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The Potential use of Reclaimed Water for Irrigation Purposes: Is it Overestimated?

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Abstract

The use of reclaimed water is expected to increase in the coming years, mainly in water-scarce areas. In the European Union (EU), an increase in the use of reclaimed water is expected to play a significant role within the European circular economy strategy and climate change adaptation policies with the aim to enhance overall sustainability of water resource management. While several institutions have offered estimations of the potential of reclaimed water reuse in the EU context, these estimations tend to overestimate potential reuse volumes since they fail to fully consider the following important issues: (a) the role of return flows in basins where cascade reuse is crucial in maintaining downstream uses (including ecological flows); (b) the availability of abundant (and cheaper) conventional resources; and (c) the economic productivity of water as an indicator of users' willingness to pay for reclaimed water. This study focuses on the Spanish case since this is currently the EU member state with the highest potential for reclaimed water reuse. Findings show that previous estimations of reusable water volumes in Spain may have overestimated potential volumes. The proposed analysis can be extrapolated to other EU regions, where realistic estimations of the potential of reclaimed water might be much needed.

Keywords Reclaimed water · Water scarcity · Irrigation · Agricultural water management · Circular economy

1 Introduction

Climate change, rapid urbanisation, and population growth have acted as global drivers of the significant growth in the use of reclaimed water observed in the last decade. The market for reclaimed water is globally dominated by agricultural irrigation uses (32%), followed by landscape irrigation (20%), and the industrial sector (19%) (Lautze et al. 2014), with envi-

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ronmental, non-potable urban uses, recreational reuse, groundwater recharge, and indirect potable reuse completing the list of potential uses.

Reclaimed water use is on the increase in certain EU Member States and is expected to rise significantly in the coming years (European Commission 2018a; Pistocchi et al. 2017). According to the recent EU Water Reuse Technology Application Guide (European Union 2020a), Cyprus already reuses 90% of its treated wastewater, followed by Greece, Malta, Portugal, Italy, and Spain, where the share of reused urban effluent ranges between 1 and 12%. In these water-scarce countries, reclaimed water may alleviate local water scarcity and improve the sustainability of water management (EEA 2018). However, estimating the capacity for wastewater reuse in the EU is a complex task due to variations in infrastructure, regulations, and water availability across different countries and regions.

According to the European Environmental Agency (EEA) report by (Pistocchi et al. 2017), the estimated capacity for reclaimed water use in the EU is approximately 6,600 hm^3 per year. The volume of reclaimed water use varies significantly across EU countries: several countries, such as Cyprus, Spain, and Italy, have well-established reuse schemes, while others have relatively limited reuse capacity.

The EU includes the promotion of water reuse as part of the 2021 EU Strategy on Adaptation to Climate Change and the 2020 Circular Economy Action Plan. These strategies are laid out in the revised Urban Wastewater Treatment Directive (revision of Directives 91/271/EEC and 98/15/EC, as provisionally approved by the European Parliament and the Council on 29th January, 2024), which aims to improve the quality of wastewater treatment and to encourage the reuse of reclaimed wastewater.

Nevertheless, regarding water reuse, it is important to clarify the distinctions between indirect and direct reuse. Indirect reuse refers to the downstream reuse of water that has been discharged in a water body (frequently a river) after a reclamation treatment (usually at a wastewater treatment plant (WWTP). In contrast, direct reuse of reclaimed water refers to the introduction of this water to be used directly without treatment (e.g., agricultural irrigation). The quality requirement for reclaimed water is dictated by the final use (agricultural, industrial, urban, environmental). Direct use of reclaimed water for irrigation has recently been regulated by the EU Reg 2020/741(European Union 2020b), which imposes highly restrictive requirements to guarantee human and environmental health.

In order to encourage the use of reclaimed water, various public institutions (e.g., the European Commission and national governments) have started to offer estimations of potential reuse volumes. In our opinion, a number of these studies overestimate reuse potential, since critical issues, such as indirect cascade reuse and the abundance of conventional resources (e.g., surface and groundwater), are not considered. Our proposed method estimates water reuse potential by considering the following aspects: (a) the role of return flows in basins where cascade reuse is relevant; (b) the availability of abundant (and cheaper) conventional resources; and (c) the productivity of water as an indicator of irrigators' willingness to pay. Previous estimation attempts may have considered several of these important issues but have failed to include them all, thereby leading to the overestimation of reuse potential. This work introduces an innovative approach by integrating the aforementioned critical issues. To illustrate the efficacy of this approach, its application to Spain as a case study is proposed, leveraging the country's status as one of the highest current users of water and its potential, as outlined by EU directives.

Subsequent to this introduction, Sect. 2 offers a brief summary of previous estimations of water reuse potential in Spain and in the EU as a whole. Our estimation assumptions and model are then presented in Sect. 3, followed by the results obtained (Sect. 4). Section 5 offers a brief discussion on the results and Sect. 6 summarises the main concluding remarks.

2 A Review of Previous Estimations in the EU Context

According to national reports, the EC estimated that reclaimed water reused in the EU was approximately 1,100 hm^3 in 2016 (European Commission 2018a). This volume of current use acts as a starting point, from which there are some estimations of total potential reuse that are based on simple hydro-economic models. Quantitative estimates of potential water reuse in the EU vary depending on the sources and methods utilised for such estimates. Following studies offer an estimation of reclaimed water reuse potential:

- The European Commission (2018a) estimated reclaimed water reuse potential to be approximately 6,000 hm^3 per year at EU level.
- Pistocchi et al. (2017) estimated the volumes of treated wastewater available for irrigation in all European regions at four cost levels (below 0.50 EUR/m^3, 0.75 EUR/m^3, 1.00 EUR/m^3, and regardless of cost), and gave an estimation of 6,600 hm^3 in the latter case. In the case of Spain, this study offers an estimation of over 2,000 hm^3 per year when cost is not considered.
- Hristov et al. (2021), who follow the method developed by Pistocchi et al. (2017) and use the CAPRI model (the mathematical programming agro-economic model available at NUTS2 regional level), estimate a potential reduction in water stress of 14% (at EU level) and 10% (Spain) thanks to the use of reclaimed water.

These estimates provide a basis for understanding the reuse potential of reclaimed water in the EU and the need for more investment in wastewater infrastructure. However, it should be borne in mind that these estimates are based on specific assumptions that determine their results. Several key factors are typically considered in these types of models: (a) sectoral water demands; (b) availability of conventional resources and exploitation index; (c) WWTPs and distribution facilities; (d) regulations and governance framework; (e) cost of alternative water resources; and (f) cost of reclaimed water (treatment and distribution). Table 1 shows a summary of water reuse estimations available for the EU as a whole and for Spain specifically. The analysis carried out in preparation for the Water Reuse Regula-

Table 1 Estimations of potential reuse of reclaimed water in agriculture by various studies

Estimation source	Potential reuse (hm^3)	
	EU	Spain
EC (2018)	6 000	-
Pistocchi et al. (2017) Cost < 0.50EUR/m^3	6 620	2 054
Pistocchi et al. (2017) Cost < 0.75EUR/m^3	10 405	2 917
Pistocchi et al. (2017) Cost < 1.00EUR/m^3	11 522	3 114
Pistocchi et al. (2017) Any Cost	13 090	3 295
Spanish National Reuse Plan	-	1 400[2]
Current reuse: EU (2016), Spain (2020)	1 100	530[1]

Source [1] Spain, based on INE (2020) and complementary data collected by the authors; [2] MARM (2010) tion estimates a total cost of reclaimed water of less than 0.5 EUR/m^3 as a reference cost, including treatment and transport (European Commission 2018b). In the case of Spain, estimations lie in the range from 1,400 to 3,300 hm^3 per year, depending on the study and reclamation cost.

3 An Alternative Estimation Approach for Water Reuse Potential: The case of Spain

Our estimation approach considers three criteria (or factors) to evaluate the direct reuse of reclaimed water: (a) the role of return flows in basins where cascade reuse is relevant; (b) the availability of abundant (and cheaper) conventional resources; and (c) the productivity of water as a proxy of irrigators' willingness to pay for reclaimed water. The first factor constitutes a technical limitation to the volume of water reuse, while the second and third factors limit the economic viability of water reuse. The role of each of these three factors in our estimation approach is explained in detail below.

3.1 The role of Return Flows

The role played by return flows in the basin is determined by the location of the reclamation plant in the basin and, in our opinion, constitutes the first critical aspect to be considered in the estimation of potential water reuse. Simons et al. (2015) explain the role of cascade water reuse in basins and highlight the importance of return flows for indirect reuse and e-flow maintenance in water-scarce basins. The role of return flows in the hydrological model is probably the most critical point to be considered when estimating the potential reuse of reclaimed water at basin level. The latest Spanish Wastewater reuse plan (MITECO 2021) states that location of the WWTP (point of discharge) is a critical factor that determines the final impact of reclaimed water reuse. Figure 1 helps to illustrate this issue.

Consequently, when planning the direct reuse of reclaimed water, the prior existence of indirect reuse in the basin must be considered, since cascading reuse in fully allocated or over-allocated basins is either already accounted for in the basin water balance as indirect (also called "planned") reuse, or the discharged treated water is critical to guarantee environmental flows in generally over-allocated Spanish rivers.

Based on this criterion, River Basin Authorities (RBA) in the main rivers of southern Spain have largely banned water reuse in the River Basin Management Plans (RBMP). This is the case of the Guadiana RBMP, which prohibits water reuse unless there is a water rights exchange of previous groundwater exploitation rights (a volume of reclaimed water reuse is granted in exchange for groundwater rights). The Guadalquivir RBA applied the same criterion in its 1st RBMP cycle, and banned water reuse, but, motivated by political interests (i.e., farmers' lobbies), a small volume of reclaimed water reuse has been permitted in the 2nd and 3rd RBMP cycles (Confederación Hidrográfica del Guadalquivir 2023).

In the current context of overexploitation and overallocation of conventional water resources that characterises the Mediterranean regions of Spain, the role played by return flows to guarantee indirect uses (including environmental flows) and the location of discharge points need to be considered. With this aim, Table 4 below shows the 'technically potential reuse' estimated for Spanish RBs in terms of the volume of treated water that is

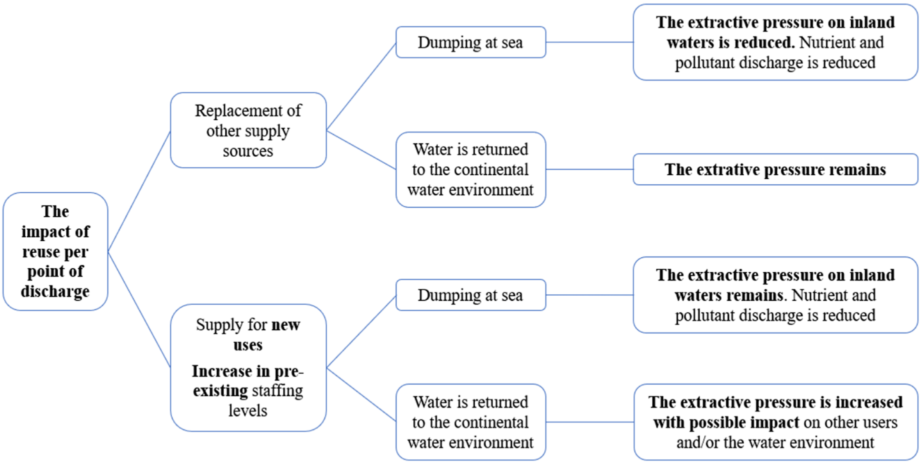


Fig. 1 Environmental impact of wastewater reuse, according to location and water body conditions. *Source* Authors' own, based on MITECO (2021)

exclusively discharged into the sea. Following empirical evidence, a maximum potential reuse rate of 90% (discharged flows into the sea) has been assumed. This is explained by the distribution losses and limited reclamation capacity of small municipalities and disseminated housing. This technical limit has been observed in four cases of small territories with extreme water scarcity: Cyprus (WISE Freshwater 2023), Israel (Mordechay et al. 2021), Murcia region in Spain (INE 2020), and Singapore, where the reuse rate is under 100%. The case of Singapore can be considered a global benchmark, with distribution losses of 8.1% reported in 2021 (Ministry of Sustainability and the Environment of Singapore 2022). At this point, it is worth noting that water reclamation facilities face high operation and maintenance (O&M) costs, which have become a critical issue to reach high reclamation rates (Marlow 2010). Hukka and Katko (2015) found that the investment in the maintenance of WWTPs can be as significant as the construction investment. In Spain, and in the EU in general, it was after the implementation of Directive 91/271/CEE (European Union 1991) that the number of WWTPs increased dramatically and became valuable components of Europe's urban water infrastructure (Hernández-Chover et al. 2019).

3.2 Users' Willingness to pay

Water reuse is economically conditioned from both the demand and supply sides. From the demand side, water productivity (understood as the economic value generated per water unit) is the critical factor, while from the supply side, the availability of conventional (and cheaper) water resources compared to the cost of water reclamation (plus transport and distribution costs) determines the irrigators' real acceptance of reclaimed water. Water productivity is a direct consequence of crop profitability, which is determined not only by natural factors (e.g., climate), but also by human and technological factors and the economies of agglomeration that determine the competitiveness of Mediterranean agriculture, as is the case in those RBs of southern and eastern Spain. Pistocchi et al. (2017) carry out a complete analysis of EU farmers' willingness to pay for reclaimed water based on this concept and offer an estimated volume of demanded reclaimed water for different price thresholds. In our opinion, specific data on elicited water productivity from basin-specific and/or local studies should be employed since this factor is heavily dependent on the agronomic characteristics of the crop mix (e.g., irrigation requirements, technification, profitability).

Figure 2 shows elicited water demand functions for various southern Spanish RBs. As can be observed, water productivity (as shown by marginal and mean values in the figures) increases with reductions in water abstraction. Water demand functions remain extremely inelastic until very high water costs are reached (at generally in excess of 0.5 EUR/m^3 in the figures). This illustrates the high willingness to pay for water of high-value crops.

3.3 Cost and Availability of Conventional Resources

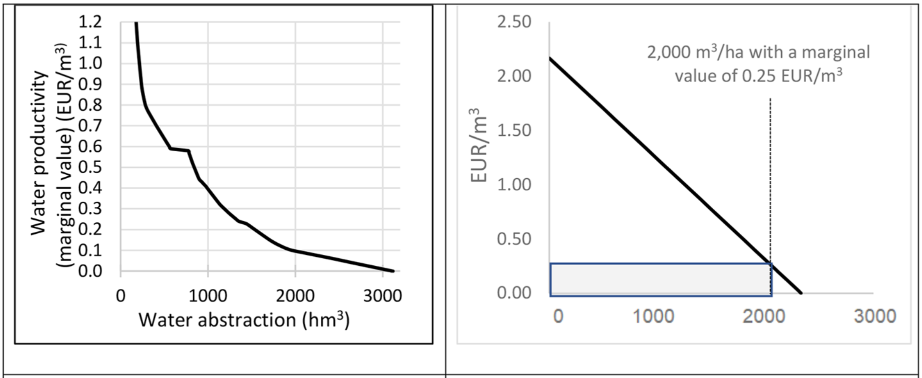
Reclaimed water demand depends on the cost of other water resources (Tsagarakis and Georgantzis 2003). In northern basins endowed with abundant water resources and low costs of conventional resources, reclaimed water fails to represent an economically viable option for farmers. Conversely, in southern and eastern basins, despite the significantly higher costs of conventional water resources compared to the conventional resources, farmers exhibit a higher willingness to pay for larger volumes of irrigation water, especially when triggered by the frequent supply restrictions due to drought and the impossibility of increasing conventional resources. Table 2 summarises the costs of conventional water resources for the main Spanish RBs.

In addition to the cost of conventional resources shown in Table 2, the resource availability can also be illustrated by analysing the EEA Water Exploitation Index (WEI+) (Kristensen et al. 2018). This indicator shows that southern and eastern basins (e.g., Guadiana, Guadalquivir, Segura, Jucar, and Andalusian basins) are already 'closed' or fully allocated, while northern basins still have certain resources available (e.g., Ebro, Duero, Tajo, and northern and Galician basins). This fact determines the potential role that the reuse of reclaimed water can play as a feasible source of water supply for irrigation, since the conventional water resources in the closed basins are insufficient to meet the increasing demand. Moreover, the high profitability of crops in southern and eastern basins, for both perennials (such as olives and fruits, including tropical and citrus trees) and vegetables

Table 2 Cost of alternative water resources per river basin in Spain

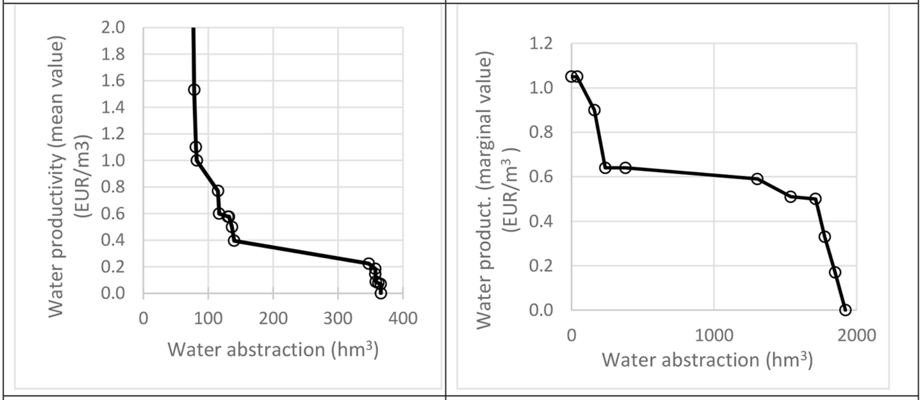
River Basin	Cost (EUR/ha)				Cost (EUR/m^3)	
	Ground- water	Surface water				
		Surface	Distribution	Total Surface	Groundwater	Surface
Ebro	828.9	12.3	49.1	61.4	0.1488	0.0110
Duero	499.7	46.1	19.9	66.0	0.0946	0.0125
Jucar	383.5	16.2	80.7	96.8	0.0744	0.0188
Tajo	541.2	67.0	36.5	103.5	0.1035	0.0198
Guadiana	231.6	102.5	19.1	121.6	0.0485	0.0254
Guadalquivir	743.8	69.9	101.2	171.1	0.1503	0.0346
Segura	789.2	150.6	33.8	184.4	0.1632	0.0381
National average	500.2	56.4	49.7	106.1	0.0909	0.0207

Source The latest official data from the Spanish Ministry of the Environment (Ministerio de Medio Ambiente 2007)



Guadalquivir RB (1)

Olive groves in the Guadalquivir RB (2)



Mediterranean Andalusian RB (3)

Segura RB (4)

Fig. 2 Water demand functions estimated by: (1) Martínez-Dalmau et al. (2023); (2) Expósito and Berbel (2017); (3) Authors' own; and (4) Calatrava and Martínez-Granados (2012)

Table 3 Cost of reclamation treatment in southern Spain

Location of the irrigation association	Volume (hm^3)	Estimated operation cost (EUR/m^3)
Guadalquivir RB - Cordoba	1	0.20
Atlantic Andalusian RB - Cadiz	5	0.11
Mediterranean Andalusian RB - Almeria	6	0.12
Mediterranean Andalusian RB - Granada	0.5	0.21
Mediterranean Andalusian RB - Malaga	10	0.10

Source Authors' own estimation based on interviews with WWTP operators

(including vast areas of greenhouse agriculture), pushes up the disposition of farmers to pay for alternative and reliable sources of water, as shown in Fig. 2.

Table 3 shows costs paid by irrigators for the use of reclaimed water in several locations in southern Spain. Although these costs are higher than those of conventional sources, farmers are willing to pay for these additional resources since their crop profitability supports these higher costs. As expected, water reclamation costs show significant economies of scale with decreasing costs per unit as the volume of treated water increases, which leads to very competitive costs when the volume is sufficiently high, at approximately 0.10 EUR/m^3.

It is worth noting that Table 3 reflects the cost of wastewater treatment (tertiary treatments) at the WWTP to reach the quality level required by Reg. 2020/741. Moreover, farmers need to pay storage and distribution costs which might vary depending on the location of the WWTP and the irrigated land. Certain studies have offered an average estimation of these costs, at approximately 0.25 EUR/m^3 (Pistocchi et al. 2017).

4 Results

Once the estimation method and main limitation factors have been presented, Table 4 summarises our main results. Estimated potential reuse volumes are shown per region, since data on treated wastewater is only available on a regional basis, and not per river basin. As observed, the estimation of the economic potential reuse (i.e., the economically viable volume of water reuse) could reach 769 hm^3 in the regions of water scarcity, that is, in the Mediterranean area and the Canary Islands, since the water demand for irrigation could be capable of absorbing this alternative water supply. This entails multiplying the current reused volume of wastewater by 1.7. On the other hand, in central and northern regions, despite their technical potential, the use of reclaimed water for irrigation would not be eco-

Table 4 Estimation of the potential of wastewater reuse for irrigation in Spain (hm^3)

Region	Treated Wastewater [1]	Discharged into the sea [2]	Already Reused 2020 [3]	Technical potential use [4]	Economic potential use [5]
Andalusia	699	248	36	233	233
Balearic Islands	113	42	51	37	37
Canary Islands	116	88	28	82	82
Catalonia	706	321	38	303	303
Valencia	468	114	199	99	99
Murcia	115	2	105	0	0
Ceuta and Melilla territories	16	16	0	15	15
Mediterranean & Canary Islands	**2,233**	**831**	**457**	**769**	**769**
Aragon	195	0	4	0	0
Asturias	163	68	10	65	0
Cantabria	107	87	2	85	0
Castille-Leon	412	0	4	0	0
Castille-La Mancha	204	0	6	0	0
Extremadura	129	0	0	0	0
Madrid	511	0	13	0	0
Navarre	105	0	0	0	0
Basque Country	370	243	3	231	0
Rioja	65	0	1	0	0
Galicia	383	114	33	107	0
Central & Northern regions	**2,644**	**513**	**75**	**487**	**0**
Total Spain	**4,877**	**1,344**	**532**	**1,256**	**769**

Sources [1] INE data base for 2018; [2] INE and the authors' own data collection; [3] Authors' own estimation nomically viable due to the availability of low-cost conventional resources. Table 4 applies the three criteria of our simplified model: (a) firstly the focus is on exclusively discharging water into the sea and applying the ad hoc 90% of technically feasible reuse, which yields column [4] 'Technical potential reuse'; and secondly, the (b) and (c) criteria reflect the economic potential use by selecting those high-value water productivity territories with scarcity of conventional water resources and high water demand driven by high water productivity (column [5]).

According to our estimation, the total water reuse potential in Spain is the sum of the actual use (532) plus the potential reuse (769); this gives us 1,301 hm^3, which is close to (but slightly lower than) the estimation of 1,405 hm^3 as calculated by the Spanish Ministry of the Environment (MARM 2010), but it is significantly lower than the EU estimate for Spain, which lies in the range of 2,054 to 3,295 hm^3 (see Table 1). According to our estimate, the maximum share of urban water reuse would be approximately 26% in the long term since scarcity is aggravated due to the impact of climate change and drought events (currently, the internal river basins of Catalonia and Andalusia are under drought emergency status, March 2024).

Other studies have offered alternative estimates of the potential reuse of reclaimed water for irrigation in the EU and Spain contexts. The study by Raso (2013) estimates a volume of reused water for the whole EU of 3,222 hm^3/year, which would help save 0.9% of total water withdrawals. In the case of Spain, the estimate reaches 1,262 hm^3/year (very similar to our estimation) and would represent 3% of total withdrawals. Hristov et al. (2021) also offer estimates of the potential volume of reused water for the EU as a whole and for several specific countries, such as Spain, although their figures stand well above our estimates, and reach 6,000 and 2,000 hm^3 per year for the EU and Spain, respectively. Alternatively, Hochstrat et al. (2005) and Raso (2013) consider that Spain has a reuse potential of approximately 1,200 hm^3/year. These figures are in line with the estimates by Hochstrat et al. (2006), which, using a water balance model and various climate scenarios, consider that the potential reuse of reclaimed water in the EU would represent savings between 1% and 17% of current total withdrawals, depending on the country and region analysed. Although Malta and Cyprus are the countries with the highest percentage of potential savings, Spain is the EU country with the highest potential volume (1,213 hm^3/year).

Consequently, and according to our proposed methodology, a realistic water reuse volume potential would lie in the range of 1,200-1,300 hm^3 in the case of Spain. This estimate would be in line with the figures offered by other studies, as previously commented.

5 Discussion

Our estimates are below the optimistic estimations offered by Pistocchi et al. (2017) and Hristov et al. (2021). In our opinion, their overestimation is due to the lack of consideration of two critical factors: firstly, the location of the WWTP and the important role of return flows in the hydrological cycle that makes direct reuse compete with 'indirect reuse' and may increase water scarcity and overallocation in the basin; and secondly, the availability of abundant conventional water resources (i.e., surface and groundwater) that renders the use of reclaimed water an economically non-viable option.

Optimistic forecasts by European institutions are usually motivated by the aim to facilitate policy adoptions and the setting of ambitious targets; an example is given by Farm to Fork strategy, which states unachievable goals of sustainable intensification of EU agriculture for 2030 (Beltran et al. 2022). Similarly, the optimistic estimation for irrigation use may either be justified as an argument towards facilitating the adoption of the recent EU Regulation 2020/741 on water reuse, or alternatively it may simply be an unrealistic model that fails to integrate hydrological (internal basins) and economic variables (willingness to pay) as this work shows.

In our opinion, most estimations handled by the EU are biased towards overestimation due to the lack of a sound economic analysis of potential demand that would take not only the costs of alternative water resources into account (e.g., surface waters), but also environmental and downstream uses in non-coastal (or close to the coastline) locations. Moreover, the main contribution of this work lies in offering a sound valuation of the realistic potential of water reuse for irrigation in Spain, which can guide public policy at EU and national levels.

Despite all the potential benefits of the circular economy in the water sector (Guerra-Rodríguez et al. 2020), water reuse is being significantly developed only in countries with a high level of hydric stress, but the extensive use of reclaimed water for irrigation is also facing limitations (Mesa-Pérez and Berbel 2020). A number of authors have studied the main limitations and barriers to the extensive use of reclaimed water in irrigation, a summary of which is given in Table 5.

Technical limitations, such as the insufficiency of technical expertise and of established competencies in the effective administration of treatment facilities, can be highlighted a main barrier. Furthermore, urban wastewater collection systems often transport water downhill to the WWTP to optimise transportation costs by leveraging gravity. However, the WWTP location poses a significant challenge in distributing reclaimed water to agricultural areas, thereby inflating distribution expenses (Kehrein et al. 2021). Consequently, the cost of treated water, which encompasses treatment, transportation, storage, and infrastructural investments, can render the use of reclaimed water unviable (Hristov 2020). As highlighted by Salgado Fagundes and Marques (2023), reclaimed water is a relatively new source of supply, and the water industry has yet to standardise a pricing approach (Bui et al. 2019). Research into reclaimed water pricing has only recently begun (Hernández-Chover et al. 2022; Molinos-Senante et al. 2013), and practitioners have relied on numerous assumptions for charging this burgeoning market.

Another main barrier involves the low acceptance of this water source from farmers and the general public. López-Serrano et al. (2022), in their study with farmers, show a significant rejection of reclaimed water due to concerns regarding potential health risks, possible consumer disapproval, and a lack of clear information regarding its quality. However, it has been demonstrated that, once farmers are informed and begin to use this type of water, their perception changes radically. However, it is society as a whole that often considers treated wastewater as waste and fears it may cause public health problems (Guerra-Rodríguez 2020). Furthermore, the study of Mizyed (2013) suggests that overly strict water treatment regulations can actually hinder their implementation. This is due to stricter regulations imposing greater constraints, thereby rendering compliance more difficult. This highlights a broader issue of institutional barriers: the lack of coordination between administrative

Table 5 Limitations to the extensive use of reclaimed wastewater

Limitation Category	Description	Reference
Technical and Economic	Insufficiency in technical expertise and in established competencies in effective treatment facility management.	Berbel et al. (2023)
	Dependence on urban water sources via distribution systems, thereby posing challenges in water distribution to agriculture.	
	Need for financial aid, such as subsidies, to offset treatment, transportation, storage, and infrastructural costs.	Hristov (2021)
	Absence of standardised pricing approaches for recycled water, thereby hindering market development.	Salgado Fagundes and Marques (2023), Bui et al. (2019)
	Limited research and reliance on assumptions for reclaimed water pricing.	Hernández-Chover et al. (2022), Molinos-Senante et al. (2013)
Social	Resistance from farmers and the general public due to concerns regarding health risks and consumer disapproval.	López-Serrano et al. (2022)
	Lack of clear information on recycled water, leading to misconceptions and fear of potential health problems.	Guerra-Rodríguez (2020)
Institutional	Stringent water treatment regulations hindering implementation due to compliance difficulties. Lack of coordination between administrative bodies, resulting in confusion and uncertainty.	Mizyed (2013)

bodies. This lack of coordination often results in confusion and uncertainty and discourages investment in essential infrastructure.

These limitations and barriers regarding the use of reclaimed water for irrigation purposes (but also for other uses) need to be considered by public institutions in order to maximise potential water reuse. Although our estimation approach takes into account several of these technical and economic limitations so that a more realistic estimate can be made of the water reuse potential for irrigation in Spain, still more work is needed for further major limitations to be taken into account. We believe that there is a tendency towards optimistic assumptions regarding the role of reclaimed water reuse in meeting the goals of the European Water Framework Directive. Such assumptions may lead to non-optimal decision-making in this critical sector, which carries significant implications for food security in Spain and across the EU.

6 Conclusions

Indirect cascade reuse and the abundance of conventional water resources (e.g., surface and groundwater) should be borne in mind when estimating water reuse potential for irrigation in order to avoid overestimation and non-optimal decision-making. The proposed method is applied to the case of Spain, whereby an estimated water reuse potential of 1,200-1,300 hm^3 is offered for irrigation, which is below the figures provided by other studies. Future research should focus on facilitating accurate estimations of wastewater reuse potential at river basin level while taking into account the special characteristics (i.e., socio-economic, hydrological, climatic, legal considerations) at river basin, regional, and country scales. Further knowledge on treatment costs and the practical implementation of the safety protocols formulated in the Reg EU 2020/741 and other quality standards (such as reclaimed water for aquifer recharge) should also constitute a principal focus of decision-makers with the aim of analysing the economic and financial feasibility of this non-conventional water resource for potential users.

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Declarations

Ethics Approval This paper has not been previously published nor is it under consideration for publication elsewhere.

Consent to Participate The authors declare that they are aware of and consent to their participation in this paper.

Consent to Publish The authors declare that they consent to the publication of this paper.

Conflict of Interest The authors declare there to be no relevant financial or non-financial conflict of interest to disclose.

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