Risk management plans to overcome barriers for safe reuse of urban wastewater for agricultural purposes in Europe.

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Abstract

Despite their multiple benefits, water-reuse practices are scarcely implemented globally owing to factors hindering the reuse process and socio-political issues that are closely related to the lack of trust in water-reuse techniques and practices. Non-homogeneity in the water-reuse regulations is also highly relevant. To overcome these challenges, the European Parliament has recently approved the Regulation 2020/741 *on minimum requirements for water reuse,* to standardise the legal requirements of wastewater to be considered fit for reuse. This regulation also requires elaboration of Water Reuse Risk Management Plans (WRRMPs) for all reclamation facilities of the Union. This review aims to provide a general overview of the current limitations and gaps in developing water-reuse practices, as well as recommendations that could overcome them. To this end, WRRMPs play a crucial role because they can ensure the healthy and safe use of reclaimed water in agriculture. Consequently, they can serve as tools to change the public perception of wastewater, from a waste to a source of water. Previous guidelines to develop risk management plans and the current regulations regarding water reuse in Europe have also been extensively analysed in this study.

Keywords

Irrigation; risk assessment; risk management; wastewater; water reuse.

1. Introduction

Water scarcity is one of the greatest challenges worldwide, because approximately 40% of the global land area is classified as arid, semi-arid, or dry sub-humid, and over two billion people experience high water stress [1,2]. The situation is deteriorating because of climate change and increasing population. The agricultural sector has the largest water use, accounting for approximately 70% of the total extracted water [3]. Therefore, alternative water sources must be explored to ensure adequate water supply. In this context, appropriately treated municipal wastewater (termed as reclaimed water) can help to compensate for the gap between available and required water worldwide, providing a regular water supply [4]. Wastewater reuse in agriculture involves numerous environmental and social benefits, both monetary and non-monetary. It reduces the exploitation of natural water resources, decreases pressure on their water basins, improves the ecological status of water bodies, alleviates poverty in water-scarce developing countries, and ensures socio-economic and political stability [5–7].

Approximately 312,000 hm^3 of municipal wastewater is estimated to be produced worldwide annually [8]. Conventional municipal wastewater treatment plants (WWTPs) have been designed with the aim to reduce the concentration of some pollutants (mainly organic matter, suspended solids and nutrients) below limits established in the legislation. Hence, they follow a linear approach where resources contained in the wastewater are not utilised (Figure 1). However, WWTPs can be substituted by (or transformed into) reclamation facilities to maximise the production of reclaimed water, combined with energy and nutrient recovery, and transition towards a circular economy [8,9]. Despite its substantial potential benefits, the percentage of wastewater reused (instead of only treated and discharged) remains low, except for certain cases, such as in Cyprus (Table 1).

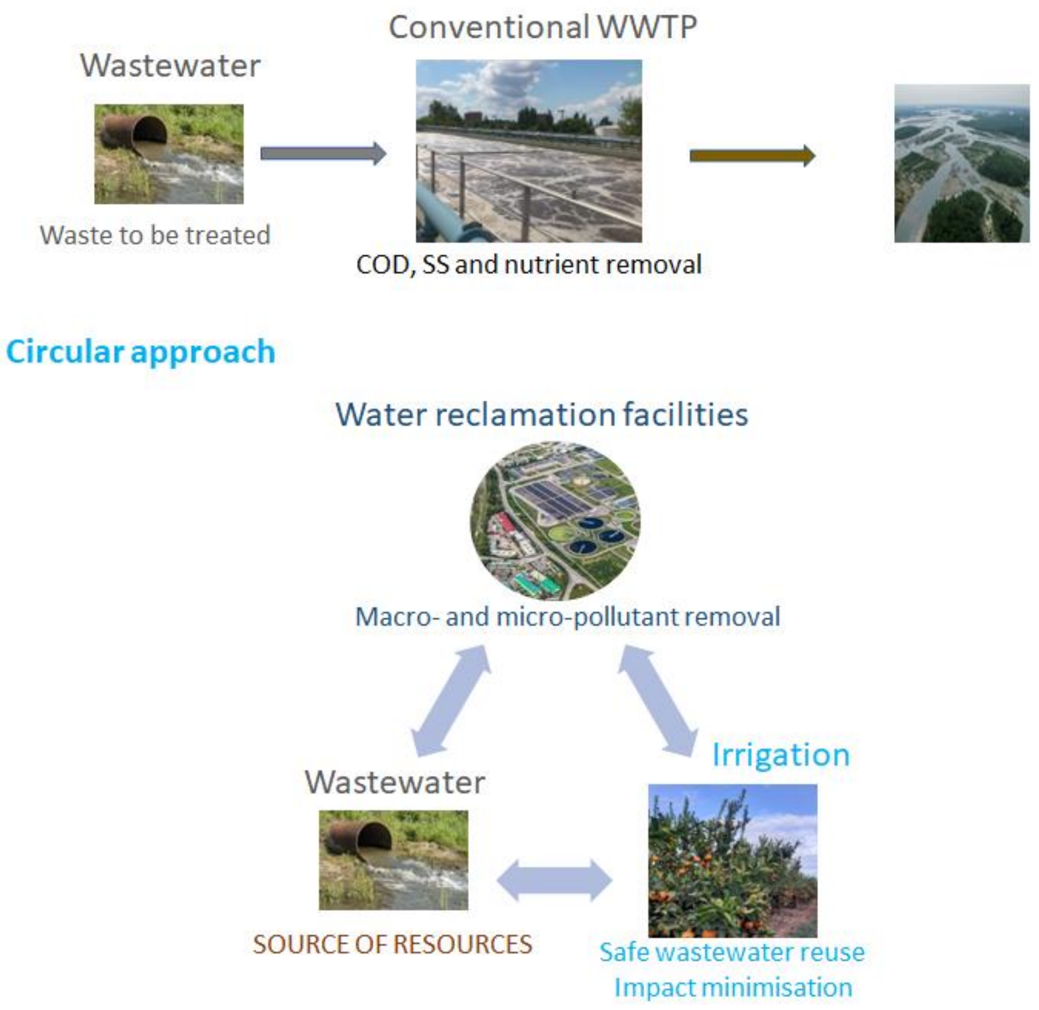

Figure 1. Representation of conventional (linear) and modern (circular) approaches used in municipal wastewater treatment systems.

Table 1. Worldwide data related to the production, collection, treatment and reuse of wastewater for agricultural purposes [10].

Area	Country	Produced municipal wastewater ($hm^3 \cdot y^{-1}$)	Collected wastewater (%)	Treated wastewater (%)	Reuse of Treated Wastewater ($hm^3 \cdot y^{-1}$)	Reused wastewater (%)	Reused wastewater in agriculture (%)	Water withdrawal for irrigation ($hm^3 \cdot y^{-1}$)
Asia	China	48,510	64.2	100	7,720	15.7	16.3	385,200[a]
	Japan	16,930	71.00	68.3	390	3.4	3.0	53,300
Africa	Egypt	7,078	91.8	60.5	2,400	56.0	12.1	45,110
	Tunisia	312	88.8	87.8	42	15.5	33.0	1,552
	South Africa	2,420	100	90.9	3,220	-	-	11,397
Central -Eastern Europe	Ukraine	1,513	-	59.1	6	0.7	-	4,052
	Romania	1,011	96.34	88.2	-	-	-	0,441
	Russian Federation	12,320	71.43	74.7	-	-	-	7,000
	Croatia	336	100	83.7	-	-	-	30
	Poland	2,168	96.36	61.3	6	0.5	-	84
Southern Europe	Cyprus	35	100	96.5	34	99.7	50.0	174
	Italy	3,926	-	99.4	90	2.3	96.7	16,000
	Malta	26	100	92.3	1	5.8	50.0	24
	Portugal	577	100	46.8	6	2.2	-	3,395
	Spain	5,206	100	90.0	1,184	25.3	-	18,645
Northern Europe	Denmark	368	100	100	-	-	-	51
Western Europe	France	4,000	94.25	94.25	822	21.8	-	2,588
	Germany	5,213[b]	100.0	99.42	-	-	-	0,363
	UK	4,089	99.0	99.0	328	8.1	-	84
Middle East	Iran	3,548	32.8	24.9	328	37.1	-	86,000[a]
	Israel	0,500	100	90.0	1,028	-	-	1,173[a]
	Saudi Arabia	1,546	74.0	100	508	31.8	100	19,000[a]

Northern America	Mexico	7,960	84.5	54.9	1,796	41.1	76.8	65,870
	Canada	6,074	97.3	95.5	-	-	-	2,950
	USA	60,410	78.2	75.1	5,548	12.2	-	163,000
Southern America	Argentina	2,458	64.9	11.8	182	62.8	-	27,930[a]
	Brazil	10,081	65.7	51.9	100	1.8	8.0	32,160
	Colombia	2,397	100	6.4	-	-	-	16,000
Oceania	Australia	2,094	87.3	95.5	280	14.0	50.0	11,099

[a]*Referred to annual quantity of self-supplied water withdrawn not only for irrigation, but also for livestock and aquaculture purposes.*
[b]*Amount of wastewater collected.*

The limited use of reclaimed water is related to the risks associated with the pollutants contained in wastewater effluents, especially in developing countries, where wastewater is partially treated or untreated [3,5]. In addition, numerous end-users and the general public commonly consider wastewater as waste rather than a source for reclaiming water. Thus, to shift this paradigm, ensuring safety of the environment and public health in the use of reclaimed water is essential. These are the main goals of the Water Reuse Risk Management Plans (WRRMPs), which are mandatory for all reclaimed water facilities implemented in the European Union (EU) after applying the Regulation 2020/741 *on minimum requirements for water reuse* (discussed in detail in Section 4.2). This review aims to analyse the factors that currently hinder water-reuse practices and discuss the role of risk management in its implementation. To this end, this paper is divided into the following sections: Section 1 is the introduction of the topic; Section 2 evaluates, from a European perspective, the main techno-economic and socio-political barriers that hinder the widespread use of reclaimed water; Section 3 analyses the role of risk assessment in water reuse, including the most relevant guidelines for risk assessment; Section 4 provides a critical discussion regarding the current national and European legislation, presenting some of their major gaps; and Section 5 proposes methodologies, tools, and practices (alternative and complementary to WRRMPs) that can help overcome the determined barriers to the implementation of water-reuse practices.

2. Barriers to the widespread application of wastewater-reuse practices

The development of wastewater reuse has diverse challenges, including those related to the water reclamation process itself, that is, process feasibility and the presence of potentially damaging microorganisms and compounds in the reclaimed water, as well as socio-political barriers, which are further described in Section 2.2.

2.1. Barriers related to the water-reuse process

Reclaimed water presents intrinsic risks associated with the presence of biological and chemical pollutants in wastewater, because they can have negative impacts on public health and the environment. These risks cannot be eliminated completely but can be minimised to safe levels. Although current WWTPs are highly efficient in removing certain pollutants (organic matter, solids, nutrients), evidence on the mechanism by which they effectively deal with other pollutants such as metals, contaminants of emerging concern (CECs), and some biological pollutants (pathogenic microorganisms, antibiotic resistance bacteria, etc.) remain limited [11,12]. The extent of the risks associated with the CECs depends on the degree of wastewater treatment (secondary, tertiary or quaternary), type of pollutant, and especially, on pollutant influent concentrations. Poorly treated industrial wastewater and/or runoff water in municipal wastewater streams can add significant amounts of pollutants, increasing the risks associated with its reuse [4]. Thus, pollutant reduction is crucial for improving the safe reuse of wastewater, especially from the source of production.

The presence of pathogens (such as bacteria, viruses, protozoa and others) in wastewater effluent streams is extremely common, as many WWTPs lack appropriate biomass-water separation systems and/or tertiary treatments. Pathogens cause human diseases, that can be both chronic and acute, and even premature mortality, thus they are of high health concern [5]. Consequently, referent pathogenic organisms are included in the risk assessment guidelines (described in Section 3) and legislation and regulations related to water reuse (discussed in Section 4).

The presence of heavy metals in wastewater is also common. They can accumulate in soils and the food chain, negatively affecting crop productivity [13,14]. Therefore, the risks associated with the presence of metals in reclaimed water must be assessed and minimised. Concerns are also increasing regarding the presence in water of CECs such as pharmaceuticals, antibiotics, pesticides, microplastics, and antidepressants. The risk assessment of CECs presents several challenges: i) detection and analyses of CECs are not always accurate because they are diverse and commonly present at trace levels [15], ii) monitoring and analysis of CECs are complex and expensive due to the requirement of specialised equipment and the excessively high number of compounds to be analysed [16,17], iii) they can affect human health and the environment (including flora and fauna) at trace levels [12,18], iv) they are usually highly resistant to biological removal in WWTPs [12], v) degradation compounds can present higher toxicity than the original CECs [4], and vi) CECs can persist and accumulate in crop lands and the food chain [19]. To effectively assess the risks associated with CECs, guidelines that provide target compounds, detection techniques, and safe CEC concentration limits must be developed by experts, but they are currently limited.

Among all groups of CECs, antibiotics require special attention, not only because of their increasing presence in urban wastewater streams and the potential toxic effects of antibiotics entering the human food chain [20], but also because they contribute to the development of antibiotic resistance genes (ARG) and antibiotic-resistant bacteria (ARB) [11,16]. This has become a topic of major concern for the scientific community [21], because the increasing spread of ARGs threatens modern medicine and lifestyles, especially in developed countries, which are highly antibiotic-dependent. However, knowledge related to long-term risks due to the presence of ARG or ARB in reclaimed water remains scarce [11,22], and most of these compounds are commonly stated as potential risks.

Some techno-economic hurdles, which typically vary for developed and developing countries, also affect the implementation of water reclamation facilities. In developing countries, wastewater collection is not always effective and wastewater treatment systems are scarce or inefficient, hindering appropriate wastewater management [5]. However, in developed countries, additional infrastructure is often required for the transition from conventional WWTPs to reclamation facilities. These infrastructures are primarily related to i) tertiary treatment for the disinfection, nutrient and salinity removal, or any other additional processes beyond traditional treatment; ii) storage infrastructures to align the production and demand of reclaimed water; iii) piping systems for the distribution of reclaimed water from the facilities to crop lands; and iv) adequate number of instructed personnel to operate and manage the reclamation facilities. These imply additional costs and difficulties that sometimes disincentivise the use of reclaimed water for irrigation [23]. For instance, based on the tertiary treatment technologies selected (ultraviolet, ozone, membrane filtration, etc.), operating costs can increase by approximately 0.02–0.21 €·m^{-3} [24,25]. For comparison, the cost of extracting water from rivers and groundwater bodies is estimated to be only 0.015–0.2 €·m^{-3} [26].

2.2. Barriers related to socio-political aspects

Other obstacles in the use of reclaimed water are related to the engagement of policy-makers and stakeholders, the high number and variety of public organisations involved in decisions related to water management, and inadequate understanding of some roles and responsibilities that can lead to conflicts and ineffective management strategies [23]. Although collaboration between these actors is intended, it is not always successful in practice. Owing to these political issues, a lack of homogeneity in regional and national regulations regarding water reclamation has been observed (refer to Section 4.1 for details), which is one of the main obstacles to the widespread development of water reuse in Europe [27]. Differences in regulations include the type and number of monitored pollutants, as well as their limiting values, which can be even as stringent as those for drinking water in certain regulations [28]. This lack of homogeneity hinders transport and supply of agricultural products irrigated with reclaimed water [23]. The EU is increasingly making efforts to align policies and government decisions in the water sector, supporting the development of guidelines and policies to help boost water reuse. The European Parliament (2020) has recently launched *Regulation 2020/741 on minimum requirements for water reuse* (to be applied in all member states from 26 June 2023) to standardise water-reuse regulations in the Union and overcome challenges hindering their implementation (more information in Section 4.2).

Social factors, such as religious beliefs or negative opinions regarding the use of reclaimed water, are also worth considering because they can threaten the technical, economic, political, and legal advances that can be made in the sector [29]. For instance, in a case study analysed in Tunisia, political and economic efforts were made to reduce the costs of acquiring reclaimed water to 0.018 €·m^{-3}, which implied lower price than surface water (0.026–0.092 €·m^{-3}). However, the farmers were reluctant to shift the paradigm and preferred to use conventional water [30]. A significant proportion of the general public does not trust water-reuse regulations, monitoring practices and the managing organisations, the technical process, and the quality and safety of the reclaimed water itself [31,32]. Hence, increasing the awareness regarding the benefits of water reuse, combined with improving transparency and ensuring the safety and low impacts of water reuse, are essential to expand this practice worldwide. Risk assessment and management plans (mandatory in Europe after the approval of Regulation 2020/741 on 26 June 2023) are clearly aligned with the abovementioned aims. By ensuring safe water reuse, the reputation and perception of reclaimed water facilities can be maintained at high levels [33]. Thus, WRRMPs seem to be useful tools for boosting water reuse in agriculture [18].

3. Risk assessment in water reuse

Risk assessment is the key step of management and implementation plans for water reuse and consists of the identifying and characterising possible hazardous events to evaluate related risks and prioritise them [34]. This requires the definition of hazards, hazardous events, and risks associated with the water-reuse process. Hazards refer to any agent that could harm people or ecosystems and can be divided into biological, chemical, physical, or radiological. Accordingly, hazardous events occur when targets (people and/or the environment) are exposed to hazards such as incidents, failures, or situations which introduce, release, or amplify the presence of a hazard in the system [35]. The likelihood of a hazard causing harm within a specified timeframe, including the severity of the consequences, represents the risk.

The risks associated with reclaimed water differ according to the reuse purpose and entail both risks for human health and for the environment. Health risks are partially addressed by the existing legislation regarding the safety of agricultural products [36]. However, this legislation does not specify the requirements for reclaimed water used to irrigate agricultural products, which can have other impacts on human health owing to the direct exposure of farmers and surrounding residents to the pollutants contained in water [37]. Environmental risks owing to the presence of chemical contaminants, inorganic salts, nutrients, and heavy metals in water must also be considered. In general, such risks should be carefully analysed prior to utilising wastewater as a water source through a risk-based approach. In summary, risks associated with water reuse in irrigation can be divided into three categories: i) health risks associated with consumers of agricultural products irrigated with reclaimed water, including those related to the health of animals that consume crops irrigated with reclaimed water; ii) health risks associated with humans exposed to reclaimed water (workers, bystanders, and residents in nearby communities); and iii) risks to the local environment, that is, surface waters, groundwater, soil, and ecosystems [5,14,38].

3.1. Existing guidelines and methodologies for risk management plans in the water-reuse sector

Minimising the health and environmental risks associated with water reuse is a complex task that requires a comprehensive knowledge of the process. Owing to the lack of specific regulations and standard procedures for risk management, the main international organisations involved in public health and environmental protection have provided guidelines and manuals to address risk management for water-reuse projects. However, this is approached from different perspectives based on the specific case at a specific time. Some organisations [34,39] aimed to provide technical indications for the design of reclaimed facility projects. In contrast, the Australian Government Initiative [40], Sanitation Safety Planning (SSP) [35], and DEMOWARE [41] guidelines have presented content to develop risk management plans to consistently ensure the safety and acceptability of water reclamation.

Owing to their relevance in the water-reuse sector recently, the following guidelines and manuals are evaluated. i) Guidelines for municipal water reuse in the Mediterranean region [42]; ii) Guidelines for the safe use of wastewater, excreta, and greywater, Volume II- Wastewater use in agriculture [34]; iii) Australian Guidelines for Water Recycling: Managing Health and Environmental Risks [40]; iv) Guidelines for Water Reuse [39]; v) ISO 16075 Guidelines for Treated Wastewater Use for Irrigation Projects [43]; vi) SSP – manual for safe use and disposal of wastewater, greywater, and excreta [35]; vii) Quantitative Microbial Risk Assessment [44]; and viii) Water Reuse Safety Plans (WRSPs)- a manual for practitioners by DEMOWARE [41] (Table 2).

Table 2: Summary of the information provided by guidelines for water reuse and safety plans.

	UNEP [42]	**WHO Guidelines** [34]	**Australian Guidelines** [40]	**EPA** [39]	**ISO 16075:2020** [43]	**ISO 20426:2018** [45]	**SSP** [35]	**QMRA** [44]	**DEMOWARE** [41]
Water reuse practices	- Urban and agricultural reuse. - 4 quality classes.	Agricultural reuse of wastewater, greywater and excreta	- Urban reuse. - Irrigation in agriculture. - Industrial reuse	- Urban. - Industrial. - Agricultural. - Impoundment. - Environmental. - Groundwater recharge. - Potable reuse.	Agricultural and urban irrigation projects;	Non-potable reuse: agricultural, urban, industrial, recreational and environmental	Agricultural reuse of wastewater, greywater and excreta	Water Safety Management. all uses.	All possible reuses
Water quality criteria	- Intestinal nematodes. - E.coli. - Faecal coliforms. - Suspended solids.	- Reference pathogens: Campylobacter, Cryptosporidium, Rotavirus. - Risks expressed in DALYs.	Reference pathogens, soil and plant toxic compounds. Risk expressed in DALYs.	Faecal coliforms, BOD, Turbidity, pH, residual Cl_2, metals and soil characteristics	BOD, TSS, Turbidity, thermotolerant coliforms, intestinal nematodes, organic matter, nutrients salts and heavy metals	*E.coli*, BOD, TSS or Turbidity Chlorine residual	Reference pathogens (e.g., Campylobacter, Cryptosporidium, Rotavirus). Risk expressed in DALYs.	Reference pathogens (e.g., Campylobacter, Cryptosporidium, Rotavirus). Risk expressed in DALYs.	Microbial, toxic, Compounds of agronomic relevance, and Compounds of emerging concern (no limits)
Risks addressed	Microbial	- Health risks (priority) - Environmental	Health and environmental	Health and environmental	Health and environmental	Health	Health	Microbial	Health risks (priority) - Environmental aspects
Risk assessment	No. Reuse based on limit values.	Microbial analysis, Epidemiological study, QMRA	Qualitative and Quantitative risk assessment	No. Reuse based on limit values. Methods for assessment specified in other documents (https://www.epa.gov/risk/conducting-human-health-risk-assessment#tab-5)	- No. Reuse based on limit values	Qualitative and Quantitative health risk assessment	Qualitative and Quantitative risk assessment.	Quantitative risk assessment	Qualitative and Quantitative risk assessment

Risk management	Multi-barrier approach	Multi-barrier approach	Multi-barrier approach	Multi-barrier approach	Multi-barrier approach	Multi-barrier approach	Multi-barrier approach	Multi-barrier approach	Multi-barrier approach
Monitoring	Minimum frequencies and sampling points	Validation, Operational, Verification	Validation, Operational, Verification at critical control points	Frequencies depending on intended use.	Operational monitoring on wastewater, crops, soil and environment in ISO 16075	Parameters to be monitored and log removals	Validation, Operational, Verification	-	Operational
Social aspects	No contemplated	- Public perception. - Economic feasibility. - Policy aspects	- Acceptance. - Communication strategies.	- Public Outreach. - Participation, and Consultation.	No contemplated	No contemplated	Supporting programs	No contemplated	- Acceptance. - Communication.
Advantages	Specific for the most common practices in the Mediterranean region.	Referenced data, e.g., epidemiologic studies, concentrations in wastewater, crops and soil, log removals.	Complete of referenced characterisations, limits, examples and recommendations for risk management	- Referenced data - Provide suggestions from the planning and management phase to the public participation and consultation phase. - Address the existing regulatory framework to minimise the related risk - Discuss the funding possibilities available for water reuse projects.	Provide design and technical specifications for treatment, storage, distribution and irrigation infrastructure.	Provide guidelines to evaluate qualitative and quantitative risk assessment	Provide examples	Address the core phase of Risk assessment in a quantitative approach	Simplify the structure of a water reuse safety plan
Disadvantages	- Not addressed all possible reuses. - Not addressed environmental risks.	Focused mainly on developing countries.	- Complex. - Lot of data required	- Focused on US applications.	No social aspects included. No guidelines on risk assessment.	No social aspects included. No limit values specified	- Focused on developing countries.	Do not consider non-technical aspects, monitoring and implementation	- Non quantitative indications.

DALYs: Disability-adjusted life years; EPA: United States Environmental Protection Agency; SSP: Sanitation Safety Planning; UNEP: United Nations Environment Programme; WHO: World Health Organisation.

3.1.1. Water-reuse practices and quality criteria

All guidelines analysed in this paper consider wastewater reuse for irrigation, although some [39–41] include numerous possible uses, from aquifer recharge to urban, industrial, and potable water reuse (Table 2). The selected wastewater reuse practice also depends on the region in which the guidelines are focused on. For instance, the WHO guidelines [34,35] are primarily formulated for developing countries where water is reused for different purposes, such as agriculture and indirect potable reuse, based on their needs. This is also considered in the EPA guidelines [39]. In contrast, the UNEP guidelines [42] are specifically devised for the Mediterranean area, thus focusing on agricultural reuse, while potable reuse is uncommon [28]. Water-use categories are also defined based on comparable levels of risk, from urban reuse to unrestricted, restricted irrigation, and irrigation using only efficient irrigation systems. The WRSP manual proposed by Hochstrat et al. [41] aims to expand water applications to any type of reuse and can enable operators and authorities to develop feasible management and safety concepts for existing water-reuse systems.

For each intended use, almost all the guidelines provide quality standards to ensure human health and environmental protection. Most of the water quality criteria consist of threshold concentrations for reference biological pollutants, such as *Escherichia coli*, *Campylobacter, Cryptosporidium*, Rotavirus, nematode eggs, and faecal coliforms (Table 2). Moreover, biological oxygen demand (BOD), turbidity, pH, and residual Cl_2 are considered in the EPA [39], whereas the WHO [34], Australian, [40] and EPA [39] guidelines also provide maximum concentrations of chemical pollutants and heavy metals. Furthermore, the maximum concentrations in soil are only considered in the WHO [34] and EPA [39] guidelines.

3.1.2. Risk assessment in existing methodologies, management, and monitoring techniques

The assessment of potential risks for health and the environment could be summarised by identifying hazards and hazardous events, estimating their likelihood, evaluating their impacts, and characterising the corresponding risks [40]. The level of detail and methodology used to assess risks may vary according to the specific needs and data available. Some guidelines, such as the UNEP [42], do not specify a methodology for risk assessment, limiting the provision of maximum values and barriers to ensure safe water reuse. In contrast, most existing guidelines suggest sophisticated microbial analyses, epidemiological studies, and QMRA and/or chemical risk assessment (QCRA) approaches to be used when data and resources are available [46].

Health protection is the focus of risk assessment, although some guidelines also consider environmental risk (Table 2). Both public health and the environment can be protected by reducing or eliminating physical, biological and chemical pollutants in reclaimed water. Limiting public exposure to reclaimed water by implementing multiple barriers, such as retention time in storage systems, selected irrigation systems, setback distances from the application site, entry restrictions, avoiding or preventing cross-connections with potable water distribution systems or backflow prevention, and encoded distribution systems, can minimise the direct contact of potentially contaminated water, especially for population with higher risk of exposure, such as farmers, crop merchants, agricultural product consumers, and residents from surrounding communities [5]. Particular attention is paid to the microbial risks caused by pathogens, providing specific information for the calculation of microbial health-based performance targets. The

WHO [34,44] and Australian guidelines [40] consider 10^{-6} disability-adjusted life years (DALYs) as the health limit, which corresponds to one infection per one million people per year [39], whereas protection measures are evaluated considering the pathogen reduction required to achieve this limit for different exposures [47]. In particular, QMRA guidelines [44] provide information, data, and formulae to evaluate microbial risk and compare them with the target DALYs. Health risks due to chemicals can be assessed quantitatively through the QCRA by comparing estimated exposures to tolerable (or acceptable) effect levels or concentrations [41]. Therefore, risk quotients (RQ), which represent the ratio between the concentration at the endpoint and the respective tolerable concentration or dose, can be calculated for each endpoint. An RQ > 1 indicates that based on the current knowledge, risk is above the acceptable levels and reduction measures should be implemented. However, an RQ < 0.1 is often defined as areas of negligible risk [48]. Other targets must be defined for environmental risks. However, limits or specific thresholds to minimise them are barely indicated in these guidelines, which commonly delegate these aspects to current environmental regulations. Some exceptions exist, such as the Australian guidelines [40] and EPA [39], which include risks associated with chemicals that may cause plant toxicity (boron, chloride, sodium, cadmium, and chlorine), soil degradation (salinity and sodium), or nutrient imbalance. Excess water is also considered. The Australian guidelines [40] also provide particular focus on CECs, which is a novel approach compared to the other guidelines (Table 2).

Among all evaluated guidelines, risk management was addressed using a multiple barrier approach (Table 2). In general, control measures can be applied to target water quality and/or to work on route exposure, including treatment (e.g. disinfection), technical (e.g. drip irrigation), and behavioural measures (e.g. harvesting practices). The

WHO [34], Australian [40], and EPA [39] guidelines provide various treatment options to meet specific water quality goals, based on the intended use. The treatment processes are then combined with on-site controls, and restrictions are used to further reduce risks.

Apart from the aforementioned factors, monitoring is crucial to ensure that the water-reuse scheme effectively achieves defined performance and water quality targets. Thus, it is a factor considered in all the analysed guidelines. Nonetheless, they differed in various aspects, including the points of monitoring (treatment plant effluent, storage, and point of use) and sampling frequency (Table 2). The WHO guidelines [34] introduced three types of monitoring, depending on the operating step: i) validation monitoring before the complete operational activity, ii) operational monitoring to ensure the effectiveness of the control measures applied, and iii) verification monitoring to ensure compliance with regulation at the end-use stage. Based on a similar approach, four types of monitoring are used according to the Australian guidelines [40]: i) obtaining baseline data, ii) validating the system, iii) obtaining operational data, and iv) verifying process effectiveness. These sampling and monitoring campaigns should be conducted (at least) at the critical control points, which represent essential points where risks are significantly reduced or prevented, to appropriately evaluate the efficiency and efficacy of barriers and preventive measures. The EPA guidelines [39] also include monitoring programs for each intended use based on online methods and warning alarms. The DEMOWARE manual [41] improves upon previous guidelines by including audits and visual inspections using checklists and interviews to help operators better understand the system’s functionality and the background of the risk management process.

3.1.3. Social aspects

Consideration of public perception, social acceptability, and communication strategies regarding wastewater reuse has increased recently (discussed further in Section 5.1); therefore, these aspects have been considered in most of the cited guidelines (Table 2). Community and stakeholder participation is often encouraged through educational and information activities, public meetings, public consultations, and workshops. In the Australian guidelines [40], particular attention is paid to public information and the development of communication strategies, because communication modes and phrasing can be highly relevant to increasing water-reuse practices [49]. Key messages, as well as the main tools for communication and stakeholder engagement, are suggested. The EPA guidelines [39] also include best management practices involving community engagement, summarise water use in the United States, discuss the expansion of water reuse nationally to meet water needs, and provide an overview of numerous national and international water-reuse case studies. In addition to the aforementioned strategies, the DEMOWARE manual [41] states that the acceptance of water-reuse projects is more challenging than implementing water supply infrastructure because water-reuse practices are generally perceived critically.

3.1.4. General advantages and disadvantages

All the analysed guidelines have contributed to developing safe water-reuse applications and have provided instructions guiding operators in the design and realisation of water-reuse projects, as well as politicians and decision-makers responsible for establishing regulations to assess and standardise those practices.

In particular, the UNEP guidelines [42] overcame the lack of existing regulations in the Mediterranean region at that time, whereas the WHO guidelines [34] were particularly helpful in determining referenced and quantitative information regarding the presence of pathogens, removal efficiencies, and proposed thresholds, as they provided summary tables and supporting material. However, these guidelines mostly focused on developing countries, and only general information about water-reuse management plans was provided. The SSP Manual [35] improved upon the WHO guidelines [34] by providing a systematic approach in six modules to assess, manage, and monitor risks from wastewater origin to its final use, including examples and case studies that are especially useful for developing countries. The QMRA guidelines [44] provide useful information on evaluating and quantifying microbial risks, even if they are not designed to cover the implementation of a management plan such as monitoring programs or communication.

The Australian guidelines [40] can be considered pioneers because they developed a complete risk management plan and established the basis for future regulations, including the European 2020/741 (further discussed in Section 4.2). However, the EPA guidelines [39] offer more detailed information about a wide range of reuse applications and introduce new concepts as well as treatment technologies that support water-reuse operations. Moreover, these guidelines emphasise the need for further investigation of CECs before establishing their threshold limits. However, methodologies that address the risks of CECs have not yet been specified; thus, considering them is extremely challenging because of the difficulties in their monitoring (refer to Section 2.1 for details). The DEMOWARE manual [41] provides a simpler (compared to its predecessors) methodological guideline for the development of WRSPs to support operators and authorities in designing and developing water-reuse schemes. Some examples of case studies are also presented, although they do not provide specific quantitative information.

4. Water-reuse regulations

Three main approaches regarding water-reuse regulations have been identified[14].

i. Based on limiting values that are defined for several parameters related to reclaimed water. Health and/or environmental risks can be minimised by meeting these values, which may be applicable at different points based on the standards (e.g. at the reclaimed water delivery point or facility outlet). This approach is followed by the EU members such as Italy, Spain, France, Cyprus, Greece and Portugal [28] and requires intensive monitoring of water quality, which can be highly challenging when analysing emerging pollutants [15,16].

ii. Based on wastewater treatment requirements and limiting values. This approach has been reported in Title 22 of California's Code of Regulations and followed by the EPA guidelines [39]. For each potential use, a specific approved and certified wastewater treatment technique is required. For certain use categories, the water quality criteria (limiting values) can also be applied.

iii. Based on implementing a risk management system for each reuse project. This approach was adopted by the Australian guidelines [40] and WHO guidelines [34], followed by the DEMOWARE manual [41]. An advantage of this approach is the prior identification and management of risks more proactively, rather than relying on post-treatment analysis and response when problems have already arisen. The approach is also more flexible because it can be applied to various scenarios. The main health and environmental hazardous events must first be identified and assessed, and measures to prevent and control the risks must be implemented, followed by the implementation of monitoring procedures to ensure that risks are effectively reduced to an acceptably low level.

4.1. National water-reuse regulations in EU member states

Although Northern EU members such as Austria, Germany, Denmark, the Czech Republic, the Netherlands, and Belgium do not present specific regulations regarding water reuse[50], some member states from the south (Cyprus, France, Greece, Italy, Spain, and Portugal) have established specific legislation to regulate water reuse in centralised WWTPs (Table 3). Thus, these countries have standardised these practices in their territories. However, amongst water-reuse regulations, large disparities occur in the approach to be followed, the number of parameters to be analysed and their limiting values, as well as the sampling points and sampling frequency [27]. This situation is often related to the fact that the regulatory framework has not addressed water reuse holistically (considering all factors that may affect water reuse such as water, energy, food, climate, health, etc.), but it has been commonly managed separately [51].

The regulations in Cyprus, Greece, and Portugal were delivered by environmental ministers, whereas health authorities collaborated with their elaboration in France, Italy and Spain. This likely influenced the main purpose of each regulation and widened the differences between them. For instance, the main concern in Cyprus is related to environmental pollution from nitrates due to land irrigation; therefore, industrial or urban reuse were not in the regulations[52]. However, Spanish and Italian regulations require the approval of the public health authorities before obtaining the permission to reuse water [53,54]. Spanish regulation permits the highest number of possible reuse applications, including private garden irrigation, sylviculture and aquaculture, varying the stringency of the limiting values of pollutants according to the final use. For each reclaimed water class, limits are provided for *E. coli*, intestinal nematodes, suspended solids, turbidity; whereas for agricultural reuse, electrical conductivity (EC), sodium adsorption ratio and twelve other metals are considered [53]. Additional parameters such as *Legionella* spp. or nutrients may be required depending on the intended use and related quality class.

In French regulations [55], limits are not imposed for heavy metals or agronomically valued compounds. Standards are only defined and divided into four quality classes for six quality parameters including *E. coli*, chemical oxygen demand (COD), total suspended solids (TSS), faecal enterococci, sulphate-reducing bacteria, and F-specific bacteriophages. Greek regulations [56] permit numerous reuse practices, defining three quality categories, combined with the required treatment performance. Quality parameters include *E. coli*, BOD_5, TSS, and turbidity. Additional requirements are set for large WWTPs, including 19 heavy metals for WWTPs > 2,000 population equivalent (PE), and other 40 organic compounds for WWTPs > 100,000 PE, and parameters of agronomic relevance. In addition, Cyprus provides limiting values for five different reuse classes, considering the WWTP size [52]. Italian regulations have established stringent limiting values, of which approximately 20% are comparable to those required for drinking water [57]. Furthermore, they must be met for all intended uses except for industrial reuse. These stringent requirements aim to ensure human health and environmental protection considering all possible uses but can hinder the economic feasibility of water-reuse practices, especially in less advanced or extended applications [32].

E. coli is the most popular indicator of pathogenic contamination and is used in all analysed regulations. Moreover, the determination of helminth eggs is included in the regulations in Spain, Cyprus, and Portugal. French regulations also include faecal enterococci as a supplementary bacterial indicator. Notably, the limiting values differ by up to one order of magnitude, varying from the strictest levels of 10 colony-forming unit (CFU)·100 mL^{-1} established by Italy and Greece to 100 CFU·100 mL^{-1} permitted by Spain for certain quality classes. Spain and Greece are characterised as having the strictest monitoring protocols (Table 3), whereas in Italy, regional authorities demand this level of stringency.

The Portuguese Regulation [58] follows the ISO standards 20760:2018 [59], 20426:2018 [45], and 16075:2020 [43] and includes risk management. It considers the definition of quality classes according to the fit-for-purpose approach, providing water quality standards based on the intended use [60] rather than defining common limits for all purposes. This requires the development of risk assessment plans for each water-reuse case. Unlike other national regulations, the Portuguese Regulation also provides detailed guidelines to support risk assessment in water-reuse projects.

Table 3. Summary of r*elevant information of National Regulations on Water Reuse in some EU countries.*

Country	Cyprus	France	Greece	Italy	Spain	Portugal
Standards reference	[52]	[55]	[56]	[54]	[53]	[58]
Issuing institution	Ministry of Agriculture, Natural resources and Environment Water development Department (Wastewater and reuse Division)	Ministry of Public Health Ministry of Agriculture, Food and Fisheries Ministry of Ecology, Energy and Sustainability	Ministry of Environment Energy and Climate Change	Ministry of Environment Ministry of Agriculture, Ministry of Public Health	Ministry of Environment Ministry of Agriculture, Food and Fisheries, Ministry of Health	Portuguese Environment Agency
Intended use	Urban areas irrigation, agriculture irrigation, golf course irrigation, aquifer recharge. Only from urban wastewater.	Urban areas irrigation, agriculture, golf course irrigation, green areas not accessible to the public	Urban areas irrigation and street cleaning, agriculture, industrial reuse, aquifer recharge, golf course irrigation, green areas not accessible to the public	Urban areas irrigation and street cleaning, agriculture, industrial reuse, golf course irrigation, green areas not accessible to the public	Urban areas irrigation and street cleaning, private gardens, agriculture, industrial reuse, aquifer recharge, golf course irrigation, green areas not accessible to the public, silviculture, environmental uses (e.g., wetlands, minimum stream flows)	Agriculture irrigation, urban uses (landscape, flushing, fire-fighting, street cleaning, recreational uses) or ecosystem support
Quality categories	5	4	3	1 (apart industrial reuse)	12	5
	Protection of waters against pollution caused by nitrates from agricultural sources					Technical Guide on wastewater reuse, to support the implementation of water reuse projects
Regulated parameters (microbial)	20 (2)	6 (4)	up to 80*	55 (2)	Up to 90* (3)	21 (2)
Monitoring frequency	1/15 days; pH: 3/week; metals: 2/year; Chlorides:	1/week 1/two weeks 1/month	Turbidity, *E. coli*, total coliforms: 7-1/week ; others: 24/year 12/year	Regional regulations	Microbial: 3/week - 1/ month; TSS: 1/day - 1/week; others: 1/two weeks - 1/month	1/week – 1/2 weeks, continuous operational monitoring

	1/month; Helminth eggs: 4/year.		4/year			
Risk management	-	Risk analysis of treatment and distribution malfunctions	-	-	Guidelines on permitting procedures and technical support for risk assessment for health and environment	Guideline for risk assessment
Public	-	Information boards in green public spaces	-	-	-	Communication to public

**: Depending on the final use and specific project requirements*

4.2. Regulation 2020/741 on minimum requirements for water reuse

The European Parliament and the Council recently approved Regulation 2020/741 *on minimum requirements for water reuse* [61] to increase the amount of reclaimed water used in the continent and solve the conflicts related to the lack of standardisation. This regulation was established following the principles of previous guidelines, to overcome their limitations and adapt water-reuse practices to the current socio-political scenario of the Union. The EU Regulation establishes quality limits for certain pollutants as well as the frequency of monitoring and treatment performance targets for reclaimed water reuse in agriculture, depending on four different quality classes in a fit-for-purpose approach. Water quality classes (Classes A–D) were defined in terms of pathogens, BOD, TSS concentrations, and turbidity. Microbiological pollution is assessed by the *E. coli* concentration in water (bacterial indicator), combined with the total coliphages (alternatively, F-specific coliphages or somatic coliphages) and *Clostridium perfringens* spores (or spore-forming sulphate-reducing bacteria), which act as virus and protozoa indicators, respectively. The limiting values of these parameters varied according to the quality class (Table 4). The limits of *Legionella* spp. and intestinal nematodes are also indicated for certain reuse practices. Water-quality classification also depends on the crop category to be irrigated and irrigation technique. Class D can only be applied to non-food crops, Class C applies to food crops with above-ground edible parts and irrigation using drip irrigation, and Class B can use other irrigation methods. The most stringent is Class A which includes the irrigation of food crops consumed raw, which are in direct contact with reclaimed water [61].

Monitoring requirements also depend on the reclaimed water-quality class, in addition to the specific parameter analysed. *E. coli* monitoring varies from twice a month (Classes

C–D) to once a week (Classes A–B), whereas BOD and TSS should be analysed once a week, and turbidity must be continuously monitored. Validation and routine monitoring should be performed before a new reclamation facility is put into operation.

The new EU Regulation also introduces WRRMPs as a mandatory step for determining the minimum requirements for specific pollutants in specific settings to reduce the risks associated with public health and the environment to the maximum extent. The WRRMP should identify and manage risks proactively to ensure that reclaimed water is safely used and managed and poses no significant risks to the environment or human or animal health. Thus, this regulation combines the first and third water-reuse approaches defined in Section 4. The Water Reuse Risk Management Plan is based on the key risk management principles as defined in Annex II of Regulation 2020/741 following: i) a preparatory step (description of the entire reuse system and the parts involved); ii) a system assessment and risk management step (identification of the potential hazards and hazardous events for human health and the environment, the population involved, and the exposure routes); iii) an operational monitoring step (monitoring specifications for different matrices involved); and iv) an implementation step (governance, management, and communication plans). Risk assessment can be performed using qualitative or semi-quantitative risk assessments. Quantitative risk assessment should be used when sufficient supporting data is available or in projects that pose a potentially high risk to the environment or public health. Based on the risk assessment outcomes, additional requirements regarding heavy metals, CECs, and/or ARG are required.

4.2.1. Innovative aspects of EU Regulation 2020/741

EU Regulation 2020/741 fills a legislative gap by defining the requirements and conditions for water-reuse applications. For the first time, a legislation is available that standardises technological and quality standards across the Union. Previously, only a few member states addressed water reuse with specific regulations, which differed significantly (as discussed in Section 4.1).

One of the most innovative aspects of this regulation is the inclusion of water-reuse risk management plans among mandatory requirements. This emphasises the importance of health and environmental protection, which must always be ensured. Thus, the regulation follows the fit-for-purpose approach, instead of the fit-for-all method that has been addressed by some EU members such as Italy. Accordingly, not only are quality limits established, but crop quality and irrigation techniques must also comply. This fit-for-purpose approach aims to facilitate the techno-economic feasibility of water-reuse applications, which is supported by the fact that, compared to national legislation, the EU Regulation selected a lower number of parameters to be monitored to accomplish quality requirements (Table 4). However, it also provides EU members the flexibility to include in their national laws limiting concentrations of other pollutants such as ARB, antibiotics, microplastics, etc. These compounds have been scarcely considered in previous legislation but are specifically considered in this EU Regulation and the updated Directive concerning urban wastewater treatment (under revision) [62] because of the growing concern they generate.

Table 4: Pollutant concentration limits in national and European Regulations

Regulation	**Cyprus** [52]	**France** [55]	**Greece** [56]	**Italy** [54]	**Portugal** [58]	**Spain** [53]	**Regulation 2020/741*** [61]
E. coli (n/100 mL)	$5\text{-}10^3$	$250\text{-}10^5$	5- 200	10	$10\text{-}10^4$	$0\text{-}10^4$	≤ 10 - 1000
BOD_5 (mg/L)	10-70	COD: 60	10-25	20	10-40		≤ 10 - 25
TSS (mg/L)	10-30	15	2-35	10	10-60	5-35	≤ 10 - 35
Turbidity (NTU)	-	-	2-no limit	-	≤ 5 – no limit	1-15	≤ 5 – no limit
Others	Helminth eggs, COD, pH, conductivity, Heavy metals and metalloids, Fat & oil, chlorides, nutrients	Faecal enterococci, Sulphate-reducing Bacteria, F-specific Bacteriophages	Total coliforms, pH, conductivity, Heavy metals and metalloids, chlorides, nutrients, TDS, SAR, bicarbonate, Toxic substances including priority substances	Salmonella sp., pH, conductivity, Heavy metals and metalloids, Fat & oil, chlorides, nutrients, SAR, Toxic substances including priority substances	Helminth eggs, Ammonia, Nitrogen, Phosphorus, Heavy metals, SAR, Salinity and Boron	Metals, EC, SAR.	Total coliphages (F-specific coliphages or somatic coliphages), Clostridium perfringens spores (or spore-forming sulphate reducing bacteria), Legionella spp.: <1 000 CFU/L; Intestinal nematodes: ≤1 egg/L

**Lowest limiting value for Class A; highest limiting value for Class D.*

Other innovative aspects of this regulation compared to the previous regulations are as follows: i) monitoring requirements are explicitly expressed and therefore normalised, whereas in some national regulations, such as in Italy, they are provided by local authorities; ii) reclamation facility operators are defined, shifting the conventional paradigm of wastewater treatment to wastewater reuse; iii) the relevance of public awareness regarding the benefits of water reuse has been highlighted, following the recommendations of previous guidelines (refer to Section 3.1.3 for details); iv) the promotion of fertigation, a practice that combines irrigation and nutrient recovery and contradicts traditional wastewater treatment schemes where nutrients are removed from water instead of being recovered [6]; and v) the proposal of financial incentives for water reuse and further research into the topic.

4.2.2. Gaps and limitations in the Regulation

Although Regulation 2020/741 has harmonised water-reuse practices providing standards and requirements, some aspects have not yet been thoroughly addressed: i) for risk management, key elements are listed but not described; ii) the methodology for risk assessment should at least be semi-quantitative, but no further information is provided; iii) some examples of control measures are provided, but a method to evaluate their contribution to risk minimisation is not well defined; and iv) the legislation specifies that the reuse system description must consider all the integrated systems from the wastewater source to its final use, including possible external contributions such as dilution of treated wastewater with other sources, but the regulation does not specify a technique to address these aspects. This creates a significant gap in some areas, such as Italy, where many distribution systems are managed by irrigation consortia that generally use surface water to irrigate crops whose quality is not monitored or regulated; thus, they do not have the infrastructure to undertake these tasks.

A detailed description of the method to assess microbiological risks related to water quality is available. Nonetheless, indicators, such as *E. coli*, *Legionella* spp., and intestinal nematodes, are not always monitored in WWTPs. In many cases, they are only analysed in the effluent, being unable to know the total log removal of pathogens in the WWTP.

Thus, it can be hard to ensure, due to the lack of data regarding the occurrence, trends, and treatment efficiencies in pathogen removal, that the treatment system could accomplish with the legislation (in terms of total pathogen removal), which may discourage the construction of new water reclamation facilities. Moreover, pathogen determination is expensive and can be affected by many variables, outer contamination of samples, and the inaccuracy of the equipment and measuring methodologies. Consequently, they sometimes provide results with high uncertainty. In addition, standard methods for their determination usually require excessively long times of around 24–48 h, which would imply an extremely long response time when pathogen proliferation occurs. Furthermore, some techniques for pathogen analysis are simply based on the presence of pathogenic microorganisms in the sample, and do not distinguish whether they are active or inactive. In cases where inactive biological pollutants are present, a reduction in their concentration is not directly related to a decrease in risk. All of these limitations in current detection techniques hinder in attaining the legal limits and increase operating costs (primarily due to the requirement of higher doses of disinfecting agents) without necessarily improving safety in the reuse of water. Thus, more innovative monitoring technologies and techniques must be developed. Monitoring programs should be supported by digital tools, including innovative sensors to monitor microbiological contamination or early warning systems (EWSs) to provide real-time signals and facilitate rapid interventions when possible hazards are detected. However, the regulation only considers standard lab measurements to verify the accomplishment of quality requirements, limiting the use of digital tools to internal monitoring procedures.

In addition to the aforementioned limitations, information is lacking on a method to manage risks from other pollutants, such as CECs, ARG, and metals [4]. Monitoring these compounds would lead to technical issues and high costs of analysis. Some authors state that reclaimed facilities, end-users and other stakeholders should share these costs [49], but no information is provided regarding cost sharing in the regulation. No references have been made to reducing pollutants at the source. This should be promoted in these (or complementary) regulations because pollutant concentrations in wastewater influents are one of the most relevant factors influencing the final water quality [63].

Another important aspect (not specified in the regulation) is the monitoring requirements of soils and/or crops. No information is provided regarding the parameters that should be monitored, frequencies, or sampling points. This is crucial for assessing the environmental impacts of water-reuse practices and evaluating potential health risks, particularly for toxic compounds that may accumulate in crops and humans. According to the proposed regulation [61], determining the need for additional requirements requires the operator to compare the outcomes of the risk assessment to acceptable levels of risk or water quality. The Regulation 2020/741 provides no further guidance, except for referring to other EU regulations under Task 4. Optimising these regulations or other environmental and health criteria to minimise requirements for reclaimed water facilities while ensuring the safe reuse of water is a complex task, even for water risk-assessment experts. Some authors have stated their concerns that these difficulties, combined with the associated costs of reuse, might unintentionally lead to indirect reuse [64]. Hence, supporting (supra)national guidelines is necessary for operators and regulators to efficiently prepare WRRMPs that protect human health and the environment without excessively hindering the water-reuse process [64]. To overcome these limitations, technical guidelines for the implementation of WRRMPs has recently been launched [65,66]. The structure is divided into 11 key risk management (KRM) elements grouped into four modules: I) preparation (KRMs 1–2); II) risk assessment (KRMs 3–6); III) monitoring (KRMs 6 and 9); and IV) governance, management, and communication (KRMs 7–11).

In the preparation phase (Module I), the objectives, influencing factors, boundaries, and actors involved must be defined. The guideline suggests the quantitative information to be collected and the factors to be considered [66]. This is a crucial step because it allows the contextualisation of site-specific characteristics into larger regional, national, and European frameworks. In the second module (risk assessment), the system functionality, exposure routes, and exposed groups must be defined; moreover, hazards and hazardous events must be identified. Relevant information can be obtained regarding health and environmental risk assessments, as well as exposure assessments, targets, and pathways. Guidelines are provided for both qualitative and quantitative risk assessment approaches. Socio-economic impact assessments are also presented. Module III encompasses operational monitoring and specifies the requirements, recommendations, and practices for the monitoring of different matrices of water, crops, and soils. Finally, in Module IV, information can be found on the governance, management, and communication plans to support water-reuse planning and implementation.

5. Overcoming the barriers to promote water reuse

The implementation of water-reuse practices is complex and is hindered by many factors (as discussed in Section 2). Consequently, in addition to managing proficient reclamation facilities and developing WRRMPs that ensure the safe use of reclaimed water, other activities, methodologies, and tools are needed to overcome these obstacles.

5.1. Improvement of social awareness and involvement of stakeholders

The water-reuse practices to be implemented must be accepted by facility operators and managers, authorities, users, consumers, and the civil population, who have to be aware of water-reuse benefits and its possible risks and safety measures. This is a highly relevant factor because a lack of trust in water-reuse management can completely impede water-reuse development [31,32]. Thus, engaging stakeholders and the general public in the planning and introduction of water-reuse systems is important, preferably at an early stage. This can ensure transparency, trust, and acceptance while gathering useful information from stakeholders, which helps to align approaches. In addition to the common dissemination strategies, consultations, and awareness campaigns that have already been suggested by the current guidelines (described in Section 3.1), novel tools for dissemination are needed. In this context, serious games can help involve and train stakeholders and the general public in more sustainable water management approaches [67]. They can also help decision-makers analyse different political options for the future. A serious game was developed under the *H2020-DWC project* to evaluate and communicate the existing nexus between water reuse, carbon emissions, energy consumption, and food production in an integrated peri-urban wastewater reuse system

[68]. In this 'game', the user can simulate different WWTP configurations to reach different water quality classes, and select different irrigation techniques and crops, according to the EU Regulation 2020/741 [61].

However, raising awareness of the benefits of water reuse must be complemented with the awareness about water scarcity problems because the perception of these concepts can significantly influence both 'willingness to use' and 'willingness to pay' for reclaimed water to ensure water availability [29,69]. In Australia, owing to a serious water scarcity period during 2007–2009, a substantial investment (ranging billions of dollars) was made to build and implement reclaimed water facilities. However, after heavy rain episodes associated with 'La Niña' in late 2010, these facilities were underused. Similarly, in France, water reuse is restricted to certain regions because this country only suffers from local and seasonal episodes of water scarcity [37], whereas Northern European countries hardly adopt water-reuse practices, as previously explained. Countries should not wait for serious scarcity events to develop political strategies based on safe water reuse. Building new water reclamation facilities, as well as the training and education of operators, technicians, managers and farmers, can take several years. Thus, immediate action is necessary to prepare for water scarcity episodes in the next decades and ensure safe water availability to all users, which is one of the sustainable development goals (SDGs) of the United Nations.

5.2. Additional methodologies and tools

Additional methodologies and tools can complement health risk assessments to boost water reuse by promoting this practice to decision-makers based on the social, economic, and environmental benefits of water reuse. They can also be used by water utilities to align their companies with the EU Taxonomy's objectives [70], increasing their competitiveness and providing them with an improved public image for administrations and the general public.

5.2.1. Nutrient management plans

In line with wastewater reuse for agriculture purposes, fertigation is a practice that combines water irrigation with nutrient addition, thereby reducing the water and nutrient needs of crops simultaneously. Consequently, fertigation can decrease (or even eliminate) the use of synthetically produced nutrients that require approximately 10 $kWh \cdot kg\text{-}NH_4^{-1}$ (in the case of nitrogen) and approximately 20.7 $kWh \cdot kg\text{-}PO_4^{-1}$ (in the case of phosphorus) [71]. In this context, Jiménez-Benítez et al. (2020) reported positive economic and environmental balances when a scenario based on fertigation of anaerobic membrane bioreactor effluents was considered, that is, a return of up to 376 $k€ \cdot y^{-1}$ and savings in CO_2 emissions of up to 898.9 $tCO_2 \cdot y^{-1}$ for mid-sized WWTPs. Thus, fertigation could be of interest to stakeholders owing to these multiple benefits. However, the conventional method to deal with nutrients in the wastewater treatment sector mostly focuses on their removal to meet legal requirements (especially when the plant emits their effluents to sensitive areas). This is an inefficient approach if wastewater is reused because nutrient removal in treatment plans is commonly energy-intensive and challenging for WWTP operators. However, excessive addition of nutrients can lead to environmental and health issues, such as crop-related problems, nutrient leaching, and runoff, which can result in groundwater pollution and/or eutrophication of water bodies [7,72]. Hence, nutrient management plans (NMPs), that are planning to be mandatory in the EU in the future, should be developed to regulate nutrient addition to soil, thus ensuring their safe use. According to Seco et al. (2018) [27], NMPs should contain the following elements: i) a water balance considering the effluents from reclaimed facilities, returns to water bodies through distribution pipelines, irrigation systems and fields, evapotranspiration, and crop requirements; ii) a nutrient balance that considers their concentrations in reclaimed water, nutrient losses associated with returns, variations in concentration due to evapotranspiration, crop nutrient requirements, and mineral fertilisation; and iii) an economic balance that accounts for different monetary flows within the reuse system, such as costs of purification, pumping, fertilisers, irrigation water, and management plans. Thus, NMPs are aligned with risk management plans and can complement them to increase reclaimed water production by strengthening the support of general users and decision-makers.

5.2.2. Assessment methodologies

Standard assessment methodologies can help to quantity the benefits of water reuse practices and analyse their risks. Thus, they can be powerful tools for raising the awareness of decision-makers, stakeholders, and the general public [71,73] , so that they can be combined with health risk management and NMPs. In this respect, life cycle assessment (LCA) aims to quantify the environmental impacts of processes through the entire production chain, can be useful in evaluating scenarios where irrigation or fertigation using reclaimed water is considered and to quantitatively demonstrate their benefits compared to conventional treatment schemes [74,75]. For instance, Foglia et al. [76] evaluated water-reuse scenarios in the Peschiera Borromeo WWTP (Italy) using an LCA. They observed lower impacts on climate change (-28%), fossil fuel depletion (-31%), mineral resource depletion (-52%), and freshwater ecotoxicity (-35%) in a treatment scenario based on anaerobic treatment coupled with ultrafiltration, compared to a baseline scenario using a conventional activated sludge system coupled with ultraviolet disinfection.

As a step beyond LCA assessment, the water-energy-food-climate (WEFC) or water-energy-food-ecosystems (WEFE) nexus link water and energy consumption, carbon emissions, environmental impacts, and food production in agriculture focusing on synergies and trade-offs at the physical, digital, socio-economic, and governance levels. It can be assessed through a systematic approach of design, scientific investigation, and policy instruments and indicates a paradigm shift in wastewater management, from simply considering the environmental impacts related to wastewater discharge to assessing all the impacts (positive or negative) related to the processes with the ultimate goal of carbon neutrality and long-term sustainability [51,71,73]. Thus, nexus assessment is a novel approach that can be combined with risk management and NMPs to ensure safe and sustainable water reuse, with the aim of ensuring water and food availability in the subsequent decades.

5.3. Digital tools related to water reuse

Water and wastewater management have improved considerably (especially in the last decade) owing to technological progress that has provided innovative sensors and tools to support and implement monitoring and control systems, combined with tools to treat, process, and analyse the data [77]. In addition to the tools used to increase awareness, such as serious games (discussed in Section 5.1), digital tools can be used to improve the performance of reclaimed water facilities in their daily activities, to achieve a smart wastewater treatment sector [51,78]. Sensors can be used for treatment optimisation and energy savings by facilitating rapid responses through real-time monitoring. In contrast, EWSs can be used for monitoring, data analysis, and decision support [79,80]. They can rapidly detect system malfunctions or anomalous event occurrences, thus overcoming technical barriers related to delay in data acquisition from grab samples due to the lag time between sampling, measuring, and data analysis. Different reclamation schemes have also used EWSs for water quality monitoring and rapid communication, such as the Médenine WWTP (Tunisia) [81]; or the Peschiera Borromeo WWTP (Italy), where an EWS has been deployed within H2020-DWC project for safe water reuse in agriculture. Data from sensors were used to forecast wastewater quality using artificial neural networks to develop soft sensors and time-series predictions, facilitating rapid response when a warning of non-compliance with reuse standards is provided [82]. Affordable sensors have been commonly used to predict trends in critical parameters that are not usually monitored or for which faulty signals may be generated. Thus, EWSs can be easily integrated into existing monitoring networks of WWTPs, supporting the digitisation of monitoring and control systems without overloading analytical laboratories or installing expensive sensors.

Conclusions

The reuse of wastewater for irrigation or fertigation is currently far from its potential use. Many factors hinder its development. Some are related to the feasibility of the reclamation process and the potentially toxic compounds present in the reclaimed water. In contrast, others are economic and socio-political, associated with a lack of trust among stakeholders and the general public in water-reuse techniques and practices, the unwillingness of politicians to invest in reclamation facilities, and others. The lack of homogeneity in water-reuse regulations has been generally another relevant challenge. The EU Regulation 2020/741 was recently approved to overcome these challenges and standardise the legal requirements of reclaimed water to be considered fit for reuse. A novel aspect of this regulation is the need to elaborate on WRRMPs in all reclamation facilities to minimise health risks and protect the environment when reclaimed water is used. In addition to ensuring safe water reuse, WRRMPs aim to transform people's opinions by increasing their awareness of the benefits of reusing water and reducing their biased opinions on the risks of using reclaimed water. To achieve these goals, the gaps in existing guidelines and regulations, as well as the difficulties faced by water-reuse professionals during the implementation of reclaimed water processes must be identified. Some key aspects to be considered are the importance of guidelines for developing efficient WRRMPs that ensure safe health and environmental protection as well as the capital and operating costs related to modern reclaimed water facilities.

NMPs and other assessment methodologies, such as LCA and WEFC nexus, can be combined with WRRMPs and contribute to the development of water-reuse practices. Digital tools have also been found to improve the efficiency and applicability of water-reuse technologies and increase public awareness. Most importantly, pollutant reduction at source is a key factor to improve reclaimed water quality and can help improve people's perception of wastewater reuse technology.

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References

[1] WWAP, Leaving no one Behind. World Water Assessment Programme. The United Nations World Water Development Report., Geneva (Switzerland), 2019.

[2] M. Farhadkhani, M. Nikaeen, G. Yadegarfar, M. Hatamzadeh, H. Pourmohammadbagher, Z. Sahbaei, H.R. Rahmani, Effects of irrigation with secondary treated wastewater on physicochemical and microbial properties of soil and produce safety in a semi-arid area, Water Res. 144 (2018) 356–364. https://doi.org/10.1016/J.WATRES.2018.07.047.

[3] M.F. Jaramillo, I. Restrepo, Wastewater reuse in agriculture: A review about its limitations and benefits, Sustainability. 9 (2017). https://doi.org/10.3390/su9101734.

[4] G. Deviller, L. Lundy, D. Fatta-Kassinos, Recommendations to derive quality standards for chemical pollutants in reclaimed water intended for reuse in agricultural irrigation, Chemosphere. 240 (2020). https://doi.org/10.1016/j.chemosphere.2019.124911.

[5] A.A. Adegoke, I.D. Amoah, T.A. Stenström, M.E. Verbyla, J.R. Mihelcic, Epidemiological evidence and health risks associated with agricultural reuse of partially treated and untreated wastewater: A review, Front Public Health. 6 (2018). https://doi.org/10.3389/fpubh.2018.00337.

[6] A. Jiménez-Benítez, F.J. Ferrer, S. Greses, A. Ruiz-Martínez, F. Fatone, A.L. Eusebi, N. Mondéjar, J. Ferrer, A. Seco, AnMBR, reclaimed water and fertigation: Two case studies in Italy and Spain to assess economic and technological feasibility and CO2 emissions within the EU Innovation Deal initiative, J Clean Prod. 270 (2020). https://doi.org/10.1016/j.jclepro.2020.122398.

[7] S. Ofori, A. Puškáčová, I. Růžičková, J. Wanner, Treated wastewater reuse for irrigation: Pros and cons, Science of The Total Environment. 760 (2021) 144026. https://doi.org/10.1016/J.SCITOTENV.2020.144026.

[8] ilje Pikaar, J. Guest, R. Ganigué, P. Jensen, K. Rabaey, T. Seviour, J. Trimmer, O. van der Kolk, C. Vaneeckhaute, W. VERSTRAETE, Resource Recovery from Water Principles and Application., 2022.

[9] M. Al-Saidi, P. Das, I. Saadaoui, Circular Economy in Basic Supply: Framing the Approach for the Water and Food Sectors of the Gulf Cooperation Council Countries, Sustain Prod Consum. 27 (2021) 1273–1285. https://doi.org/10.1016/j.spc.2021.03.004.

[10] Aquastat, Aquastat, Https://Www.Fao.Org/Aquastat/En/. (2022).

[11] A.J. Sorinolu, N. Tyagi, A. Kumar, M. Munir, Antibiotic resistance development and human health risks during wastewater reuse and biosolids application in agriculture, Chemosphere. 265 (2021). https://doi.org/10.1016/j.chemosphere.2020.129032.

[12] N.H. Tran, M. Reinhard, K.Y.H. Gin, Occurrence and fate of emerging contaminants in municipal wastewater treatment plants from different geographical regions-a review, Water Res. 133 (2018) 182–207. https://doi.org/10.1016/j.watres.2017.12.029.

[13] B.S. Choudri, Y. Charabi, Health effects associated with wastewater treatment, reuse, and disposal, Water Environment Research. 91 (2019) 976–983. https://doi.org/10.1002/wer.1157.

[14] C. Becerra-Castro, A.R. Lopes, I. Vaz-Moreira, E.F. Silva, C.M. Manaia, O.C. Nunes, Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health, Environ Int. 75 (2015) 117–135. https://doi.org/10.1016/j.envint.2014.11.001.

[15] M. Wilson, M. Aqeel Ashraf, Study of fate And transport of emergent contaminants at waste water treatment plant, Environmental Contaminants Reviews. 1 (2018) 01–12. https://doi.org/10.26480/ecr.01.2018.01.12.

[16] A. Christou, A. Agüera, J.M. Bayona, E. Cytryn, V. Fotopoulos, D. Lambropoulou, C.M. Manaia, C. Michael, M. Revitt, P. Schröder, D. Fatta-Kassinos, The potential implications of reclaimed wastewater reuse for irrigation on the agricultural environment: The knowns and unknowns of the fate of antibiotics and antibiotic resistant bacteria and resistance genes – A review, Water Res. 123 (2017) 448–467. https://doi.org/10.1016/j.watres.2017.07.004.

[17] European Commission, COMMISSION IMPLEMENTING DECISION (EU) 2020/1161 of 4 August 2020 establishing a watch list of substances for Union-wide monitoring in the field of water policy pursuant to Directive 2008/105/EC of the European Parliament and of the Council, 2020.

[18] L. Semerjian, A. Shanableh, M.H. Semreen, M. Samarai, Human health risk assessment of pharmaceuticals in treated wastewater reused for non-potable applications in Sharjah, United Arab Emirates, Environ Int. 121 (2018) 325–331. https://doi.org/10.1016/j.envint.2018.08.048.

[19] R. Delli Compagni, M. Gabrielli, F. Polesel, A. Turolla, S. Trapp, L. Vezzaro, M. Antonelli, Risk assessment of contaminants of emerging concern in the context of wastewater reuse for irrigation: An integrated modelling approach, Chemosphere. 242 (2020). https://doi.org/10.1016/j.chemosphere.2019.125185.

[20] Y. Ben, C. Fu, M. Hu, L. Liu, M.H. Wong, C. Zheng, Human health risk assessment of antibiotic resistance associated with antibiotic residues in the environment: A review, Environ Res. 169 (2019) 483–493. https://doi.org/10.1016/j.envres.2018.11.040.

[21] WHO, Antimicrobial Resistance: Global Report on Surveillance., 2014.

[22] L. Ma, H. Yang, L. Guan, X. Liu, T. Zhang, Risks of antibiotic resistance genes and antimicrobial resistance under chlorination disinfection with public health concerns, Environ Int. 158 (2022). https://doi.org/10.1016/j.envint.2021.106978.

[23] D. Goodwin, M. Raffin, P. Jeffrey, H.M. Smith, Collaboration on risk management: The governance of a non-potable water reuse scheme in London, J Hydrol (Amst). 573 (2019) 1087–1095. https://doi.org/10.1016/j.jhydrol.2017.07.020.

[24] J. Melgarejo, D. Prats, A. Molina, A. Trapote, A case study of urban wastewater reclamation in Spain: Comparison of water quality produced by using alternative processes and related costs, Journal of Water Reuse and Desalination. 6 (2016) 72–81. https://doi.org/10.2166/wrd.2015.147.

[25] European Commission, Directorate-General for Research and Innovation, T., Wintgens, D., Bixio, Water reuse system management manual : Aquarec, 2006. https://op.europa.eu/en/publication-detail/-/publication/b1912e31-3945-45a9-a01e-b29bfd058949 (accessed January 10, 2023).

[26] IMPEL, Report on Urban Water Reuse (2018/07)., 2018.

[27] A. Seco, A. Jiménez, A. Ruiz-Martínez, J. Ferrer, AnMBR technology to treat sewage and reuse it in agriculture (Tecnología AnMBR para tratamiento de aguas residuales urbanas y reutilización de agua en agricultura), RETEMA-Revista Técnica de Medio Ambiente. 207 (2018) 8–16.

[28] S. Lavrnić, M. Zapater-Pereyra, M.L. Mancini, Water Scarcity and Wastewater Reuse Standards in Southern Europe: Focus on Agriculture, Water Air Soil Pollut. 228 (2017). https://doi.org/10.1007/s11270-017-3425-2.

[29] X. Garcia, D. Pargament, Reusing wastewater to cope with water scarcity: Economic, social and environmental considerations for decision-making, Resour Conserv Recycl. 101 (2015) 154–166. https://doi.org/10.1016/j.resconrec.2015.05.015.

[30] H. ben Brahim-Neji, A. Ruiz-Villaverde, F. González-Gómez, Decision aid supports for evaluating agricultural water reuse practices in tunisia: The cebala perimeter, Agric Water Manag. 143 (2014) 113–121. https://doi.org/10.1016/j.agwat.2014.07.002.

[31] S. Ofori, A. Puškáčová, I. Růžičková, J. Wanner, Treated wastewater reuse for irrigation: Pros and cons, Science of the Total Environment. 760 (2021). https://doi.org/10.1016/j.scitotenv.2020.144026.

[32] M. Troldborg, D. Duckett, R. Allan, E. Hastings, R.L. Hough, A risk-based approach for developing standards for irrigation with reclaimed water, Water Res. 126 (2017) 372–384. https://doi.org/10.1016/j.watres.2017.09.041.

[33] M.C. Almeida, Vieira P., P. Smeets, Water cycle safety plan framework. Final. Report number PREPARED 2013.025 Deliverable number D2.1.4. , 2013.

[34] World Health Organization, Guidelines for the safe use of wastewater, excreta and greywater - Volume 2, 2006. https://www.who.int/publications/i/item/9241546832 (accessed January 10, 2023).

[35] World Health Organization, Sanitation safety planning: manual for safe use and disposal of wastewater, greywater and excreta, 2015. https://apps.who.int/iris/handle/10665/171753 (accessed January 10, 2023).

[36] European Parliament, Council of the European Union, REGULATION (EC) No 852/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2004 on the hygiene of foodstuffs, (2004).

[37] N. Ait-Mouheb, A. Bahri, B. ben Thayer, B. Benyahia, G. Bourrié, B. Cherki, N. Condom, R. Declercq, A. Gunes, M. Héran, N. Kitir, B. Molle, D. Patureau, A. Pollice, A. Rapaport, P. Renault, K. Riahi, B. Romagny, T. Sari, C. Sinfort, J.P. Steyer, S. Talozi, B. Topcuoglu, M. Turan, N. Wéry, E. Yıldırım, J. Harmand, The reuse of reclaimed water for irrigation around the Mediterranean Rim: a step towards a more virtuous cycle?, Reg Environ Change. 18 (2018) 693–705. https://doi.org/10.1007/s10113-018-1292-z.

[38] L. Semerjian, A. Shanableh, M.H. Semreen, M. Samarai, Human health risk assessment of pharmaceuticals in treated wastewater reused for non-potable

applications in Sharjah, United Arab Emirates, Environ Int. 121 (2018) 325–331. https://doi.org/10.1016/j.envint.2018.08.048.

[39] U.S. Environmental Protection Agency, Guidelines for Water Reuse, EPA/600/R-12/618, 2012. https://www.epa.gov/sites/default/files/2019-08/documents/2012-guidelines-water-reuse.pdf (accessed January 10, 2023).

[40] Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Ministers Conference, Australian Guidelines for Water Recycling: Managing Health and Environmental Risks, 2006.

[41] R., Hochstrat, M., Peter, T., Wintgens, F., Kraus, W., Seis, U., Miehe, J. Frijns, DEMOWARE Project. D3.4 Water Reuse Safety Plans. Handbook of risk management and environmental benefit analysis for decision-making in water reuse (Public deliverable), 2017. www.demoware.eu (accessed January 11, 2023).

[42] United Nations Environment Programme, Guidelines for municipal water reuse in the mediterranean region, 2005.

[43] International Standard Organization, ISO 16075-1:2020 Guidelines for treated wastewater use for irrigation projects — Part 1: The basis of a reuse project for irrigation, 2020. https://www.iso.org/standard/73482.html (accessed January 10, 2023).

[44] World Health Organization, Quantitative Microbial Risk Assessment: Application for Water Safety Management, 2016. https://apps.who.int/iris/handle/10665/246195 (accessed January 10, 2023).

[45] International Standard Organization, ISO 20426:2018 Guidelines for health risk assessment and management for non-potable water reuse, 2018. https://www.iso.org/standard/67972.html (accessed January 10, 2023).

[46] W. Seis, Risk assessment of Braunschweig wastewater reuse scheme, 2012.

[47] F. Kraus, W. Seis, C. Remy, M. Rustler, I. Jubany Güell, M. Viladés, J. Jorge Espí, F. Clarens, DEMOWARE Project. D3.2 Show case of the environmental benefits and risk assessment of reuse schemes, 2017. www.demoware.eu.

[48] X. Lin, J. Xu, A.A. Keller, L. He, Y. Gu, W. Zheng, D. Sun, Z. Lu, J. Huang, X. Huang, G. Li, Occurrence and risk assessment of emerging contaminants in a water reclamation and ecological reuse project, Science of The Total Environment. 744 (2020) 140977. https://doi.org/10.1016/J.SCITOTENV.2020.140977.

[49] M. Salgot, M. Folch, Wastewater treatment and water reuse, Curr Opin Environ Sci Health. 2 (2018) 64–74. https://doi.org/10.1016/j.coesh.2018.03.005.

[50] M. Gancheva, McNeill Alicia, M. Muro, Water Reuse-Legislative Framework in EU Regions, 2018. https://doi.org/10.2863/846239.

[51] S. Radini, E. Marinelli, Ç. Akyol, A.L. Eusebi, V. Vasilaki, A. Mancini, E. Frontoni, G.B. Bischetti, C. Gandolfi, E. Katsou, F. Fatone, Urban water-energy-food-climate nexus in integrated wastewater and reuse systems: Cyber-physical framework and innovations, Appl Energy. 298 (2021). https://doi.org/10.1016/j.apenergy.2021.117268.

[52] KDP, Law 106 (I) 2002 Water and Soil pollution control and associated regulations KDP 772/2003, KDP 379/2015, 2015.

[53] Government of Spain, Royal Decree 1620/2007: The legal framework for the reuse of treated wastewater, 2007.

[54] Ministry of Environment and territory protection, DECREE 12 June 2003, n. 185 - Regulation containing technical standards for the reuse of waste water in

implementation of article 26, paragraph 2, of the legislative decree 11 May 1999, n. 152., 2003.

[55] Government of France, JORF num.0153, Order of 2014, related to the use of water from treated urban wastewater for irrigation of crops and green areas, 2014.

[56] Government of Greece, Joint Ministerial Decree 145116/11 or CMD No 145116 Measures, limits and procedures for reuse of treated wastewater, Ministry of Environment, Energy and Climate Change Save water. A modern challenge in the face of climate change, 2011.

[57] F. Brissaud, Criteria for water recycling and reuse in the Mediterranean countries, Desalination. 218 (2008) 24–33. https://doi.org/10.1016/j.desal.2006.07.016.

[58] Government of Portugal, Law Decree 119/2019. Legal Regime of Water Production for Reuse. , 2019.

[59] International Standard Organization, ISO 20760-1:2018 Water reuse in urban areas — Guidelines for centralized water reuse system — Part 1: Design principle of a centralized water reuse system, 2018. https://www.iso.org/standard/68987.html (accessed January 10, 2023).

[60] G. Mannina, H. Gulhan, B.J. Ni, Water reuse from wastewater treatment: The transition towards circular economy in the water sector, Bioresour Technol. 363 (2022). https://doi.org/10.1016/j.biortech.2022.127951.

[61] European Parliament and Council, EU-Regulation 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse, 2020.

[62] European Parliament and Council, Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning urban wastewater treatment (recast), 2022.

[63] G. Deviller, L. Lundy, D. Fatta-Kassinos, Recommendations to derive quality standards for chemical pollutants in reclaimed water intended for reuse in agricultural irrigation, Chemosphere. 240 (2020). https://doi.org/10.1016/j.chemosphere.2019.124911.

[64] M. Dingemans, R. Bartholomeus, G. Medem, Evaluation of the proposed EU regulation on minimum requirements for water reuse for irrigation, 2018.

[65] European Commission, EUROPEAN COMMISSION NOTICE Guidelines to support the application of Regulation 2020/741 on minimum requirements for water reuse, 2022. https://circabc.europa.eu/ui/group/9ab5926d-bed4-4322-9aa7-9964bbe8312d/library/.

[66] R. Maffettone, B.M. Gawlik, Technical Guidance Water Reuse Risk Management for Agricultural Irrigation Schemes in Europe, 2022. https://doi.org/10.2760/590804.

[67] A. Mittal, L. Scholten, Z. Kapelan, A review of serious games for urban water management decisions: current gaps and future research directions, Water Res. 215 (2022) 118217. https://doi.org/10.1016/J.WATRES.2022.118217.

[68] E. Marinelli, S. Radini, Ç. Akyol, M. Sgroi, A.L. Eusebi, G.B. Bischetti, A. Mancini, F. Fatone, Water–energy–food–climate nexus in an integrated peri-urban wastewater treatment and reuse system: From theory to practice, Sustainability (Switzerland). 13 (2021). https://doi.org/10.3390/su131910952.

[69] EIT Water Scarcity, Innovative Solutions to Cope with Water Scarcity, EIT Climate-KIC, 2021.

[70] EU Technical Expert Group on Sustainable Finance., Financing a sustainable European economy. Taxonomy: Final report of the Technical Expert Group on Sustainable Finance, 2020.

[71] X. Zhang, Y. Liu, Circular economy is game-changing municipal wastewater treatment technology towards energy and carbon neutrality, Chemical Engineering Journal. 429 (2022). https://doi.org/10.1016/j.cej.2021.132114.

[72] N. Ait-Mouheb, A. Bahri, B. ben Thayer, B. Benyahia, G. Bourrié, B. Cherki, N. Condom, R. Declercq, A. Gunes, M. Héran, N. Kitir, B. Molle, D. Patureau, A. Pollice, A. Rapaport, P. Renault, K. Riahi, B. Romagny, T. Sari, C. Sinfort, J.P. Steyer, S. Talozi, B. Topcuoglu, M. Turan, N. Wéry, E. Yıldırım, J. Harmand, The reuse of reclaimed water for irrigation around the Mediterranean Rim: a step towards a more virtuous cycle?, Reg Environ Change. 18 (2018) 693–705. https://doi.org/10.1007/s10113-018-1292-z.

[73] E. Marinelli, S. Radini, A. Foglia, N. Lancioni, A. Piasentin, A.L. Eusebi, F. Fatone, Validation of an evidence-based methodology to support regional carbon footprint assessment and decarbonisation of wastewater treatment service in Italy, Water Res. 207 (2021). https://doi.org/10.1016/j.watres.2021.117831.

[74] S. Radini, E. Marinelli, Ç. Akyol, A.L. Eusebi, V. Vasilaki, A. Mancini, E. Frontoni, G.B. Bischetti, C. Gandolfi, E. Katsou, F. Fatone, Urban water-energy-food-climate nexus in integrated wastewater and reuse systems: Cyber-physical framework and innovations, Appl Energy. 298 (2021). https://doi.org/10.1016/j.apenergy.2021.117268.

[75] M. Sgroi, F.G.A. Vagliasindi, P. Roccaro, Feasibility, sustainability and circular economy concepts in water reuse, Curr Opin Environ Sci Health. 2 (2018) 20–25. https://doi.org/10.1016/j.coesh.2018.01.004.

[76] A. Foglia, C. Andreola, G. Cipolletta, S. Radini, Ç. Akyol, A.L. Eusebi, P. Stanchev, E. Katsou, F. Fatone, Comparative life cycle environmental and economic assessment of anaerobic membrane bioreactor and disinfection for reclaimed water reuse in agricultural irrigation: A case study in Italy, J Clean Prod. 293 (2021). https://doi.org/10.1016/j.jclepro.2021.126201.

[77] K.B. Newhart, R.W. Holloway, A.S. Hering, T.Y. Cath, Data-driven performance analyses of wastewater treatment plants: A review, Water Res. 157 (2019) 498–513. https://doi.org/10.1016/j.watres.2019.03.030.

[78] Water Europe Technology & Innovation, THE VALUE OF WATER Multiple Waters for Multiple Purposes and Users Multiple Waters for Multiple Purposes and Users - Towards a Future-Proof Model for a European Water-Smart Society, 2020. https://watereurope.eu/wp-content/uploads/2020/04/WE-Water-Vision-english_online.pdf (accessed January 10, 2023).

[79] W.M. Grayman, R.A. Deininger, R.M. Males, Design of early warning and predictive source-water monitoring systems, American Water Works Association, 2001.

[80] U.S. Environmental Protection Agency, Guidelines for Carcinogen Risk Assessment, Washington, DC, 2005. https://www.epa.gov/sites/default/files/2013-09/documents/cancer_guidelines_final_3-25-05.pdf (accessed January 10, 2023).

[81] K. Bedoui, Good Water Governance in Wastewater Reuse in case study: Medenine, Tunisia. In Sustainable Integrated Wastewater Treatment and Reuse. Sharm El-Shaikh, 2014.

[82] F. Fatone, DWC-Digital-Water.City (820954). D1.1: Practical manual on innovative sensor integration, validation and operation and maintenance in existing water infrastructure, 2021. https://doi.org/10.5281/zenodo.6496855 (accessed January 10, 2023).