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Will the European Regulation for water reuse for agricultural irrigation foster this practice in the European Union?

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ABSTRACT

The development of the water reuse sector within the European Union (EU) varies considerably. In 2020, Portugal, Spain, Italy, Greece, France and Cyprus had the most comprehensive regulations for the reuse of reclaimed water for agriculture. The approval of a common regulation by the EU Parliament and the Council in May 2020 (which came into effect in June 2023) elicits the question of how each country will comply with it. This review compares (i) national regulations to the 2020 European Regulation, (ii) existing projects with respect to their performance in terms of water quality and (iii) raises a debate about the role of the EU Regulation in fostering water reuse at the EU level. The European Regulation will probably strengthen consumer confidence as common minimum requirements are now required. However, the issues related to micropollutants, disinfection by-products or possible changes in the water quality downstream of the compliance point are not fully considered by the EU Regulation. Moreover, other techno-economic obstacles to be overcome include the distance between the production of treated water and agricultural needs, the low economic competitiveness of reclaimed water and the implementation of the multi-barrier approach.

Key words: agricultural reuse, EU Regulation 2020/741, minimum requirements for water reuse, quality classes, reclaimed wastewater, water circular economy, water circularity

HIGHLIGHTS

- The EU Regulation harmonises standards and procedures for water reuse: some countries need to adapt their regulations and current projects.
- It does not necessarily represent a driver for the development of this practice.
- The main challenges are associated with the economic competitiveness of reclaimed wastewater, risk management planning, the sharing of responsibilities and the implementation of the multi-barrier approach.

1. INTRODUCTION

The 21st century is projected to see increased water variability and scarcity in many parts of the world, as well as significant demographic changes, leading to increased water stress and competing demands between and within countries (World Health Organization 2006). An estimated 4 billion people live in areas that suffer from severe physical water scarcity for at least 1 month per year (United Nations 2021). Europe's population lives more and more in urban areas, and an increasing demand for drinking water supply and other water uses is observed. Concentrated and growing populations near coastlines, where local freshwater supplies are generally limited, drive the search for alternative supplies. The largest use of water resources in southern and southeastern Europe is for agricultural food production; it is considered that irrigation represents about 60% of total freshwater abstraction (European Environment Agency 2018; Proposal for a Regulation COM 337 2018/0169/COD 2018). Climate change is expected to affect all European countries but in differing ways and timescales. The southern European countries will see increasingly dry climatic patterns, particularly compared to eastern and northern Europe (Cammalleri *et al.* 2020).

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Reclaimed water has long been seen as a complementary source of water and nutrients, or a potential substitute for unreliable surface water or groundwater sources, mostly for agriculture, since prehistoric times (Angelakis *et al.* 2018; Ventura *et al.* 2019). During the early Middle Ages, the practice was not very widespread in Europe. Most cities were not initially equipped with sewers, but gradually, systems were developed to collect sewage and waste which were then released into surface waters. From the 18th century, sewage farms developed to dispose of wastewater (Angelakis *et al.* 2018). These farms were focused on crop production. During the 20th century, the move towards organised and centralised methods for removing wastewater from urban areas due to health and aesthetic reasons created the infrastructure (especially sewers and wastewater treatment plants) to enable its reuse in the modern sense.

The late 20th century saw two distinct methods developed for regulating the reuse of water, mainly for agricultural purposes. The first was in California, where water reuse for agriculture was practiced and first regulated in 1918 by the California State Board of Health (Paranychianakis *et al.* 2015). California then implemented its first modern water reuse regulation in 1978, which imposed advanced treatment requirements and restrictive quality thresholds to produce effluent safe for intended uses. It took a precautionary, risk-averse approach that required the adoption of the 'best available technology' (Licciardello *et al.* 2018). Its quality limits were considered by many as overly strict and difficult to meet by many less developed or poorer countries (Licciardello *et al.* 2018).

Recognising the differences in technical and economic capacity around the world, the World Health Organization (WHO) attempted to find an alternative approach based on data. The WHO released its water reuse guidelines in 1973 (World Health Organization 1973), revised in 1989 (World Health Organization 1989) and again in 2006 (World Health Organization 2006). This approach was based on epidemiological research attempting to quantify, or if not qualify, the risks posed to human health from wastewater reuse. This research indicated that the risks posed were often not as great as the Californian approach seemed to imply (Licciardello *et al.* 2018). The WHO guidelines used a smaller number of quality parameter limits compared to the Californian regulations, which were set at higher values, and followed a more flexible 'calculated risk' approach (Licciardello *et al.* 2018).

Over the following decades, starting in 1977, water reuse regulations developed in several countries in Europe where the need for alternative water sources was greatest (Italy, Spain, France, Portugal, Greece and Cyprus). Italy, Greece and Cyprus passed regulations based more on the Californian regulations that include many physical and chemical parameter limits. An additional contribution to the debate came from Australia, where the water reuse sector was emerging in response to a highly variable climate. The Australian approach aligned more closely with the WHO guidelines but added different classes of reclaimed water used for different purposes. France ultimately aligned its current 2010 regulation with the WHO guidelines and the Australian guidelines, while not yet developing a comprehensive risk assessment methodology. Portugal and Spain introduced, in 2005 and 2007, respectively, an intermediate approach by including a long list of quality parameter requirements as well as a risk assessment approach (Paranychianakis *et al.* 2015). Portugal has since updated its approach, in 2019, having developed its risk assessment methodology more extensively and having reduced the number of water quality parameters listed (Rebelo *et al.* 2020). Note that some regions in Italy and Spain developed specific regulations before the national regulations emerged. At the international level, in 2015, the publication of the ISO 16075 standard proposed a unification of procedures and quality criteria for the reuse of water in agriculture (ISO 16075:2015 – Guidelines for Treated Wastewater Use for Irrigation Projects).

The inconsistent regulatory environment in Europe was seen as a potential trade problem if countries were to impose their own standards for food and agricultural products across borders. This was a risk to one of the European Union's foundational tenets – the single market – and calls grew during the 2010s for the EU to develop a union-wide regulation (Gancheva *et al.* 2018). Additionally, Fawell *et al.* (2016) stated that the absence of a common standard was the biggest obstruction for water reuse expansion. Other factors pushing regulatory development were occasional outbreaks of disease coming from the agricultural sector. These included the example of an *E. coli* (*Escherichia coli*) O104 H4 outbreak in the EU in 2011, which was responsible for the deaths of 48 people in Germany and 1 in Sweden. Although the results of the investigations suggested otherwise, the outbreak was initially associated with the exchange of vegetables among EU countries and the lack of appropriate legislative tools, which stressed the importance of uniform and common policies to protect public health (European Food Safety Authority 2011; Paranychianakis *et al.* 2015).

The EU aimed to harmonise the state of water reuse for agricultural irrigation, to encourage the practice into the future as part of promoting a vision of a circular economy and to advance towards the UN Sustainable Development Goals. The EU implemented a series of preliminary reports and consultations with member states to determine a coherent regulation that

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would protect human health, while also encouraging the uptake of reclaimed water. Notably, the JRC 2018 policy report on water reuse (Alcalde-Sanz & Gawlik 2018) provided advice on the values for the minimum requirements for water reuse, using the 'tolerable', or acceptable, risk for human health based on the value of 10^{-6} Disability Adjusted Life Years (DALYs) per person per year (pppy) that was used in the WHO Guidelines for Drinking Water Quality (WHO 2004, 2011) and the WHO guidelines for water reuse (WHO 2006). The EU developed Regulation 2020/741 of the European Parliament and of the Council on 25 May 2020 on minimum requirements for water reuse (Regulation (EU) 741 2020) to align broadly with the WHO guidelines and the ISO Standard 16075 (ISO 16075:2015 – Guidelines for Treated Wastewater Use for Irrigation Projects). The new regulation came into effect for all Member States on 26 June 2023. The ISO Standard, explicitly cited in Regulation 2020/741 in reference to the 'multi-barrier approach', can complement the Regulation to compensate for the risk to consumers and workers when the minimum water quality requirements associated with each class of uses are not met. A 'multi-barrier approach' refers to technical or organisational actions that can reduce the risk of contamination when reusing reclaimed water (World Health Organization 2016). The reference to this multi-barrier approach can be considered a turning point in the development of regulatory texts on water reuse for some European countries, as it proposes a risk-based approach rather than minimum universal requirements. However, the multi-barrier approach appears to have been understood differently in Member states.

This paper attempts to explain to what extent the new European regulation will support the expansion of water reuse for agricultural irrigation in the EU. To differentiate from other papers and technical reports focused on economic and regulatory aspects, it focuses mainly on the operational challenges raised by the Regulation for the providers and users of treated wastewater. To provide a basis for the debate, the former national regulations were compared with the new 2020 EU Regulation. Another objective was to understand if emblematic existing projects already meet the new EU Regulation and what degree of adaptation may be necessary for selected countries. The article first briefly explains water reuse and regulation development in the EU, then describes and compares the former national and EU Regulations. Next, case studies of existing water reuse projects in EU countries are presented and compared to the new EU Regulation. Finally, developing from the first three parts and a recent literature review, some insights are discussed on the prospects offered by the new regulation for the development of water reuse for irrigation in Europe.

2. METHOD: SCOPE OF THE STUDY AND METHODOLOGY

The review focuses on the comparison of water quality standards for water reuse in agriculture in six countries in southern Europe: Italy, Spain, France, Portugal, Greece and Cyprus. These six countries were chosen because, according to Alcalde-Sanz & Gawlik (2018), they had the most comprehensive regulation for the reuse of treated wastewater prior to the implementation of the EU Regulation. Other Member States practice wastewater reuse to a greater or lesser extent (for example, Malta, Belgium, the Netherlands and Germany), however, no specific water reuse regulations or guidelines could be found referenced in the literature or in searches conducted in the countries' official languages. This review highlights the potential efforts required by each of the six countries to meet the new EU Regulation and the specific obstacles encountered in each of these countries. To gather data on the subject, the regulations of the different countries were consulted (all web links were accessible on 12 September 2022), as well as four scientific databases: Science Direct, Wiley Online Library, Springer Link and Google Scholar. All the papers that contained both the keywords 'water reuse' and 'regulation', or 'reclaimed water' and 'regulation' that focused on the six studied countries were collected. After sorting the relevant papers for our study, 32 papers or books remained.

Technical reports of the EU and reports dealing with water reuse projects were also gathered, as well as data from five European projects for which sufficient data was available to ensure a suitable comparison.

3. WASTEWATER REUSE REGULATIONS IN ITALY, SPAIN, FRANCE, PORTUGAL, GREECE AND CYPRUS

This section briefly describes the history of water reuse and the regulatory approaches taken in six European countries that see the highest levels of water reuse – Italy, Spain, France, Portugal, Greece and Cyprus. It then provides a comparison of the current national regulations with the new European regulation that came into effect in 2023.

3.1. Italy

The substitution of freshwater for treated wastewater for irrigation in Italy has a long history. Its use in agriculture has been regulated since 1977 (the first European country to legislate water reuse), in which extensive treatment processes were

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described, but no limits were set for toxic compounds. In 2003, new legislation was enacted that considers the same water quality for three categories of reuse: irrigation of food and non-food crops; street cleaning; and industrial uses (Decree n. 185 2003). It does not distinguish between restricted irrigation, where generally lower quality water is used in conjunction with actions to limit exposure to people and/or animals, and unrestricted irrigation, which allows for fewer management actions when using higher quality water. The Italian decree does not permit vegetables irrigated with treated wastewater to be eaten raw under any circumstances. The Italian legislation was based on the Californian regulations and was considered to follow a 'risk averse' approach. It required the monitoring of a list of 54 chemical parameters, 37% of which were not considered for drinking water analysis. The high effort and cost required by this approach are often cited as a reason for the low number of active projects in a region with high water stress. Moreover, the limits fixed by the Italian regulations were very stringent for some parameters such as BOD_5 ($<$20 mg/L), total suspended solids ($<$10 mg/L) and *E. coli* ($<$10 cfu/100 mL) for 80% of samples (Licciardello *et al.* 2018).

Treated wastewater is used mainly for agricultural irrigation (Raso & Gutiérrez-San Miguel 2013). Around ten years ago, Italy reused around 10% of its treated wastewater (233 mm^3 each year) (Melgarejo *et al.* 2015). In 2022, 475 mm^3 was reused for agriculture (Utilitalia 2022).

3.2. Spain

The first water reuse projects in Spain began in the 1960s, mainly on the Costa Brava, the autonomous region of Murcia and the Balearic and Canary Islands, where the available water supplies could not meet the demand. Initially, there were no national regulations. A law requiring the development of quality limits for reclaimed waters was instituted in 1985; however, upon joining the European Union in 1986, Spain had to focus on meeting the EU water quality obligations. This eventually included the 1991 EU Directive 91/271/EEC concerning urban wastewater treatment (Jódar-Abellán *et al.* 2019).

The 1990s and 2000s saw continuing droughts and water shortages in some regions and increasing water demands from agriculture, industry and tourism. Spain saw large investments in various water supply augmentations: inter-basin water transport, desalination and water reuse (Paranychianakis *et al.* 2015). The south-east of Spain has one of the highest desalination and water reuse rates in the world in terms of production (m^3/day) (Jódar-Abellán *et al.* 2019). The autonomous region of Valencia reused approximately 40% of its treated wastewater (149 mm^3/year) and Murcia reused more than 70% or almost 100 mm^3 in 2016 (Ministerio para la Transición ecológica y el reto demográfico 2020). The Canary and Balearic Islands reused around 20 and 30%, respectively, in 2016 (Ministerio para la Transición ecológica y el reto demográfico 2020).

The Spanish Law 11/2005 again required quality criteria to be developed for water reuse. In 2007, the Royal Decree 1620 (2007) did just that, setting out the legal framework, including authorised and prohibited uses, as well as the quality conditions required for each use. The Spanish decree defines 14 different classes of water, each for specific end uses, including 5 classes for different irrigation uses: urban; agricultural irrigation; industrial; recreational; and environmental (Melgarejo *et al.* 2015). Fourteen additional quality parameters were required to be monitored for agricultural reuse than for other end uses; these were mainly heavy metals and metalloids. Although there were only 22 mandatory parameters identified in the regulation, aquifer recharge projects may also have additional water quality parameter limits imposed under the decree regulating discharge into the environment (Royal Decree 849 1986 (Spain); Royal Decree 1620 2007 (Spain)).

Spain reused around 10% of its annual treated wastewater volume, or 500 mm^3/year, in 2016 (Ministerio para la Transición ecológica y el reto demográfico 2020). Hochstrat *et al.* (2005) estimated in 2005 that the potential for water reuse in Spain could be around 1,300 mm^3. In 2008, there were around 140 active projects in Spain (Iglesias Esteban and Ortega de Miguel 2008). Mugdal *et al.* (2015) noted that according to government representatives, a key factor in the development of water reuse in Spain was the implementation of water reuse standards, but there have also been strong economic drivers due to high water stress.

3.3. France

In France, as in other places in Europe, crops have been irrigated with wastewater for centuries, harnessing the fertilising benefits. The practice was mostly observed around big cities, especially Paris, because, until 1940, it was the only method used to treat and dispose of wastewater (Angelakis *et al.* 2003). Its use decreased with efforts to improve public health and more intensive wastewater treatment technologies, but there was renewed interest in water reuse in the early 1990s due to the development of intensive irrigated farming, in particular in south-western France and the Paris region. Another

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reason was the impact of several droughts that saw a fall in the water tables, which affected the regions traditionally considered to be the wettest (western and north-western France) (Angelakis *et al.* 2003).

In 1991, France was amongst the first European countries to set criteria for water reuse. The criteria, mainly influenced by the WHO 1989 guidelines (World Health Organization 1989), included additional requirements such as irrigation method, timing, distance and other preventive measures (Paranychianakis *et al.* 2015). It focused on irrigation for agriculture and green spaces and included three classes of water quality, A, B and C, depending on the risks of the proposed project (Cerema 2020).

Following an update to the WHO guidelines in 2006 (World Health Organization 2006) and other advances around the world, France implemented a water reuse regulation in 2010, which was subsequently amended in 2014 and 2016. An additional class of water quality, D, was added as well as requirements for microbiological monitoring. Six microbiological and physico-chemical parameters were included as water quality limits (see Table 1 for the details of the different quality parameters). It also included restrictions relating to setback distances and wind speed for irrigation, soil water content, soil properties and irrigation method. Furthermore, it imposed limits on the quality of the treated sludge that was produced from a wastewater treatment plant, which determined whether the treated water could be authorised for reuse or not (Order n°0201 2010). Sewage sludge quality is monitored because it is considered to be a reliable indicator of the effectiveness of overall pathogen and hazardous substance removal (Mugdal *et al.* 2015). Further detail on these management restrictions was provided in an inter-ministerial instruction in 2016 (Interministerial Instruction DGS/EA4/DEB/DGPE/2016/135 2016).

Additionally, following the severe drought of 2022, calls came from many sectors of society for the government to act more rapidly to secure water supplies and improve water management. The President of France announced the Water Plan on 30 March 2023, which included the objective to ‘massively increase the recovery of non-conventional water (water reuse, rainwater, grey water, etc.) and develop 1,000 reuse projects across the country by 2027’ (Ministère de la Transition Ecologique et de la cohesion des territoires 2023).

In 2019, France reused less than 1% of its annual treated wastewater volume (around 10 mm^3) and there are estimated to be 128 active projects in France (OiEau 2019; Cerema 2020).

3.4. Portugal

Portugal joined the EU in 1986 and made efforts to provide a greater proportion of its population with access to water, wastewater collection and treatment services, particularly to align with the 1991 EU Directive 91/271/EEC. By 2000, it had several water reuse projects, including a tertiary treated irrigation project covering over 1,000 ha (Angelakis *et al.* 1999).

Portugal issued its water reuse regulation in 2019, which replaced its 2005 non-binding standard (NP 4434:2005) with the legal decree 119/2019 (Decree-Law No. 119 2019). The regulation uses a combined approach of parameter limits for different classes of water, as well as integrated risk assessment, based on the principles of the ISO 16075:2015 (Parts 1 and 2) and ISO 20426:2018; Decree-Law No. 119 2019 (Portugal) (Rebelo *et al.* 2020). The previous 2005 standard made reference to Decree number 236/98 regarding additional water quality parameter limits for irrigation water (Marecos do Monte 2008). These are no longer referenced in the new regulation which now identifies fewer additional parameters required for monitoring (Decree-Law No. 119 2019) (Portugal). This provides greater flexibility in project design, using a risk assessment approach and encouraging new projects.

An interesting comparison can be seen in the evolution of the Portuguese water quality limits from the 2005 standard to the current 2019 regulation (see Table 1). Where the old standard used faecal coliforms as the microbiological indicator species, the new regulation aligns with the trend of evidence promoting *E. coli* as a more reliable indicator of the microbial contamination of waters (Alcalde-Sanz & Gawlik 2014). This is also the indicator species used in the new 2020 EU Regulation and Portugal’s quality limits generally align well in comparison.

Portugal reused around 1% of its annual treated wastewater volume, or 8.1 mm^3/year in 2020 (AEPSA 2023).

3.5. Greece

In Greece, water shortages are often experienced due to temporal and regional variations of rain, high tourism and agriculture-related water demand during summer months and the difficulty of transporting water across the mountainous terrain (Angelakis *et al.* 2003).

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Table 1 | Maximum limit values according to the intended use for water quality parameters included in the evaluated water reuse standards

Analytical parameters	(i) **EU** Directive 91/271/EEC	**EU** Reg. 2020/741	(ii) **France** Order 0190 (2015)	**France** Order 0201 (2010)	(iii) **Portugal** NP4434:2005 Decree nº 236/98	**Portugal** Decree 119 (2019)	**Spain** R.Decree 1620 (2007)	**Greece** JMD 145116 (2011) This regulation does not identify the water quality classes with a label. The letters (b, c) are used for clarity.	**Italy** Decree 185 (2003)	**Cyprus** Regulation 379 (2015) This regulation does not identify the water quality classes with a label. The letters (a, b, c) are used for clarity. Limits under the Cypriot regulation only applied to urban wastewater treatment plants in agglomerations with a population equivalent of less than 2000.
Microbiological parameters										
- *E. coli* (cfu/100mL)		A : 10 B : 100 C : 1000 D : 10^4 A^v : ≥ 5 (log10 reduction)		A : 250 B : 10^4 C : 10^5 D : -		A : 10 B : 100 C : 1000 D : 10^4 E : 10^4	1.1 : 0 1.2 : 200 2.1 : 100 2.2 : 10^3 2.3 : 10^4 4.1 : 200	c : 200 (Restricted irrigation) b : 5 (Unrestricted irrigation)	10 (50 : lagoons)	
- Faecal coliforms (cfu/100mL)					A : 100 B : 200 C : 10^3 D : 10^4					a : 5 b : 50 c : 200
- Total coliforms (cfu/100mL)										
- Faecal enterococci (log reduction)				A : 4 B : 3 C : 2 D : 2						
- *Legionella sp.* (cfu/L)		< 1000 (risk of aerosols)				Specific legislation (Decree-law 52/2018) is applicable on this parameter (all irrigation waters when the water temperature in pipes rises above 20°C)	1.1 : 100 1.2 : 100 2.1 : 1000 2.2 : - 2.3 : 100 4.1 : 100			
- *Salmonella sp.*							absence		absence	
- *Clostridium perfringens* spores (log10 reduction) - Spore-forming sulfate-reducing bacteria (log10 reduction) -		A^v : ≥ 4 A^v : ≥ 5		A : 4 B : 3 C : 2 D : 2						
- Helminth eggs (Intestinal nematodes) (eggs/L)		<1 (irrigation of pastures or forage)			1	A : - B : - C : 1 D : 1 E : -	0.1			
- F-specific bacteriophages (log reduction)		A^v : ≥ 6		A : 4 B : 3 C : 2 D : 2						

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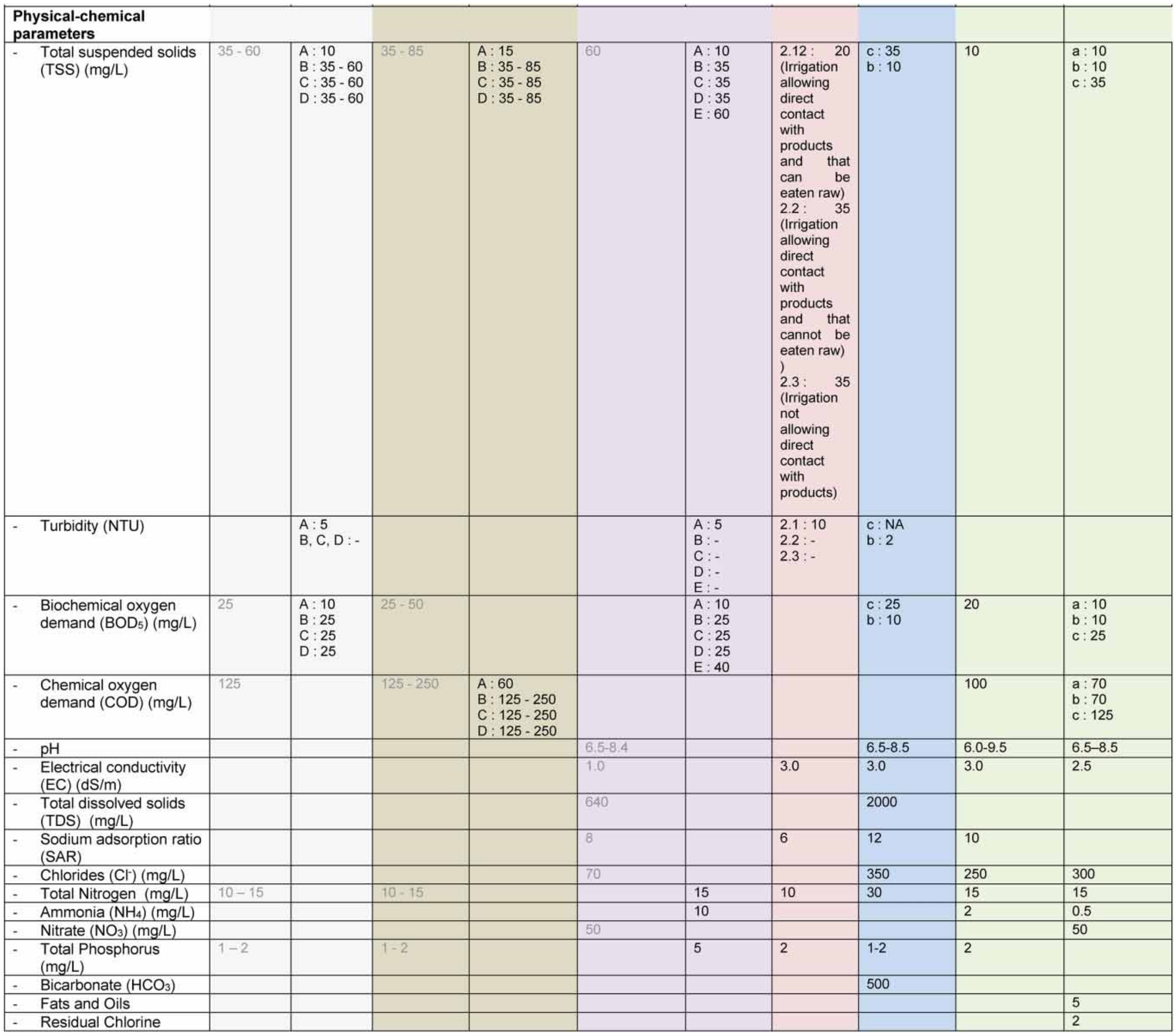
Table 1 | Continued



Physical-chemical parameters										
- Total suspended solids (TSS) (mg/L)	35 - 60	A : 10 B : 35 - 60 C : 35 - 60 D : 35 - 60	35 - 85	A : 15 B : 35 - 85 C : 35 - 85 D : 35 - 85	60	A : 10 B : 35 C : 35 D : 35 E : 60	2.12 : 20 (Irrigation allowing direct contact with products and that can be eaten raw) 2.2 : 35 (Irrigation allowing direct contact with products and that cannot be eaten raw) 2.3 : 35 (Irrigation not allowing direct contact with products)	c : 35 b : 10	10	a : 10 b : 10 c : 35
- Turbidity (NTU)		A : 5 B, C, D : -				A : 5 B : - C : - D : - E : -	2.1 : 10 2.2 : - 2.3 : -	c : NA b : 2		
- Biochemical oxygen demand (BOD_5) (mg/L)	25	A : 10 B : 25 C : 25 D : 25	25 - 50			A : 10 B : 25 C : 25 D : 25 E : 40		c : 25 b : 10	20	a : 10 b : 10 c : 25
- Chemical oxygen demand (COD) (mg/L)	125		125 - 250	A : 60 B : 125 - 250 C : 125 - 250 D : 125 - 250					100	a : 70 b : 70 c : 125
- pH					6.5-8.4			6.5-8.5	6.0-9.5	6.5–8.5
- Electrical conductivity (EC) (dS/m)					1.0		3.0	3.0	3.0	2.5
- Total dissolved solids (TDS) (mg/L)					640			2000		
- Sodium adsorption ratio (SAR)					8		6	12	10	
- Chlorides (Cl^-) (mg/L)					70			350	250	300
- Total Nitrogen (mg/L)	10 – 15		10 - 15			15	10	30	15	15
- Ammonia (NH_4) (mg/L)						10			2	0.5
- Nitrate (NO_3) (mg/L)					50					50
- Total Phosphorus (mg/L)	1 – 2		1 - 2			5	2	1-2	2	
- Bicarbonate (HCO_3)								500		
- Fats and Oils										5
- Residual Chlorine										2

Column titles written in black are former national water reuse standards and column titles written in grey are: (i) for EU Directive 91/271/EEC: the quality standards for the European Directive on urban wastewater treatment; (ii) for Order n°0190 (2015): the quality standards on collective sanitation systems and non-collective sanitation facilities; and (iii) for Portugal NP4434:2005 Decree n° 236/98: non-binding standard that included quality objectives for wastewater treatment and reuse.

Av : Validation monitoring limit only; not for ongoing monitoring. Only applies to Class A water.

Adapted from Table 12, Alcalde-Sanz and Gawlik (2014)

Additional input: Council Directive 91/271/EEC (1991); Decree n. 185 (2003) (Italy); Royal Decree 1620 (2007) (Spain); Order n°0201 (2010) (France); Joint Ministerial Decision No.145116 (2011) (Greece); Ilias *et al.* (2014); Bourazanis & Kerkides (2015); Melgarejo *et al.* (2015); Order n°0190 (2015) (France); Paranychianakis *et al.* (2015); Water Pollution Control (Discharge of Urban Waste Water) Regulations, P.I. 379/2015 (2015) (Cyprus); Gatta *et al.* (2018); Licciardello *et al.* (2018); Decree-Law No. 119 (2019) (Portugal); Regulation (EU) 741 (2020)

The Hellenic Union of Water Supply and Sewerage Services Association (E.D.E.Y.A.) completed a study of treated wastewater quality criteria in 2000, which was mainly influenced by the 1989 WHO guidelines (World Health Organization 1989). This study was updated in 2009 to consider the updated scientific standards suggested by the revised 2006 WHO (World Health Organization 2006) and Australian guidelines for water recycling (2006). However, these criteria were not subsequently adopted by Greek authorities (Ilias *et al.* 2014). A Ministerial Decision for water reuse was ultimately established in Greece in 2011 (Joint Ministerial Decision No.145116 2011 (Greece)), which defined treatment processes, water quality limits and, in some applications, additional measures to protect consumers, workers, public health and the environment (Petousi *et al.* 2015). This Decision was modified in 2013 (Amendment of Joint Ministerial Decision No.145116/2011 2013).

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The Greek regulation contained different microbiological limits and indicator organisms for unrestricted irrigation and restricted irrigation. In the Greek regulation, unrestricted irrigation referred to irrigation for all types of crops that are consumed raw and floriculture. These uses require the highest water quality and public access was allowed in the irrigation area. Restricted irrigation was reserved for non-edible crops, crops not in contact with the soil or crops eaten after an appropriate process. The regulation allowed a lower quality for this use (Table 1) and public access was not allowed, nor was sprinkler irrigation. Restricted and unrestricted irrigation required similar treatment requirements (advanced) and exactly the same disinfection requirements for each end use (the only difference was that in unrestricted irrigation, there was an additional tertiary treatment). This approach has been criticised as lacking a coherent technical rationale (Paranychianakis *et al.* 2015).

Additionally, the Greek regulation required strict monitoring of 19 metals and metalloids and 40 priority substances of concern (Joint Ministerial Decision No.145116 2011 (Greece)), which was seen as inhibiting the implementation of treated wastewater projects (Paranychianakis *et al.* 2015). A feasibility study and a detailed monitoring plan also had to be provided before project implementation (Prochaska & Zouboulis 2022).

Greece reused around 23 mm^3 of treated wastewater before 2016 (Kirhensteine *et al.* 2016). Only 13% of the urban treated wastewater was reused at this date, mainly because of the distance between treatment plants in the country and agricultural fields to irrigation (Prochaska & Zouboulis 2022). Indeed, these authors highlighted the fact that townships with less than 2,000 inhabitants were not obliged to connect to sewerage networks. According to Hochstrat *et al.* (2005), there was an estimated potential for 57 mm^3 of reuse by 2025.

3.6. Cyprus

Cyprus is the third largest island of the EU in the Mediterranean Sea with a dry climate, frequent droughts and an economy heavily influenced by tourism. Towards the end of the 20th century, the island saw an increase in groundwater extraction along with increasing risks of seawater intrusion into the groundwater (Lazarova *et al.* 2013). Like the other countries mentioned above, Cyprus invested in urban wastewater treatment facilities to comply with European Directive 91/271/EEC, but also to encourage the reuse of treated wastewater for certain uses in order to manage increasing demands in a dry climate. These uses are principally for agricultural and landscape irrigation, golf courses, hotel green spaces, aquifer recharge for agricultural irrigation and saline intrusion protection (Raso & Gutiérrez-San Miguel 2013). The use of reclaimed water is widely accepted and considered to be an environmentally acceptable solution to the water deficits experienced on the island (Water Pollution Control (Code of Good Agricultural Practice) Order (P.I. 263/2007) 2007; Lazarova *et al.* 2013).

Another driver for improving wastewater treatment in Cyprus was to achieve conformity with the water quality guideline values set by the Bathing Water Directive 2006/7/EC, as many of its beaches are used for bathing by tourists (Lazarova *et al.* 2013).

The main legal instrument pertaining to water reuse was State Law N.106(I)/2002 concerning 'The Control of Water Pollution' and its associated regulations (KDP 772/2003, KDP 379/2015). Cyprus first defined a list of water quality parameter limits in 2005 for water reuse from urban wastewater treatment plants in agglomerations with a population equivalent of less than 2,000. This Regulation 269/2005 was replaced in 2015 by Regulation 379/2015 with some minor changes. The list included nine physico-chemical parameters, one microbiological parameter (*E. coli*) and three different quality classes relating to five different identified uses. If treated wastewater is used to recharge aquifers through infiltration basins –a common practice for later withdrawal and reuse– then a second list of water quality parameters is enforced. This includes the same parameters from the previous list, as well as 12 additional physico-chemical parameters.

The Cypriot approach is somewhat similar to the French regulation, as it also had additional, but less restrictive, management requirements for water reuse projects. These management requirements were identified in Regulation 263/2007 and included the specification of appropriate irrigation equipment permitted for certain uses, access limitations and waiting periods prior to access or harvesting.

No general list of water quality parameter limits could be identified for agglomerations with a population equivalent of 2,000 or more. It is assumed that projects in large agglomerations were authorised on a case-by-case basis. For the purposes of comparison, the limits identified in Regulation 379/2015 mentioned above were used in this article. These limits included three different quality classes; however, they were identified by uses and not by a letter or number.

Nearly 100% of treated wastewater in Cyprus is reused each year. This is a result of it being a necessity in a dry climate, as well as strong pollution abatement regulations and actions to improve wastewater treatment, and also price subsidies from the government (reclaimed water is less than half the price of freshwater) making projects attractive and sustainable (Mugdal *et al.* 2015). In 2015, this amounted to 30.05 mm^3 of water reused (Gancheva *et al.* 2018).

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In summary, different countries have legislated water reuse following different international standards. France followed the Australian guidelines and the revised WHO Guidelines, Italy and Greece were inspired by California's regulation, while Cyprus and Spain followed a combination of the Californian State Regulation, Australian guidelines and WHO (Prochaska & Zouboulis 2022). Portugal's 2019 regulation more closely aligns with ISO 16075 (parts 1 and 2) and ISO 20426:2018.

4. EU REGULATION 2020 AND COMPARISON OF STANDARDS

4.1. EU Regulation 2020

The European regulation on minimum quality requirements (MQR) for water reuse (Regulation (EU) 741 2020) was published in May 2020 and details the minimal requirements for water reuse for agricultural irrigation (and forestry), including food crops and non-food crops (pastures ad forage, energy crops, fibre and ornamental crops. It does not, at this time, address other uses, such as landscape irrigation (parks, gardens and sports fields), or industrial reuse, although it is mentioned that the member states may use it without prejudice to 'other relevant Union law'. The regulation came into effect on 26 June 2023. The new regulation builds on two EU instruments containing provisions that encourage water reuse: the Water Framework Directive 2000/60/EC and the Urban Waste Water Treatment Directive 91/271/EEC (Gancheva *et al.* 2018).

The approach taken is closely aligned with ISO 16075 (parts 1 and 2). It includes four classes of water with different quality criteria for different end uses (according to agricultural use and irrigation method) (Truchado *et al.* 2021a). The regulation places limits on the following quality parameters: *E. coli*, BOD_5 and TSS. Agriculture use of reclaimed water requires at least secondary treatment and disinfection (for class A, an additional filtration is required and turbidity is imposed as a quality parameter). Monitoring frequencies for *E. coli* are fixed once a week for classes A and B and twice a month for classes C and D. Additionally, it details treatment validation monitoring protocols for Class A water uses. These require wastewater treatment to provide $\log_{10}$ reduction performance for indicator bacteria, viruses and protozoa. The indicator microorganisms that were chosen were *E. coli* for pathogenic bacteria, F-specific coliphages, somatic coliphages or coliphages for pathogenic viruses and *Clostridium perfringens* spores or spore-forming sulphate-reducing bacteria for protozoa (respectively $\geq 5 \log_{10}$ reduction for E. coli, $\geq 6 \log_{10}$ reduction for coliphages and ≥ 4 for *Clostridium perfringens* spores or ≥ 5 for spore-forming sulphate-reducing bacteria). Water reclamation facilities that already met the water quality requirements in the regulation on 25 June 2020 will be exempted from the validation monitoring obligation (Regulation (EU) 741 2020).

The regulation also briefly outlines the risk assessment approach to be taken in the development and consideration of any project, by demanding an identification of hazards and risks associated with the project and describing potential supplemental barriers in the reuse system. Similar to the Portuguese regulation, this includes reference to existing international risk assessment and risk management plan approaches, including ISO 20426:2018, ISO 16075:2015 and the WHO guidelines. The risk management plan encompasses distribution, storage and use. When setting the conditions of use for the end-user, the relevant EU food and feed hygiene legislation must be considered. A permit for the production and supply of reclaimed water is needed, and this permit ensures that the water quality reaches minimal quality requirements at the point of delivery. Compliance should be assessed regularly by competent authorities. Penalties need to be developed in all member states if the conditions described in the permit are not met. Careful consideration should be given to transparency through the provision of clear and complete data to the general public.

Guidelines to support the application of the new regulation were issued in August 2022, as required by the 2020 regulation (Commission Notice 2022/C 298/01 2022). This notice presents elements for carrying out the risk management plan. It includes suggested barriers needed for irrigation with reclaimed water, depending on water quality (from ISO 16075:2020), as well as the types of accredited barriers and pathogen log reductions according to these barriers. The reference to these barriers is possible when the quality for a specific end use is not met at the compliance point (subject to justification in the risk management plan). They further develop the requirements of the permitting process as well as the risk assessment and management processes. It encourages the use of a risk framework described in the Joint Research Centre (JRC) technical report 'Technical Guidance – Water Reuse Risk Management for Agricultural Irrigation Schemes in Europe' (Maffettone & Gawlik 2022). The JRC report proposes the identification of 11 key elements of risk management (KRMs), which are structured into four modules: I Preparation; II Risk Assessment; III Monitoring; and IV Governance, Management and Communication. The guidelines suggest that qualitative risk assessments are generally the most suitable given common data availability, time and cost constraints. However, it also provides guidance for semi-quantitative and quantitative risk assessment methods and directs the reader to further resources including the 2006 WHO Guidelines (World Health

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Organization 2006) and ISO 20426 (Guidelines for health risk assessment and management for non-potable water reuse). The risk assessment in Maffettone & Gawlik (2022) explicitly includes a reference to metals and organic pollutants and reminds us that the minimum thresholds of any relevant regulations (e.g. EQS Directive 2013/39/EU) must be respected. The report specifies that non-regulated pollutants must be evaluated on a case-by-case basis.

4.2. Comparison of quality parameters

There are large disparities in the number of parameters associated with limit values between countries. In France, 6 water quality parameters are defined in the regulation, compared with up to 22 in Spain and Cyprus, up to 53 in Italy and up to 76 in Greece. Portugal's legislation includes 21 quality parameters, but as this legislation proposes a fit-for-purpose approach, the risk assessment determines how many parameters need to be considered. The EU Regulation also proposes this fit-for-purpose approach, and any modifications to the number of control parameters must be explained in the risk management plan. Monitoring costs could therefore become significant and prohibitive for water reuse projects in Italy, Spain, France and Greece (Decree n. 185 2003 (Italy); Royal Decree 1620 2007 (Spain); Order n°0201 2010 (France); Joint Ministerial Decision No.145116 2011 (Greece); Mugdal *et al.* 2015). Some water quality parameter limit values vary by orders of magnitude between the national regulations (Table 1). Certain water quality parameters important in water reuse projects were not included directly in the EU Regulation, as they already appear in Directive 91/271/EEC for Urban Waste Water Treatment (e.g. BOD_5 and TSS for classes B, C and D). The EU Regulation also sets out validation monitoring for any new project to ensure it meets certain reductions in pathogen loading (Regulation (EU) 741 2020). Similarly, France's ministerial order of 2010 (Order n°0201 2010) that defines reclaimed water quality limits refers to a more general wastewater treatment ministerial order of 2015 (Order n°0190 2015) for some parameters. Hence, these two references are shown separately in Table 1 for comparison. The parameters identified in the EU Regulation and the 1991 EU Directive can also be seen in Table 1. The most recent European national regulations put into place were in Portugal in 2019. Table 1 shows the evolution of the limit values between the previous national non-binding standard (NP 4434:2005) and the newer Law decree n.° 119/2019.

Table 1 also presents a comparison of the different classes by each country and their corresponding parameter limit values. Although the classes are not completely comparable in the different countries, as each country defines its classes and end uses differently, it provides an appreciation for the variation that existed prior to the EU Regulation. A fuller description of these class categories is provided in the following section. Note that not all water quality parameters for each country are presented. It shows only a selection of the most common water quality parameters used in each country's regulation and those that are relevant to the EU Regulation. Additional water quality parameters for each country are presented in Annex 1.

4.3. Comparison of classes

Table 2 provides a comparison of how each country and the 2020 EU Regulation categorises different water quality levels intended for various end uses, with the *E. coli* limit provided in parentheses. Greece defined 3 principal quality classes, France and the EU identified 4 each, Portugal used 5 and Spain 14. However, not all of these classes defined by the countries relate solely to agricultural uses, which is the case for the EU Regulation. Hence, not all of the classes are shown in Table 2, only those relevant to irrigation uses. Figure 1 presents the same information for a selection of four of the uses in a chart format for easier comprehension.

Considering the quality parameter limits from Table 1, Portugal's classification is the most similar to the 2020 EU Regulation. A major difference stands in the presence of quality E, which applies to non-centralized systems (domestic, industrial). The EU quality limit for *E. coli* for irrigation of crops eaten raw allowing contact of water with the edible part is stricter (10 cfu/100 mL) than for France (250 cfu/100 mL) and Spain (100 cfu/100 mL). This indicates that these countries will need to amend their current regulation to match the EU ones. The EU Regulation differentiates between irrigation of crops eaten raw with and without water contact to the edible part; however, France, Spain and Greece do not.

In general, compared to the country regulations, the EU Regulation is more detailed in its identification of irrigation practices that allow lower-quality water to be used for a greater variety of end uses. This is demonstrated in allowing class B or C to be used for irrigation of pastures and fruit trees depending on the irrigation method employed.

5. CASE STUDIES

After studying the differences between quality parameters and classes between countries and with the 2020 EU Regulation, five existing projects within Europe are now considered in order to assess their current degree of compliance with the EU

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Table 2 | Intended uses for water reuse included in the standards of the 2020 EU Regulation and of the Member States

Intended use of reclaimed water	EU	France	Portugal	Spain	Greece[a]	Italy[b]	Cyprus[c]
Irrigation of crops eaten raw, contact with water permitted	**A** (10)	**A** (250)	**A** (10)	**2.1** (100)	**b** (5)	✗	**a** (5)[d]
Irrigation of crops eaten raw, no contact with water	**B** (100)	**A** (250)	**B** (100)	**2.1** (100)	**b** (5)	✗	–
Irrigation of crops not eaten raw	**B** (100)	**B** (10^4)	**B** (100)	**2.2** (10^3)	**c** (200)	✓ (10)	**b** (50)
Irrigation of pastures for milk or meat producing animals	**B, C**[e] (10^3, 10^4)	**B** (10^4)	**B, C**[e] (10^3, 10^4)	**2.2** (10^3)	**c** (200)	✓ (10)	–
Irrigation of trees without contact of reclaimed water with fruit for human consumption	**B, C**[e] (10^3, 10^4)	**C** (10^5)	**B, C**[e] (10^3, 10^4)	**2.3** (10^4)	**b** (5)	✓ (10)	–
Irrigation of ornamental flowers without contact of reclaimed water with the product	–	**C** (10^5)	–	**2.3** (10^4)	—	✓ (10)	–
Irrigation of industrial non-food crops, fodder, cereals	**D** (10^4)	**C** (10^5)	**D** (10^4)	**2.3** (10^4)	**c** (200)	✓ (10)	**c** (200)

Note: The figures in parentheses indicate the *E. coli* limit (cfu/100 mL) for that class, except for class a in Greece, which is total coliforms (table created by the authors).

[a] No identifiers were given in the Greek legislation for classes. The letters used were defined by the authors: (b) unrestricted irrigation, (c) restricted irrigation.

[b] Italy allowed an *E. coli* limit of 50 cfu/100 mL for treatments using lagoons and phyto-purification.

[c] No identifiers are given in the Cypriot legislation for classes. The letters used are defined by the authors: (a) All crops and green spaces with free use, (b) cooked vegetables, (c) products for human consumption, green spaces with limited use by the public, fodder plants and industrial crops.

[d] Irrigation forbidden for leafy vegetables, bulbs and tubers eaten raw.

[e] Class B could be used for all irrigation methods; class C water may be used with drip irrigation or another irrigation method that avoided direct contact with the edible part of the crop.

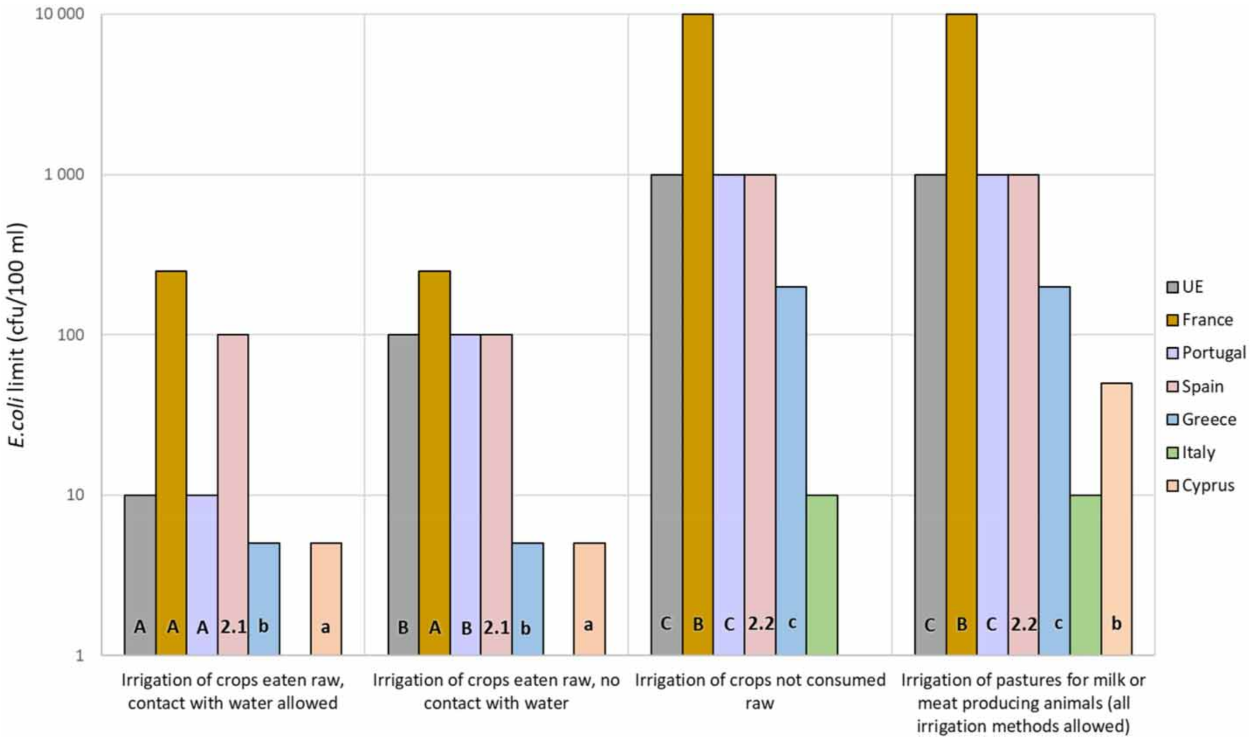

Figure 1 | Selection of intended uses for water reuse included in the EU 2020 Regulation and former Member States' standards.

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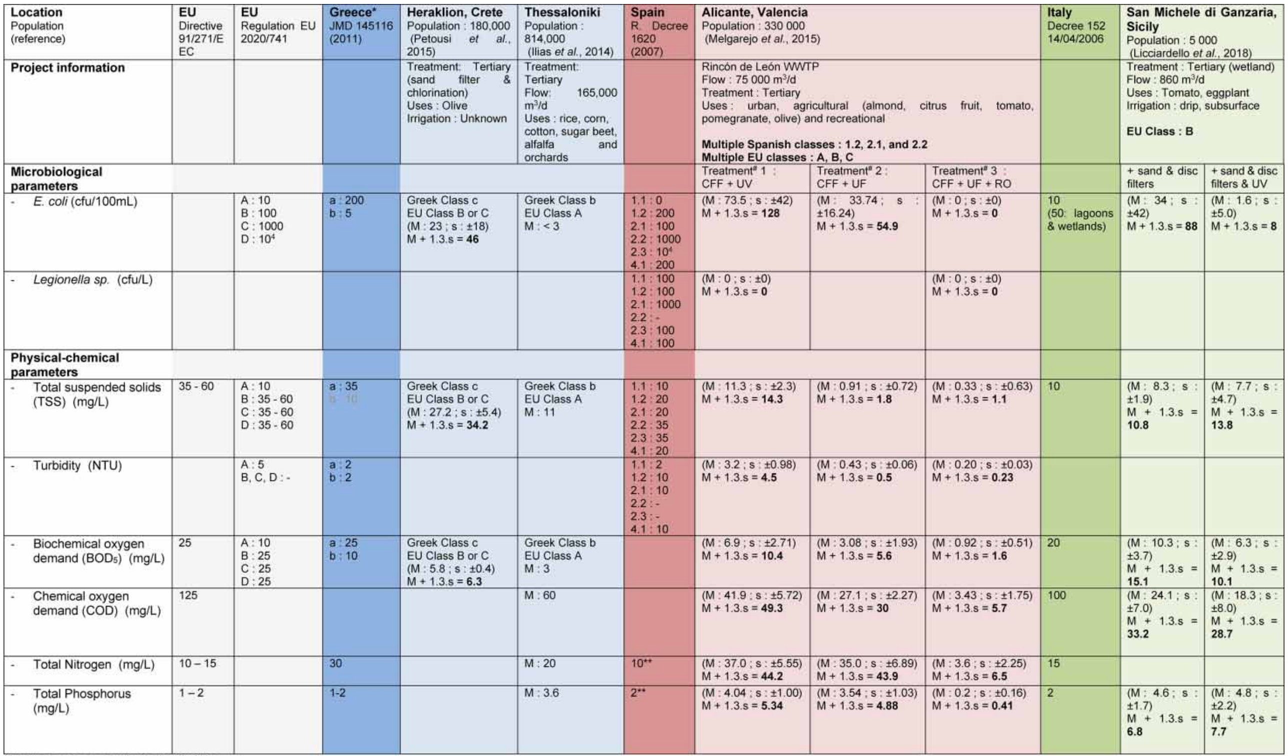
Regulation (and therefore assessing the needed degree of adaptation to comply with its standards). They include two projects from Greece and one each from Italy, Spain and France. The projects were chosen based on the relevance of the end use (agricultural irrigation) and the availability of data for multiple relevant water quality parameters. There are a variety of sizes of treatment plants, from San Michele di Ganzaria in Sicily, Italy, with a population of around 5,000 inhabitants and an average daily treatment plant inflow of 455 m^3/d, to Thessaloniki in Greece where the treatment plant services a population of around 814,000 people and with an average daily flow of 165,000 m^3/d. The basic details of each project, including location, size, treatment type, end uses and irrigation method, are provided in the first three rows of Table 3. The water quality data available from each study included the mean value (M) and the standard deviation (s) of the samples tested. For Greece and Italy, 80% of the tested samples during a given period must be under the limit value identified in their respective regulations. For Spain, this value is 90%, which is in line with the EU Regulation.

In order to provide an indication of compliance with the EU Regulation, it was necessary to transform the mean and standard deviation water quality data to estimate the value where compliance reaches 90% of the samples. With no access to the raw data, nor any advanced statistical measures (skewness, kurtosis) of the datasets, it was decided to assume a normal distribution for each dataset. Given this assumption, approximately 90% of the samples of a normal distribution fall 1.3 standard deviations from the mean. Therefore, this value (the mean + 1.3 standard deviations) of each dataset was used to compare to the EU Regulation (see the values 'M + 1.3s' in bold in Table 3). For the Thessaloniki project in Greece and the Noirmoutier project in France, only the mean values were provided. Hence, this calculation was not performed for these two case studies; therefore, the values presented in the table cannot be directly compared to the EU Regulation values.

The Heraklion project in Crete (Greece) was considered as 'restricted irrigation' (Greek class c) and EU class B or C depending on the irrigation method (unknown). Based on the data provided by Petousi *et al.* (2015), the project would comply with the EU Regulation, as well as comply with the Greek regulation. The data provided for the project in

Table 3 | Case studies comparing water quality of active reuse projects to country and EU Regulations



Location Population (reference)	**EU** Directive 91/271/EEC	**EU** Regulation EU 2020/741	**Greece*** JMD 145116 (2011)	**Heraklion, Crete** Population : 180,000 (Petousi *et al.*, 2015)	**Thessaloniki** Population : 814,000 (Ilias *et al.*, 2014)	**Spain** R. Decree 1620 (2007)	**Alicante, Valencia** Population : 330 000 (Melgarejo *et al.*, 2015)			**Italy** Decree 152 14/04/2006	**San Michele di Ganzaria, Sicily** Population : 5 000 (Licciardello *et al.*, 2018)	
Project information				Treatment: Tertiary (sand filter & chlorination) Uses : Olive Irrigation : Unknown	Treatment: Tertiary Flow: 165,000 m^3/d Uses : rice, corn, cotton, sugar beet, alfalfa and orchards		Rincón de León WWTP Flow : 75 000 m^3/d Treatment : Tertiary Uses : urban, agricultural (almond, citrus fruit, tomato, pomegranate, olive) and recreational **Multiple Spanish classes : 1.2, 2.1, and 2.2** **Multiple EU classes : A, B, C**				Treatment : Tertiary (wetland) Flow : 860 m^3/d Uses : Tomato, eggplant Irrigation : drip, subsurface **EU Class : B**	
Microbiological parameters							Treatment# 1 : CFF + UV	Treatment# 2 : CFF + UF	Treatment# 3 : CFF + UF + RO		+ sand & disc filters	+ sand & disc filters & UV
- *E. coli* (cfu/100mL)		A : 10 B : 100 C : 1000 D : 10^4	a : 200 b : 5	Greek Class c EU Class B or C (M : 23 ; s : ±18) M + 1.3.s = **46**	Greek Class b EU Class A M : < 3	1.1 : 0 1.2 : 200 2.1 : 100 2.2 : 1000 2.3 : 10^4 4.1 : 200	(M : 73.5 ; s : ±42) M + 1.3.s = **128**	(M : 33.74 ; s : ±16.24) M + 1.3.s = **54.9**	(M : 0 ; s : ±0) M + 1.3.s = **0**	10 (50: lagoons & wetlands)	(M : 34 ; s : ±42) M + 1.3.s = **88**	(M : 1.6 ; s : ±5.0) M + 1.3.s = **8**
- *Legionella sp.* (cfu/L)						1.1 : 100 1.2 : 100 2.1 : 1000 2.2 : - 2.3 : 100 4.1 : 100	(M : 0 ; s : ±0) M + 1.3.s = **0**		(M : 0 ; s : ±0) M + 1.3.s = **0**			
Physical-chemical parameters												
- Total suspended solids (TSS) (mg/L)	35 - 60	A : 10 B : 35 - 60 C : 35 - 60 D : 35 - 60	a : 35 b : 10	Greek Class c EU Class B or C (M : 27.2 ; s : ±5.4) M + 1.3.s = **34.2**	Greek Class b EU Class A M : 11	1.1 : 10 1.2 : 20 2.1 : 20 2.2 : 35 2.3 : 35 4.1 : 20	(M : 11.3 ; s : ±2.3) M + 1.3.s = **14.3**	(M : 0.91 ; s : ±0.72) M + 1.3.s = **1.8**	(M : 0.33 ; s : ±0.63) M + 1.3.s = **1.1**	10	(M : 8.3 ; s : ±1.9) M + 1.3.s = **10.8**	(M : 7.7 ; s : ±4.7) M + 1.3.s = **13.8**
- Turbidity (NTU)		A : 5 B, C, D : -	a : 2 b : 2			1.1 : 2 1.2 : 10 2.1 : 10 2.2 : - 2.3 : - 4.1 : 10	(M : 3.2 ; s : ±0.98) M + 1.3.s = **4.5**	(M : 0.43 ; s : ±0.06) M + 1.3.s = **0.5**	(M : 0.20 ; s : ±0.03) M + 1.3.s = **0.23**			
- Biochemical oxygen demand (BOD_5) (mg/L)	25	A : 10 B : 25 C : 25 D : 25	a : 25 b : 10	Greek Class c EU Class B or C (M : 5.8 ; s : ±0.4) M + 1.3.s = **6.3**	Greek Class b EU Class A M : 3		(M : 6.9 ; s : ±2.71) M + 1.3.s = **10.4**	(M : 3.08 ; s : ±1.93) M + 1.3.s = **5.6**	(M : 0.92 ; s : ±0.51) M + 1.3.s = **1.6**	20	(M : 10.3 ; s : ±3.7) M + 1.3.s = **15.1**	(M : 6.3 ; s : ±2.9) M + 1.3.s = **10.1**
- Chemical oxygen demand (COD) (mg/L)	125				M : 60		(M : 41.9 ; s : ±5.72) M + 1.3.s = **49.3**	(M : 27.1 ; s : ±2.27) M + 1.3.s = **30**	(M : 3.43 ; s : ±1.75) M + 1.3.s = **5.7**	100	(M : 24.1 ; s : ±7.0) M + 1.3.s = **33.2**	(M : 18.3 ; s : ±8.0) M + 1.3.s = **28.7**
- Total Nitrogen (mg/L)	10 – 15		30		M : 20	10**	(M : 37.0 ; s : ±5.55) M + 1.3.s = **44.2**	(M : 35.0 ; s : ±6.89) M + 1.3.s = **43.9**	(M : 3.6 ; s : ±2.25) M + 1.3.s = **6.5**	15		
- Total Phosphorus (mg/L)	1 – 2		1-2		M : 3.6	2**	(M : 4.04 ; s : ±1.00) M + 1.3.s = **5.34**	(M : 3.54 ; s : ±1.03) M + 1.3.s = **4.88**	(M : 0.2 ; s : ±0.16) M + 1.3.s = **0.41**	2	(M : 4.6 ; s : ±1.7) M + 1.3.s = **6.8**	(M : 4.8 ; s : ±2.2) M + 1.3.s = **7.7**

M : sample mean ; s : sample standard deviation
Note 1: The numbers shown in **bold** for each reuse project are the result of the calculation explained in the text above this table. These are the numbers to be compared to the EU regulation limits.
Note 2: The classes identified for each project in the table are those that are required according to the end uses identified by the sources, not according to the quality of the water.
CFF = coagulation, flocculation, and filtration ; UV = ultra-violet treatment ; UF = ultra-filtration ; RO = reverse osmosis
* : The Greek regulation does not identify its water quality classes with a label. The letters (a, b) used in the table are used by the authors for clarity.

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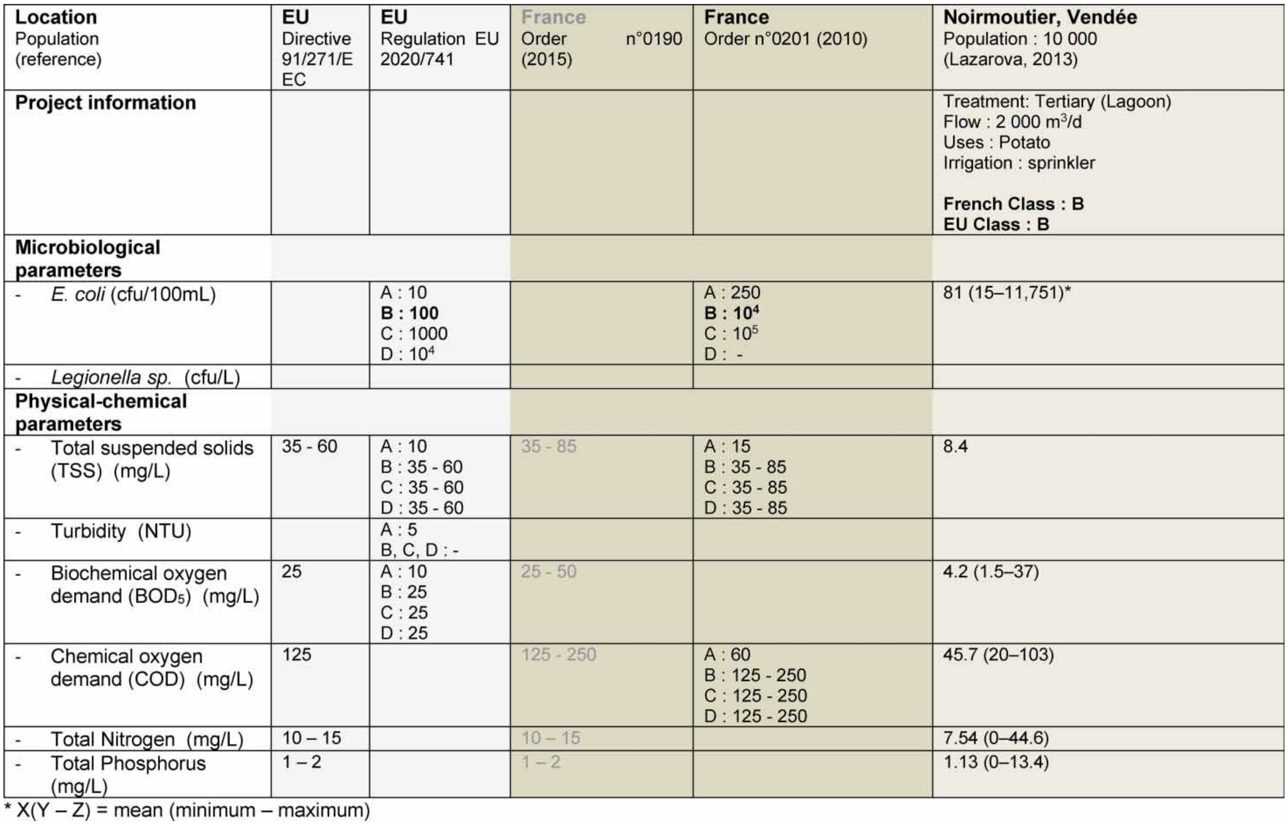
Table 4 | Case studies comparing water quality of active reuse projects to country and EU regulations



Location Population (reference)	**EU** Directive 91/271/EEC	**EU** Regulation EU 2020/741	France Order n°0190 (2015)	**France** Order n°0201 (2010)	**Noirmoutier, Vendée** Population : 10 000 (Lazarova, 2013)
Project information					Treatment: Tertiary (Lagoon) Flow : 2 000 m^3/d Uses : Potato Irrigation : sprinkler **French Class : B** **EU Class : B**
Microbiological parameters					
- *E. coli* (cfu/100mL)		A : 10 **B : 100** C : 1000 D : 10^4		A : 250 **B : 10^4** C : 10^5 D : -	81 (15–11,751)*
- *Legionella sp.* (cfu/L)					
Physical-chemical parameters					
- Total suspended solids (TSS) (mg/L)	35 - 60	A : 10 B : 35 - 60 C : 35 - 60 D : 35 - 60	35 - 85	A : 15 B : 35 - 85 C : 35 - 85 D : 35 - 85	8.4
- Turbidity (NTU)		A : 5 B, C, D : -			
- Biochemical oxygen demand (BOD_5) (mg/L)	25	A : 10 B : 25 C : 25 D : 25	25 - 50		4.2 (1.5–37)
- Chemical oxygen demand (COD) (mg/L)	125		125 - 250	A : 60 B : 125 - 250 C : 125 - 250 D : 125 - 250	45.7 (20–103)
- Total Nitrogen (mg/L)	10 – 15		10 – 15		7.54 (0–44.6)
- Total Phosphorus (mg/L)	1 – 2		1 – 2		1.13 (0–13.4)

* X(Y – Z) = mean (minimum – maximum)

Thessaloniki (Greece) indicate that the project may have some difficulties meeting the EU Regulation for suspended solids requirement for class A.

The Alicante project in Valencia (Spain) provides an opportunity to compare three treatments. The base treatment consists of coagulation, flocculation and filtration. This process is supplemented by UV disinfection, ultrafiltration or ultrafiltration plus reverse osmosis. Each subsequent treatment train improves in treatment performance with the reverse osmosis train achieving very low levels of contaminants as expected.

The San Michele di Ganzaria project in Sicily (Italy) uses a wetland lagoon secondary treatment followed by either sand and disk filters, or sand and disk filters and UV disinfection. Again, this treatment train conforms with EU class B and Italian regulations, given the data provided.

Finally, the project on the island of Noirmoutier in the Vendée region of France uses activated sludge treatment and secondary clarification, followed by lagoon treatment which also acts as storage. There is currently no chemical or physical disinfection treatment. The microbiological data available for *E. coli* indicates that the project meets the French class B requirements (a limit of 10,000 cfu/100 mL). However, it is unclear if the project could consistently meet the EU class B requirement of 100 cfu/100 mL. More data would be needed to establish conformity or non-conformity.

6. DISCUSSION

The historical inconsistency of regulations across the EU, the slow development of reuse projects in some countries that could benefit greatly from it in the face of a changing climate, and the risks of cross-border trade disputes all pointed to the need for regulation harmonisation. Given the requirement for countries to conform their regulations with the 2020 EU Regulation, these problems are expected to be ameliorated in the years to come. At the EU level, it is thought this common regulation will accelerate the implementation of treated wastewater in agriculture, as underlined by Shoushtarian & Negahban-Azar

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(2020), and help to reach the objective of 6.6 billion m^3 reused annually in the agricultural sector (Proposal for a Regulation COM 337 2018/0169/COD 2018) (for comparison, in 2018 around 1.7 billion m^3 of water was reused). Although the new regulation may encourage the uptake of water reuse to some extent, it is likely that the objectives will not be fully met due to the obstacles listed below.

6.1. Challenges associated with the adoption of the EU Regulation at the level of countries

National regulations in Greece, Italy, Spain and Cyprus required the monitoring of a great number of parameters compared to the EU Regulation (Gancheva *et al.* 2018). Italy published a draft Presidential Decree in March 2023 that would bring its regulation in line with the EU Regulation (MASE, the Presidential Decree on the reuse of purified & refined urban waste (2023) (Italy)). Contrary to its current regulation, the proposed draft regulation differentiates between different quality classes based on crop types. A list of 81 persistent pollutants, mainly from the existing regulation, is included as a minimum list to be considered in risk assessment and control requirements. The requirement to undertake ongoing monitoring of these pollutants for all projects has been removed. In Italy, it is unclear whether the administrative treatment of this type of risk assessment will allow for the implementation of more water reuse projects than is currently the case.

As of June 2023, Greece had not publicly communicated that any activity was underway to update its water reuse regulation. Should Greece decide to relax its current regulation, it is expected to face a significant challenge, like that of Italy, in modifying its regulatory framework to conform with that of the EU. Greece explicitly mentioned many pollutants in its water reuse regulation (heavy metals, organic contaminants, etc.). These high water quality limits led until now to significant costs for water quality monitoring that will likely be alleviated by aligning with the new regulation. If Greece were to modify its existing regulations to more closely resemble the EU Regulation, it may encourage the implementation of additional projects. However, given that the EU Regulation provides minimum requirements, it is understood that countries may choose to maintain parts of their existing regulations as long as they are as strict as or stricter than the EU Regulation. It's not clear how Greece will choose to modify its regulations. Greece also faces the challenge of the distance between major wastewater treatment plants and potential water reuse locations, as currently there is no formal obligation to connect townships with less than 2000 inhabitants to sewers (Prochaska & Zouboulis 2022). Consequently, there is a geographical disconnection between treated wastewater and locations with reuse potential that the new EU Regulation does not address, as the decision to connect small townships depends on other regulatory tools. It is not certain that the new regulation constitutes a significant driver to increase water reuse in Greece.

Cyprus does not face difficulties in implementing water reuse projects. It is unlikely that any changes to its current regulations will significantly affect the level of water reuse on the island, which is already above 95%. No public information was found to indicate that Cyprus was, in 2023, in the process of updating its regulations to meet the requirements of the EU Regulation. In 2018, the main avenues for improvement in quantitative terms for water reuse included the increase in the collection of urban wastewater (around 14% was not collected at that time and no recent figure has been found) (WISE Freshwater 2021).

In France, although the number of water quality parameters regulated was low, the national regulation included strict requirements in terms of additional management measures (sludge quality, wind speed, soil type, irrigation methods, monitoring measures, administrative process, etc.). These were seen as key factors that discouraged the practice of water reuse (Mugdal *et al.* 2015). France's national regulation was somewhat similar in its functioning to the EU Regulation, although microbiological thresholds and DBO_5 are stricter within the EU Regulation (the *E. coli* class A quality limit in the national regulation corresponds to class C in the new EU Regulation). This will probably require some adaptations: (i) either additional costs for projects where tertiary treatments will be necessary to meet the EU quality requirements (ii) either in terms of the implementation of the multi-barrier approach. In June 2023, the French Government released a draft update of its water reuse regulation for comment. If enacted, the water quality parameter limits will match those of the EU Regulation, except that it includes two additional parameters (Coliphages (bacteriophages Specific F-RNA and/or somatic phages) and *Clostridium perfringens*) as parameters for ongoing monitoring, not just during validation testing as in the EU Regulation. For the moment, the draft regulation keeps all the risk management requirements for agricultural irrigation from the existing regulation relating to wind speeds, irrigation methods and characteristics and minimum distances from neighbouring activities.

On the one hand, France is not expected to face significant challenges to conform with the EU Regulation; on the other hand, a new regulation will probably not accelerate water reuse by itself either. In the 5 last years, very few agricultural reuse projects have emerged in France (mostly urban projects (Cerema 2020)). France, along with most of western Europe, experienced an extremely hot and dry summer in 2022 and 2023. A marked increase in media reports discussing

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water reuse compared to previous summers was observed during June, July and August of 2022 and 2023. As has been the case in other countries around the world, severe weather and climate factors may contribute more to accelerating the implementation of new projects rather than regulatory factors. Indeed, this was seen in the announcement of a Water Plan in March 2023 by the French President in response to the extremely dry conditions. The plan includes an objective to reach 1,000 water reuse and other non-conventional water projects by 2027 (Ministère de la Transition Ecologique et de la cohesion des territoires 2023), but for the moment, the incentives are more on urban uses (cleaning of sanitation networks, street cleaning, etc.) that are considered less risky and more readily accepted by the population.

Similarly, the Spanish Government announced a series of actions to address the severe drought conditions through its Royal Decree of 11 May 2023. It states, in light of the drought and the application of the EU Regulation in June 2023, that it is urgent that a new chapter III of title V, 'On the reuse of water', is incorporated into the revised text of the Water Law (Royal Decree-Law 4 2023 (Spain)). The decree included the requirement that by 31 December 2028, every urban agglomeration of more than 50,000 inhabitants must have developed a plan to promote the reuse of water associated with urban uses (provided for in paragraph 2 of article 109 of the revised text of the Water Law). The current regulatory framework in many autonomous communities clearly encourages water reuse and the Spanish Circular Economy Strategy constitutes an incentive to reuse water. However, economic barriers, especially due to the cost of tertiary treatments for certain autonomous communities remain an obstacle to the development of the water reuse sector (Gallego Valero *et al.* 2018). With the 2020 EU Regulation, some autonomous communities, such as Murcia, that have numerous market gardens, will have to irrigate with class A quality (or justify an equivalent level of safety through the multi-barrier approach).

In 2019, Portugal aligned its regulation with the future project of the European Union, and few changes will be expected with the implementation of the EU Regulation. Portugal currently faces difficulties due to the lack of adequate treatment infrastructure and the costs of reuse projects. Since 2019, the country has also faced the challenge of implementing the risk management plans necessary for water reuse projects (Rebelo *et al.* 2020).

All countries except Portugal will therefore be required to make significant changes to their regulations regarding validation monitoring, risk management planning and measures to inform the public about proposed projects (Gancheva *et al.* 2018).

Regarding the adaptation of former projects, the case studies assessed in this report conform mostly with the EU Regulation regarding minimum quality requirements and are not expected to face serious challenges in this respect. This, however, may not be the case for other small existing projects that will need adaptation either in terms of treatment or the development of a proper risk management plan. In some places, this may not be possible without public subsidies or support, and some projects may face difficulties in complying with the EU Regulation.

6.2. Towards regulatory adjustments in the future?

The implementation of the new regulation introduces elements of flexibility in some countries by reducing the number of monitored parameters; however, it adds complexity in terms of risk assessment. Long-term hazard assessments of treated wastewater reuse have not yet been deeply explored by science due to their complexity (for example the association between domestic water reuse and antibiotic resistance). The lack of regulation on micropollutants (Helmecke *et al.* 2020), which are poorly eliminated in treatment plants (Kosek *et al.* 2020; Rogowska *et al.* 2020), causes some concern for experts and the general public regarding the real safety of the food products and on the consequences in the long-term for soil and groundwater quality (Kodešová *et al.* 2024). Similarly, disinfection by-products, although mentioned in Regulation 2020/741 and the Commission Notice 2022/C 298/01 (2022), will need to be considered only when there is 'clear scientific evidence that the risk originates from reclaimed water and not from other sources', despite the relevance of considering them for direct uses from a water treatment plant (Guerra-Rodríguez *et al.* 2023).

The EU Regulation also proposes a fit-for-purpose approach to adapt to local conditions. However, in such a framework, the abundance of individual cases could limit the spreading of water reuse and would limit cross-border trust in trade required for the EU single market. The reference to ISO 16075 opens the possibility of relying on the multi-barrier approach if the performance of the wastewater treatment plant does not make it possible to reach the threshold values proposed by the EU Regulation. However, at least in France, the stakeholders and the State seem hesitant about how to implement this multi-barrier approach due to technical obstacles and a lack of confidence in water reuse systems. Consequently, project authorisation requests with reference to the multi-barrier approach will follow a strengthened permitting procedure, compared to those reaching the minimum requirements, as mentioned in the French Decree N°835 (2023).

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Another important point that is not addressed in the new EU Regulation is the fact that the quality objectives are given at the exit of the reclamation plant (the 'compliance point'), and nothing is imposed in relation to storage, transport or irrigation systems (however, these points are expected in the risk management plan and the permit issued by the competent authority); this is despite the fact that pathogen concentrations can increase in these systems between the wastewater treatment plant and agricultural field (Jjemba *et al.* 2010; Lequette *et al.* 2020; Truchado *et al.* 2021b). These two examples raise the question of the allocation of responsibilities that needs to be determined in the risk assessment plan, particularly in projects that include several types of stakeholders (public entities, private companies, farmers and even private citizens in some cases). The 'Technical guidance – water reuse risk management for agricultural irrigation schemes in Europe' for the Joint Research Centre (Maffettone & Gawlik 2022) proposes technical guidelines for the application of the key risk management principles. However, national laws take precedence after the point of compliance for ruling on the division of responsibilities.

Finally, the European Commission is in the process of developing updated regulations concerning wastewater treatment. A proposal for a Directive of the European Parliament and of the Council was released in October 2022. It proposes to increase the treatment requirements for many parameters for all treatment plants in agglomerations with over 10,000 inhabitants. This includes more stringent limit values for nitrogen and phosphorous releases, as well as new limit values for micropollutants. The improvement in treatment standards following the introduction of the 1991 EU Directive 91/271/EEC concerning urban wastewater treatment can be seen to have aided the development of water reuse projects. If another period of advances in treatment performance leads to higher-quality effluent across large areas of the EU, this may lead to another period of water reuse growth. A requirement to add tertiary treatment in order to meet the new standards may reduce the burden of meeting many water quality parameter limits off water reuse projects themselves and onto general wastewater treatment plant operating costs. This may improve the economics of such projects.

6.3. Is regulation a driver for water reuse development?

Additionally, a major obstacle to the development of the water reuse sector at the EU level remains its economic competitiveness. As raised by project stakeholders, in many places the cost of treated wastewater is higher than conventional irrigation water (from surface or groundwater). The outlier to this observation is Cyprus, where subsidies have reduced the price of reused water to less than half that of potable water. This is often cited as a major reason for the very high levels of water reuse in that country. Reclaimed water projects for agriculture are therefore currently more developed in places where there is no other water resource available, or when the users are willing to pay for the additional security that a constant volume of water will be provided by the water treatment plant all along the irrigation season, whatever the climatic conditions. For example, in the case of 'drought decrees' impairing or limiting irrigation, as experienced in France and Spain in the summer of 2022 and 2023, agricultural water reuse projects were generally not concerned by the decrees, and plots irrigated with reclaimed water were irrigated without restriction. Except for these specific cases where there is no other resource available, reclaimed water remains more expensive than conventional water, and a reframing of public subsidies on reclaimed and conventional irrigation waters would be a driver to foster the use of this alternative resource.

Therefore, regulation is not a driver as such for the uptake of this practice. Major drivers are water scarcity due to physical or economic constraints (Asano *et al.* 2007) and social tensions about water resources. The use of treated wastewater as an alternative relies first of all on political will at the level of countries and territories. Indeed, it is through political action that a transformation of the competitiveness of water reuse projects can take place. Recent events associated with the 2022 and 2023 droughts have seen France and Spain shake up their political agendas by displaying more ambitious water reuse objectives (the objective in France is to increase from 1% to 10% of non-conventional water used by 2030 and to increase from 10% to 20% for Spain by 2027). These countries responded to growing pressure around resource sharing and to the appeals of the agricultural and industrial sectors. It remains to be seen whether these objectives can be met and how the regulations, policies and funding decisions will help or hinder water reuse project implementation.

7. CONCLUSION

The EU Regulation proposes a consistent framework dealing with many technical and health issues associated with water reuse. The 2020 EU Regulation is expected to reduce the costs associated with monitoring, as the number of compulsory quality parameters will likely decrease for many countries (especially Greece, Italy and Spain).

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However, in its current form, some knowledge gaps and long-term risks persist and are not fully addressed by the new EU Regulation. The regulation does not clearly propose a simplification of the procedure for new projects (procedures are decided at the national level). The review of different papers on the subject suggests that

(i) more details have to be provided by Member States on risk management plans, for obtaining permits, for the implementation of the multi-barrier approach, and for the sharing of responsibilities between parties;
(ii) a clear position is expected regarding micropollutants and disinfection by-products, in a context where there is no scientific consensus about the ecotoxicological risk associated with these substances and about the consequences for soils and groundwaters in the long term; and
(iii) complementary studies should be completed regarding the evolution of water quality in storage and irrigation networks after the compliance point.

Lastly, for many countries, one of the main obstacles is the cost of projects compared to their benefits. The recent meteorological events (severe droughts at the European scale in 2022 and 2023) have illustrated the fact that water scarcity and social tension about water are the most important drivers for water reuse in agriculture and other uses. Ambitious objectives in southern European countries have recently been announced in 2023 (Spain, France). Water reuse is first of all a political choice because politics creates favourable conditions for its adoption (subsidies, loans). Indeed, the design of public subsidy systems for water reuse should be reconsidered by some European countries because water reuse remains generally poorly competitive compared to conventional waters. However, even in a favourable political context, other obstacles can be observed, such as the spatial discordance between the needs of users and the availability of the resource (Greece), the competition between different water uses (some treated wastewater uses, such as urban uses, are more readily adopted by populations and are more competitive because they are mostly substituting for potable water, in comparison to agricultural uses which use raw surface water or groundwater) (France), or the lack of adequate treatment infrastructure in some municipalities (Cyprus).

In conclusion, treated wastewater remains an 'alternative resource' in the new European regulatory framework, in the sense that the European Union did not legislate to easily replace freshwater with treated wastewater in agriculture, but rather to harmonise the state of water reuse for agricultural irrigation and consequently prevent trade disputes. As a consequence, it is probable that the EU Regulation 2020/741 will only partly support the spreading of wastewater reuse in Europe. However, the updated wastewater treatment regulations for agglomerations of more than 10,000 inhabitants being developed by the European Commission could be a driver to alleviate costs associated with reuse projects in the future, by raising the minimum requirements at the outlet of wastewater treatment plants.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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