel demand is concerned, they were constructed using estimates provided by IEA (2024), which is also in line with the authors' work. Additionally, this scenario assumes that total productivity (TFP) in the agricultural sector is said to increase in all regions of the world by 2030. Said increments were econometrically estimated using a panel data model to estimate productivity and a time series model to forecast output and input data for 2030 based on the methodology of Van Beveren (2007).

Secondly, a climate change scenario is introduced to the baseline scenario to evaluate the potential impacts of unexpected climatic events connected to precipitation and temperature variations affecting the agricultural sector in Italy. From a technical perspective, this scenario is achieved by negatively shocking the input neutral technological change of both irrigated and rainfed crop production function. This shock is performed at a grid level to account for the local heterogeneities inherent in climate shock. In this way, Italian areas most affected by the negative shocks will suffer greater reductions in crop production.

This paper elaborates three policies scenarios intended to quantitatively measure the impacts of additional reclaimed availability for agriculture on the following economic outcomes: crop production, prices, and input use. Given the focus on Emilia Romagna regions, the shocks represent three different potentials, and realistic, increase of surface water availability for agriculture thanks to the use of treated wastewater. From a technical perspective, a positive shock will be introduced to the availability of surface water of the baseline scenario.

The first policy scenario assumes an increase of 30% in the existing surface water availability if the Emilia Romagna region. The value reflects the potential new water availability thanks to wastewater sources estimated from AQUASTAT data.

In the second policy scenario, surface water availability is increased by 47%. Said value corresponds to the EU estimation of the potential of water reuse for agricultural irrigation in Emilia Romagna provided by from Pistocchi et al. (2017).

The last policy scenario recalls the ENEA VALUE CE-IN project that estimated an increase of 70% of the regional agricultural water need thanks to efficient and correct wastewater management.[10]

[10] Valorisation of treated wastewater and sludge in view of Circular Economy and Industrial symbiosis is a project funded by the Emilia-Romagna Regional Operational Programme 2014-2020 (ERDF ROP)

Expected results from this simulation will quantify the potential of this regulation to lessen the detrimental effects of climate change and enhance the agricultural sector's resilience.

Table 2. Scenarios summary.

No.	Name	Description	Scenario drivers
1	Baseline	Business As Usual. Increasing crop demand.	Demand: Population growth, rising per capita incomes, and biofuel requirements. Supply: Increase of TFP
2	Baseline+Climate change	Precipitation and temperature variations affecting negatively the agricultural sector	Supply: Negative shock in the input neutral technological change
3	Baseline+Climate change+47% of watewater	Scenario 2 with a 47% increase of existing water availability	Supply: Increase in water input availability
4	Baseline+Climate change+30% of watewater	Scenario 2 with a 30% increase of existing water availability	Supply: Increase in water input availability
5	Baseline+Climate change+70% of watewater	Scenario 2 with a 70% increase of existing water availability	Supply: Increase in water input availability

Source: Own elaboration.

4. Results

The reuse of purified wastewater in agriculture can supplement water availability for irrigation and limit withdrawals from groundwater (Manganiello et al., 2024). The resilience of local agrifood systems will depend on the adoption of strategic water management models and irrigation strategies, including non-conventional grey solutions, such as wastewater (Tran & Cook, 2023).

The hypothesis is that, with more available water, farmers are switching from rain-fed to irrigated crop activities, leading to an increase in production. Consequently, crop prices may decrease thanks to an increase in yield and productivity or, conversely, increase if the infrastructure costs for water treatment are too high, and paid by farmers.

However, some heterogenous effects emerge.
To be updated.

5. Conclusion and policy implications

Several are the socio-economic and environmental issues, with the related policy projections, that can be investigated thanks to SIMPLE-G. In this paper, we investigated the

in the field of the Smart Specialization Strategy (S3) and area Energy and Sustainable Development. The project is based on the key concepts of Circular Economy and Sustainable Development and started in 2019. More information available at: https://www.valuecein.eu/it/

potential effects of wastewater use for irrigation as a valuable alternative to tackle potential water supply shortages in the future. Even if there are potential benefits, a critical question remain open: who will pay in the future for wastewater? So far, it seems that the water cost is like the actual cost of water for producers (around less of 0,01 €/m3). In Italy, in fact, given the regulatory system in force (Ministerial Decree 185/03), it is assumed that the operators of the purification and refining plants will bear all the costs of the treatment, which will not in any way fall on the irrigation body that handles the distribution.
Farmers will not pay any difference between withdrawn from the storage basin and the treated wastewater.
However, according to the EU estimations (Pistocchi et al., 2017) the total cost of potential of water reuse for agriculture in Italy is higher and, on average, between 0.25 and 0.50 EUR/m3, with some regional differences. This value is also the average total cost in Emilia Romagna. However, as some existing paper demonstrated
What is different is the cost of the infrastructure construction and maintenance. The expenditure for it in Italy is increasing around 10% yearly reaching 13.1 billion EUR in 2022) (ISTAT, 2025). Most of the costs so far have been covered by private and public authorities (80%).

From the policy perspective, it is relevant to highlight some governance limitations that in Italy are mainly related to the differences between collective and self-managed supply. While, in fact, in the first case is it possible to design and implement policy interventions, in the latter case individual behaviours are the responsible of water management leaving public policies not a suitable tool. In the case of collective management, the diffusion of purified wastewater will be therefore easy to manage and support (Manganiello et al., 2024), especially the direct reuse. Conventional and non-conventional water will be supplied via the Consortium network and farmers do not need to choose which type of water used, avoiding bias self-selection. It was demonstrated, in fact, that farmers are still sceptical on wastewater use for several reasons (Mirra et al, 2024). This reflection is particularly relevant in the context of Italy, where there is a dual nature of the irrigation systems that reflects, at least in part, the economic value of the Italian agrifood sector and the climatic conditions of the country. While collective water systems are more common in the North, where there are higher added value productions, lower temperature and extreme raining events, in the South, characterised by lower added value productions and higher temperature and droughts, self-supply is the most common approach. This may generate a criticality on the public decision-maker to spur the use of wastewater in those regions that maybe address water scarcity the most. Unfortunately, the current version of the model does not allow us to use different water supply curves based on different management strategies (collective *vs* self-supply).

The model has also other limitations. First, it does not account for different irrigation techniques (sprinkler irrigation *vs* micro irrigation systems)[11], which might be included in future modules as a change in technology. Second, the model should consider different crops to account for the fact that reclaimed water can be used differently among crops (Reg

[11] With sprinkler irrigation systems, water is sprayed into the air and falls on the soil surface like rainfall, while with micro-irrigation water is applied locally with drip, trickle or micro-spray systems.

EU, 2020/741).[12] Lastly, it is not possible to unpack the emissions associated with a wastewater irrigation policy. The linkage between irrigation practices and emissions is a particularly hot topic, given that it is still almost unknown in literature, especially at the local level. Even those papers that have started to address this issue, such as Oin et al. (2024), do not consider wastewater supply in their models.[13]

Addressing all these limitations is in our future research agenda.

[12] According to the EU regulation, reclaimed water can be used for (i) food crops consumed raw (crops cultivated for human consumption, which will not undergo additional processes, based on the distance of the edible part of the crop from the ground; (ii) processed food crops cultivated for human consumption that will undergo additional processes (i.e. cooked or industrially processed) and will not be eaten raw (e.g. rice, wheat); (iii) crops cultivated not for human consumption but for pastures and forage or in other sectors (industrial, energy and seeded crops).

[13] Oin et al. (2024) analyze both surface and groundwater pumping at a global scale using a spatial resolution of 10 × 10 km. Their assessment quantifies energy consumption across various irrigation methods, including surface, sprinkler, and drip systems, as well as different types of pumping technologies, covering both electric and diesel-powered pumps. The findings are then spatially aggregated to estimate country-level and global energy use and CO_2 emissions associated with irrigation practices.

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