Policy and legislative barriers to close water-related loops in innovative small water and wastewater systems in Europe: A critical analysis

Policy and legislative barriers to close water-related loops in innovative small water and wastewater systems in Europe: a critical analysis

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ABSTRACT

Water supply and reuse through non-conventional water resources can significantly decrease the stress on natural water resources. Decentralized systems can help not only to alleviate issues of water security in arid areas, but also to create a sustainable framework within a circular economy. Although these small-scale innovative technologies are able to achieve ready-to-use, high quality of recovered/treated water on-site, the loop cannot be closed in most cases due to legislative barriers. Similarly, the end-use of sewage sludge after treatment in decentralized systems still lacks specific regulations that limit its valorization. This work analyzes the current policy and legislation related to water supply, wastewater treatment, water reuse, and resource valorization within the context of decentralized state-of-the-art technologies applied in rural areas. The drawbacks in the current EU legislation that set barriers to close water-related loops in European countries are highlighted. A regulatory fitness check is applied to each type of loop to identify the key factors to accomplish the legislative compliance, and financing pathways are further evaluated at the EU level. As a possible solution, further development of an innovation deal approach is recommended to address the environmental, regulatory, and financial gaps in water management through an integrated framework, providing ad-hoc policies and prescriptions for the sustainable reuse of all water resources.

Keywords: environmental policy; innovation; non-conventional water resource; rural area; sustainability; wastewater reuse

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1. Introduction

The depletion of natural resources at a fast rate leads to a transition of the current society to re-evaluate these resources in a sustainable manner. Water is a fundamental resource to sustain life and irregularly distributed both spatially and temporally; furthermore, anthropogenic activities continuously contaminate the limited water reserves (Voulvoulis, 2018). Consequently, water sustainability is among the most discussed sustainability issues in the last years where every applicable sustainability principle has been adopted to water from reuse to recycle (Sodiq et al., 2019). These issues are increasingly discussed by the European Commission as Europe has become more and more vulnerable to water shortages and to the social, economic, and environmental impacts deriving from increasing demand and global climate change in recent times. In fact, in several areas of Europe, there's a critical issue regarding the balance between the demand and availability of water. As a result, the reduction of available water resources has been followed by a deterioration in the quality of water caused by poor dilution of pollutants. Consequently, EC sets increasingly ambitious objectives to cope with these environmental pressures (European Targets2020, 2020; European Targets2030, 2020).

The circular economy concept has been developed to overcome the problems of a linear economy 'take-make-use-dispose' model and found great application areas in the water sector to preserve the availability of water (Sodiq et al., 2019; Voulvoulis, 2018). The linear economy aims to treat waste streams involving a potential risk to the receiving environment, while recovery/reuse strategies belong to the circular economy concept (Robles et al., 2020). This transition triggered innovative technologies/processes for efficient water utilization, finding alternative water sources, and closing the water-related loops to balance water demand and supply (Peng et al., 2019).

The design and operation of a water supply and treatment system should ensure the sustainability of the technology considering the water-energy-food-ecosystem (WEFE) nexus in urban and rural planning (Vakilifard et al., 2018). Land boundaries are of great concern during the implementation of these technologies in terms of the governance of environmental resources. There are two major concepts used by policymakers, researchers, national administrations, and international organizations for the characterization of settlements as rural and urban areas. The most commonly used method, for the identification of areas, was developed by the Organisation for Economic Cooperation and Development

(OECD) and is based on population density (Brezzi et al., 2011). The OECD method classifies areas with a population density below 150 inhabitants/km^2 as rural. Moreover, the method also addressed the predominantly urban, intermediate, and predominantly rural regions when the share of the population is below 15%, between 15%-50%, and higher than 50%, respectively.

According to the World Health Organisation (WHO, 2016), in the pan-European region, approximately 264 million people lived in rural areas in 2015 and 40% of the population had no access to wastewater collection and treatment systems. For instance, 15-20% of the population in Estonia is not supplied with centralized sewer systems due to dispersed rural settlement (Spin Project, http://www.spin-project.eu). At this point, small-scale decentralized collection and treatment systems can bring not only a long-term solution for small and rural communities, but is also reliable, flexible, and cost-effective. Furthermore, adopting decentralized solutions may advance conditions of sustainability and resilience in water management (Leigh and Lee, 2019).

Innovative technologies and concepts for water and wastewater systems already exist, but they have been mostly implemented in pilot/demonstrative projects so far, mainly as a result of the institutional barriers they face (Trapp et al., 2017). Although the technological, ecological, and economical sustainability of decentralized water/wastewater treatment systems are often promising; the adoption of decentralized systems often fails to go beyond. In fact, crucial dynamics relating to how the water sector can shift towards decentralized infrastructure are not well-understood where technological approaches are not sufficient to promote more sustainable systems. There is no doubt that an innovation in the water infrastructure takes place both at the technical and at the institutional or organisational level. In order to replicate these technologies and close the water-related loops, these solutions should be evaluated under the legislative/policy frameworks at the macro-scale. In most cases, the European Union (EU) legislations are the starting-points for the EU Member States and accession countries. At this point, we analyzed policy and legislative barriers that hinder the adoption of alternative decentralized systems by seeking answers to the following questions: What is the state of the art on small-scale water cycle facilities in Europe? Which legislations are related to water loops at the EU level? What kind of barriers should be dealt with to close water-related loops? What are the key considerations while developing projects which aim to close the water loops? Is there any difference between rural and urban environments regarding the limitations? What are the possible solutions for overcoming the existing barriers? To address these questions, this work critically assesses the fitness within relevant EU directives, on-going policy initiatives, and minimum requested quality standards, regulatory, and financing frameworks.

2. Technology readiness levels of solutions to close water loops

Technologies on non-conventional water resources are becoming fundamental contributors in the water loop such as desalination of seawater and brackish water, rainwater harvesting, atmospheric water harvesting, and wastewater reuse. Today, we have technologies (e.g. desalination of seawater and highly brackish groundwater via osmosis or distillation; rainwater harvesting systems by means of micro/macro catchment areas or fog harvesting, etc.), valorizing these water sources at high technology readiness level (TRL) which can be implemented to partially alleviate water scarcity in rural areas where renewable water resources are extremely scarce (Imteaz et al., 2015; Qadir et al., 2007). In addition to potable water supply through non-conventional water resources, treated wastewater can be used for different purposes such as irrigation in the agricultural fields or parks, restoration of water bodies and wetlands, recharging in the aquifer for storage, etc. Over the last decade, many researchers have studied various decentralized options for wastewater treatment and reuse (Lijó et al., 2017), such as membrane bioreactor (MBR) (Tai et al., 2014), constructed wetland (CW) (Nivala et al., 2019; Wu et al., 2015), or integrated systems (e.g., bioreactor + CW) (Tanner et al., 2012). In smalls-scale decentralized systems (onsite systems, population 1-40), the resources recovered consist of water and nutrients, but at least one option exists for energy recovery. Meanwhile, medium-scale (satellite) facilities can serve 20-47,000 inhabitants with a minimum capacity of 8 m^3/d and maximum flow of 20,000 m^3/d (Diaz-Elsayed et al., 2019). Decentralized wastewater treatment systems favor water recycling and reuse in the proximity of their location, while other resources can be readily recycled as bio-energy and nutrients (Capodaglio, 2017). Considering sludge processing, co-treatment with biowaste may offer a promising solution either by decentralized anaerobic digesters (Thiriet et al., 2020) or composting systems (Panaretou et al., 2019). Some examples from Europe are summarized in the **e-Supplementary file** to highlight the most commonly used decentralized technologies at high TRLs. For instance, Meuler et al. (2008) used both decentralized membrane bioreactors for the reuse of greywater and rainwater harvesting systems to produce water for irrigation or as service water in households. The authors further confirmed their findings' compliance with the national (German) requirements for treated effluent reuse. In another study, Yan et al. (2018) set up a rainwater harvesting system in an office building on the University of Exeter's Streatham campus with around 300 occupants. Although the rainwater harvesting system aimed to reduce water consumption in the toilet flushing, the system enabled to get water with a quality met with the criteria for the potable water in the UK which can also be used for washing the building and drinking. Since there is no regulation in the UK for such systems, there is a code for practice (BS 8515:2009) specifically for rainwater harvesting covers design, installation, and maintenance of the system, water quality, and risk management and rainwater collection systems encouraged in The Code for Sustainable Homes. In Noorderhoek (Netherlands), a biogas plant serving 232 apartments is under operation since 2007 (Bautista Angeli et al., 2018). An UASB reactor (2.5-7 m^3) is operated with blackwater, kitchen waste, and greywater under mesophilic conditions and produces 13.8–12.2 m^3 CH_4/cap/year which is equal to 133–148 kWh/cap/year heat with CHP unit. The national regulations such as "Regulation designating sustainable energy production categories (enforced 01.10.2014)" for definition of technologies and regulation for subsidies and "Renewable Energy Production Incentive Scheme (enforced 16.10.2007, last recast 01.04.2017) for the market price of the electricity and biomethane must be followed for the renewable energy projects in the Netherlands (Hermann et al., 2019). In the study of Starkl et al. (2007), a policy-oriented approach was followed to develop an integrated assessment for rural wastewater management in Austria based on a separation of the wastewater into its constituent parts using various technologies. It was concluded that the co-treatment of black-water in a regional biogas plant would be technically feasible, but it is not supported by regulations in Austria as well as in my EU member countries. In fact, limitations in the ability of governance structures to adapt was stated as one reason for the stagnation in the implementation of novel water systems in Germany (Schramm et al., 2018). Although these technologies bring innovative solutions to decrease water and energy stress in the regions they are applied, most of them may face legislative obstacles for further reuse and/or valorization of resources as analyzed in the following sections.

3. Legislative framework and barriers

Following the afore-mentioned water stress and possible decentralized solutions, the enabling environment was initially analyzed by checking whether the relevant policies support or hinder the implementation of small-scale decentralized collection and treatment systems when inputs (e.g. water categories) are considered to produce and reuse different outputs (e.g. reclaimed water and recovered materials and potentially marketable products). **Table 1** shows the relevant legislation, policies, and guidance for the input and output of water-related loops.

Fitness check was specifically assessed within the following main directives. A summary of these directives are given in the **e-Supplementary file**.

Table 1. Fitness check-in international policy/regulatory/guidance framework.

Directive / Regulation / Decision / Recommendation / Guidelines	Relevant input	Relevant output
European Parliament, 2020, Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse	Municipal/Domestic wastewater	Water for irrigation reuse
European Commission Council Directive 91/271/EEC (amendment 98/15/EC) (Urban Waste Water Treatment Directive) and ongoing revision COM (2017) 749)		
World Health Organization Guidelines for the Safe Use of Wastewater, Excreta and Greywater (2006)		
ISO/TC 282 (2015)/ ISO16075-2:2015 (2015)		
EN 12566- Small wastewater treatment systems for up to 50 PT (Parts 1-7)		
European Commission, Sewage Sludge Directive 86/278/EEC, followed by EC 219/2009a)		
STRUBIAS Technical Proposal (JRC Science for Policy report, 2019)		
EC report on Digestate and compost as Fertilizers (Corden et al., 2019)		
European Commission, 178/2002 on procedures in matters of food safety (2002)	Water for irrigation, compost, seawater, and domestic wastewater	Crops (for Food and industrial uses), Salts from brine
European Commission, 2006a (EC 1881/2006 on maximum levels for certain contaminants in foodstuffs)		
EC Best Environmental Management Practice in The Tourism Sector (Styles et al., 2013)	Rainwater	Rainwater for: Irrigation, drinking water, and domestic uses
Environment Agency, 2010 (Harvesting Rainwater for Domestic Uses: An Information Guide)		
European Commission, 1998 (European Commission, 83/1998 EC Drinking Water Directive) and amendment (European Commission, 2015a)	Rainwater, water vapor	Drinking water
European Commission, 2017 (Proposal EC COM 753/2017 on the quality of water intended for human consumption)		
World Health Organization, Guidelines for Drinking-Water Quality (GDWG) (2017)		
World Health Organization, 2011 (Small-scale drinking water supplies in the pan-European region) and World Health Organization, 2012 (Water safety planning for small community water supplies)		
European Commission, 2006b (EC 118/2006 - The Groundwater Directive-GD)	Rainwater, stormwater runoff	Water for aquifer recharge/storage
European Commission, 2000 (2000/60/CE - Water Framework Directive-WFD)		
European Commission, 2014 (EU 80/2014 on the protection of groundwater against pollution and deterioration)		
European Commission, 2003 (EC 2003/2003 Fertilizer Regulation) and following European Commission, 2013 and European Commission, 2019	Municipal/Domestic wastewater	Recovered fertilizers
European Commission, 2018 (EC 2001/2018 on the promotion of the use of energy from renewable sources)	Municipal/Domestic wastewater	Biogas for biofuel
CEN - EN 16726, 2015 (European standard on the quality of gas of the H category)		
CEN-EN 16723-2, 2017 (Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network)		

3.1. Water reclamation and sanitation for water safety

When considering the implementation of any solution that aims at ensuring sustainable management of water and sanitation (Sustainable Development Goal-SDG 6) in the EU, the fitness check with the Water Framework Directive (WFD) 2000/60/EC cannot be overlooked. In the WFD, the use of reclaimed water is considered as a means of increasing water availability while ensuring a good quality status of water resources. Specifically, the Directive (Annex VI(x)) refers to 'efficiency, reuse measures, and water-saving techniques for irrigation' to help to achieve good environmental status. In this perspective, the implementation of small-scale decentralized technologies could contribute to tackling the problem of reaching a good status in Europe, as already highlighted in the Regulatory Fitness and Performance program evaluation (REFIT) of the WFD by the European Environment Agency (European Commission, 2019b). In this perspective, the WFD (Art.11(3-f)) allows to artificially recharge the groundwater bodies with water that *"…may be derived from any surface water or groundwater…"*, after the necessary authorization. Thus, no clear constraint on the use of specific water sources is stated, as long as the water used does not compromise the achievement of the environmental objectives for a good water status.

Furthermore, no explicit permission or prevention is detected for drinking water production from rainwater, as the WFD referred only to conventional water bodies as sources for drinking water production (Art.7(1) and (2)).

No specific barriers are identified even when considering the compliance with the Directive 2006/118/EC, "Groundwater Directive" (GD). However, a focus on national/local legislation should be further assessed to evaluate how monitoring strategies are carried out in different countries to ensure the safety of aquifer recharge regarding contamination (e.g. pesticides) by the stormwater runoff.

Compliance with the Council Directive 91/271/EEC "Urban Waste Water Treatment Directive" (UWWTD) is crucial for the implementation of small-scale decentralized systems, when reclaimed water production from wastewater is involved. In this regard, the UWWTD (Art.12(1)), promotes the reuse of "treated wastewater…whenever appropriate", as long as it is not prohibited by other EU legislative instruments and does not implicate environmental deterioration. Therefore, no limitations are detected for treated wastewater reuse when quality standards are achieved. To comply with the UWWD's requirements, the priority was given by EU member states to urban areas where huge investments in wastewater collection and treatment systems took place. This situation may lead to rural areas to take a backseat. Furthermore, the WWTD (Art. 14(1)) promotes the reuse of sludge from WWT *"…whenever appropriate…"*. Although this generic statement does not define specific prescriptions for reuse, it does not forbid the implementation of technologies whose objective is the treatment and the subsequent reuse of sewage sludge.

The recent (December 2019) REFIT of the UWWTD (European Commission, 2019c) highlighted that further efforts are still necessary to reach the full compliance with the WWTD in terms of the collection, secondary and stricter treatment applied to wastewater (compliance decreased from 98.4% to 94.7%, from 91.9% to 88.7% and from 87.9% to 84.5% respectively) (European Commission, COM (2017) 749 final).

During the consultation period of the EU, the consortium of the Innovation Action project of HYDROUSA focused its evaluation of the UWWTD at the challenge of individual or appropriate systems. The consortium commented that "*Despite the generally high level of implementation of the UWWTD, a number of challenges remain, including the need for further investments in the wastewater sector to increase or maintain implementation, operating costs optimisation, individual or appropriate systems (IAS), stormwater overflows, as well as improving coherence with other European Union water policy*." And concluded that "…*IAS should be framed by specific regulations in the future. Specifically, the requirements for designing, constructing, and maintaining IAS must be defined and environmental protection must be ensured on the same level as a collecting system followed by centralised wastewater treatment*."

It has to be remarked that when considering IAS, small individual wastewater treatment plants and septic/storage/holding tanks should be provided (European Commission, 2015b) for small agglomerate (up to 50 PT) or isolated houses. Specific prescriptions on sizing criteria and operation of septic tanks, prefabricated treatment units, and tertiary treatment should be followed according to standard EN12566 1-7:2016 "Small wastewater treatment systems for up to 50 PT".

To increase the compliance, small-scale decentralized systems might contribute to support the initiatives of the European Commission (European Commission, COM (2017) 749 final) as follows:

- improve the sludge quality and recovery;
- minimize the consequences of the stormwater overflows pollution;
- increase the treated wastewater reuse, while ensuring appropriate water quality;
- reduce the energy demand of sanitation systems, using (when possible) energy from renewable resources at the treatment plant (e.g. biogas).

In the context of reclaimed water reuse for irrigation purposes, the fitness Check with the European Parliament, regulation on minimum requirements for water reuse (European Parliament, 2020) is necessary. Since the regulation encourages the reuse of treated urban wastewater, small-scale decentralized systems could be legally supported in their implementation. This could result in an integrated water management approach that is also applicable in rural areas by increasing the sustainability of agricultural irrigation and providing a reliable alternative to freshwater supply.

It should be noted that for small-scale systems it is crucial to adopt the risk-based approach outlined in the Water Reuse Risk Management Plans (WRRMPs), which are also included in the proposal 2018/0169 (COD), currently under evaluation by the European boards. When considering small-scale collection and treatment systems, human, technical, and financial resources are often limited (WHO, 2006) and thus monitoring strategies of water resources might be challenging. However, the hazard prioritization and risk ranking introduced by the WRRPM could represent a valuable control strategy for a small-scale water system. Specifically, control measures can be implemented for the minimum monitoring of community supplies, by monitoring the essential parameters of water quality and thus reducing the overall monitoring costs. Furthermore, a legal instrument that can be used as a reference for technical, economic, and environmental aspects is represented in the ISO/TC 282: “Guidelines for Treated Wastewater use for Irrigation Projects” for decentralized systems. Applying the water safety plan to water reuse was examined elsewhere (Goodwin et al., 2015), indicating that similar to the WHO's Framework for Safe Drinking Water, the risk management framework for reuse would guide scheme managers in setting targets and assessing management performance.

Most of the published literature on the reclaimed water reuse has focused on the technologies and implementations (Capodaglio, 2020; Lee et al., 2018; Rizzo et al., 2020; Salgot and Folch, 2018). In fact, we need more critical analysis and opinion papers on the legislative perspective, such as Rizzo et al. (2018) presented the opinion of the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) on the draft version of the European Commission’s “Proposed EU minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge” (draft V.3.3, February 2017). The authors suggested that common criteria should be defined for the development of case-by-case assessments, in order to ensure comparable minimum quality requirements across the EU member countries.

Similarly, principal barriers limiting the reclaimed water use for agriculture in Italy (particularly in Sicily) were analyzed by Ventura et al. (2019), highlighting the complex and strict Italian legislations on the reuse of treated wastewater, and commenting that potential users should rely on the support of private or public agencies such as the Italian Irrigation Consortia.

Regarding the systems aiming to produce drinking water, the “Drinking Water Directive” (DWD) Council Directive 98/83/EC (and its revision EU 2015/1787) is the starting-point legislation for setting actions at the national level. Despite the binding character of the Directive, measures are mandatory to distribution systems serving more than 50 people or that provide more than 10 m^3 of water per day, while for small-scale systems some exemptions can be applied (Art.3 (2)). Therefore, under the DWD, household and small-scale supply systems (e.g. wells or local springs) for rural communities are not regulated as well as the possibility to produce drinking water from alternative sources (e.g. rainwater and/or water vapor). These aspects highlight how the existing EU regulatory instruments for drinking water are not in line with the latest scientific knowledge of the WHO recommendations.

Specifically, the Joint Monitoring Program (JMP) by WHO defines rainwater as an “improved” water source for potable uses in rural and urban areas, concerning the protection from fecal matter contamination. Moreover, guidelines apply both to large and small-scale piped and non-piped drinking water systems in rural communities and individual dwellings.

It should be noted that, even for small-scale collection and treatment systems, no exemptions are allowed when potential risks to human health are evident. In this perspective, WHO guidelines provide scientific support, by highlighting the need for a water safety plan (WSP) risk-approach for public health protection when small-scale decentralized systems are applied (World Health Organization, 2017). These guidelines (evaluated also in the Proposal EC COM 753/2017 (01.02.2018)) provide prescriptions for the safe management, operation, and monitoring of wastewater, excreta, and greywater in agriculture and drinking-water quality. In most cases, the successful implementation of WSPs is limited by a number of factors such as the lack of financial resources and the absence of legislation (Tsoukalas and Tsitsifli, 2018). It should be noted that when considering small-scale solutions, economic sustainability is a crucial factor. In addition, alternative water sources for drinking water production should also be considered. In this regard, it is fundamental to introduce the main elements of the WHO guidelines in the revision of DWD to provide an EU regulatory instruments which could be fully implemented for both centralized and decentralized systems. This means mainly to update the existing safety standards, introduce a risk-based safety assessment, and to include measures for drinking water production from alternative sources. Since compliance with water directive might not be sustainable from an economic point of view, enabling the environment for decentralized systems needs to be analysed at national and local levels considering a risk-based approach to water safety. In terms of aspects related to the water supply from unconventional water sources, e.g. recycled and desalinated water, public acceptance is also stated as one of the major barriers in Europe and all over the world(Adapa et al., 2016; Hurlimann and Dolnicar, 2016).

At the global scale, similarly, there is not a unified regulation for water reuse. Although policies on alternative water sources differ between states in the United States, the U.S. Environmental Protection Agency (EPA) introduced the National Water Reuse Action Plan: Collaborative Implementation on February 27, 2020, to develop serious actions on water recycling. In Canada, guidelines are released both by the federal government and provincial governments (Van Rossum, 2020). There is only one guideline prepared by the federal government for water reuse in 2010, named as Canadian Guidelines for Domestic reuse Water for Use in Toilet and Urinal Flushing. Whereas Alberta Provinces released a fact sheet on Alternative Solutions Guide for Small System Water Reuse, Atlantic Provinces have a

Wastewater Guidelines Manual including informations for reuse applications. British Columbia is the only province with the regulation for water reuse. Moreover, in Australia, water guidelines were published in two phases as a part of the National Water Quality Management Strategy. The first phase includes a framework and guideline for managing health and environmental risks including recycled water quality and guidance on the use of treated sewage and greywater, the second phase focuses on the augmentation of drinking water supplies, aquifer recharge, and stormwater harvesting and reuse (NRMMC, 2006).

3.2. Sludge treatment and reuse for food safety

Organic matter and nutrients are the two main elements that make the use of treated sludge suitable for soil fertilization (European Commission, 2019e). Also, the 86/278/EEC "Sewage Sludge Directive" (SSD) (and its in-force revision Regulation (EC) No 219/2009) promotes the application of treated sewage sludge in agriculture (Art.3(2)) as long as the Member States implement necessary measures for protecting human and environmental health and preventing harmful effects on soils (Art.6(a), Art.7). The treatment/recovery of sludge and its reuse through agricultural applications is indeed a major barrier in Europe. In fact, when looking at national legislation, each country has different thresholds, and within certain countries, even individual states/provinces may have different threshold values.

When considering applications of small-scale treatment systems to decentralized contexts, rural community or neighborhood-based solutions should be implemented for treating the sludge. In these cases, fecal sludge could represent the relevant input for producing compost. In this regard, the SSD sets limits on the concentrations allowed (in soil and sludge) for the application of the residual sludges from septic tanks (Art.2 (a -i, -ii, -iii)). Consequently, no explicit barriers are detected for the replicability of small decentralized systems. Despite this, the European Legislative Framework lacks ad-hoc regulation for community-based composting and co-composting systems to fully support and regulate the recovery and reuse of sludge in small and rural communities. Furthermore, the SSD often receives criticism as being outdated and does not include limits for pathogens and organic micropollutants in soil and sludge.

Considering the compost production, a further aspect is to analyse the possibility of labeling and marketing of the fertilizer as an EU product. In this perspective, the European Fertilizer Regulation (2009b, No 1069/2009) limits the exploitation of small decentralized systems, since compost derived from digestate and sewage sludge cannot be labeled and marked as EU fertilising products (Annex II). A possible way to address this barrier is currently provided by different valuable works and projects. In 2019, the report "Digestate and compost as fertilizers: Risk assessment and risk management options" was published by Wood with partners Peter Fisk Associates and Ramboll for European Commission (Corden et al., 2019). In this work, no limitation on input materials or uses is detected for compost or digestate when an environmental and human health risk assessment and a risk management options analysis (RMOA) are implemented. In a JRC Science for Policy report (JRC, 2019) possible legal framework for marketing fertilising products, derived from precipitated phosphate salts, thermal oxidation materials and pyrolysis, gasification materials, and derivates (STRUBIAS), is explored. The main attention in STRUBIAS material is given to phosphate salts, which can be obtained from wastewater and sewage sludge from municipal WWTPs by AD or by composting. This study shows how STRUBIAS can be considered as a valuable framework to provide phosphorus in a safe way to reduce the demand for the primary raw material from phosphate rocks. Hence, the compost produced within decentralized systems might decrease the demand for synthetic fertilizers and reduce economic/environmental impacts associated with fertilizer production and waste disposal also in rural areas. In Europe, the European Sustainable Phosphorus Platform (ESPP) serves as a hub for information exchange and facilitates communication between all cross-sectoral stakeholders. In fact, political interest in phosphate sustainability has grown a lot at the European level. Incorporation in the EU critical materials list is seen as vital in this respect (de Boer et al., 2018). European legislation governing phosphorus recycling was critically reviewed by Hukari et al. (2016), where legislation harmonisation, the inclusion of recycled phosphorus in existing fertiliser regulations, and support of new operators were proposed to speed up market penetration of novel technologies, reduce phosphorus losses and safeguard European quality standards. When using compost produced from waste and/or irrigate the site with reclaimed water for food crops, food safety is a crucial factor to assess. Namely, the fitness check with Commission Regulation (EC) No. 1881/2006 on maximum levels for certain contaminants in foodstuffs should be analysed. According to this regulation, no relevant barriers were detected for the marketability of products irrigated with reclaimed water and/or fertilized with compost from waste, as the compliance depends exclusively on the final product. Major constraints were detected when considering organic farming. In fact, according to the Organic Farming Regulation (EC) No. 889/2008 (and its revision Regulation (EU) No. 848/2018) no information is provided regarding sewage sludge matrix for fertilizer production. Thus, the sewage sludge cannot be used to improve soil quality. However, "composted or fermented household waste" can be authorized as long as it contains only vegetable and/or animal waste. For instance, in the study of Viaene et al. (2016), among the 28 identified barriers to on-farm composting and compost application, the complex regulation was listed as one of the main five barriers. In fact, the authors recommended a certain degree of flexibility in current policies and institutional arrangements to stimulate compost production and application.

3.3. Renewable resources exploitation for energy efficiency

To close the loop of the Integrated Resources Management, the energy sector should also be assessed. In this regard, small-scale decentralized systems can offer a valuable alternative to methane extraction from natural deposits, such as upgrading methane from biogas produced in anaerobic treatment. With the view to reuse methane in the transport sector, small-scale decentralized systems are supported by the renewable energy directive 2018/2001/EU (EC, 2018) to meet the 10% of renewable resources used in transport. Specifically, in Annex IX(f) sewage sludge can be used to produce biogas for transport and advanced biofuels. It should be considered that biogas and biomethane should ensure the quality requirements as defined in the technical standards for biogas EN 16726 and EN 16723 on Liquefied Natural Gas (LNG), biomethane, and blends for automotive fuels. Concerning the investigated barriers for the implementation of technologies promoting biogas reuse, many studies highlighted the lack of institutional support and specific action programs to support biogas technologies (Nevzorova and Kutcherov, 2019). In this regard, complex institutional and legal pathways could block and prevent the implementation of such applications. Furthemore, Yaqoot et al. (2016) analysed barriers to the dissemination of decentralized renewable energy systems. Among the institutional barriers, the authors include the lack of a suitable legal and regulatory framework for dissemination of decentralized renewable energy systems as a major institutional barrier, together with the other sub-barriers such as the lack of agencies to disseminate information, uncertain government policies, strict bureaucratic procedures, unstable macro-economic environment, lack of stakeholder participation in decision making, clash of interests among stakeholders; lack of R&D culture; insufficient professional institutions and lack of private sector participation.

4. Regulatory fitness check

To check and outline available conditions or possible obstacles in the implementation of the small-scale decentralized collection and treatment systems within the European legislative framework, Evaluation Fitness Check is reported in **Table 2**. The main parameters of the solutions, intended as key factors to get the Legislative compliance, were highlighted concerning the prescriptions of the policies analysed (see column “parameters to consider”).

For each parameter, the reference documents were listed (see column “reference documents”). Documents were grouped according to directives, technical standards, guidelines, manual (see column “document type”). Finally, “relevant information” was reported to point out whether the regulatory instruments “support” or “hinder” the recovery and use/reuse of specific resources/by-products.

Table 2. Summary of fitness check for small-scale decentralized systems (A: “considered no barrier”, in green: if quality and/or safety standards are met and the output reuse is generally allowed; B: “not considered”, in yellow: no explicit reference/information in the legislation; C: “considered, potential barrier” in red: if legislation highlights possible constraints to be overcome).

Application field	Parameters to consider	Reference documents		Relevant information
		Document type	Reference number	
From wastewater to reclaimed water for irrigation	Categories of crops allowed to be cultivated	Directive	Proposal 337/2018 and 2019 revision ISO/TC 282	A
	Indicative treatments required for reaching water quality effluent		Proposal 337/2018 and 2019 revision ISO/TC 282	A
	Influence of flow quality on the final intended use		Proposal 337/2018 and 91/271/EEC and revisions ISO/TC 282	A
From sewage sludge to compost	CE Labelling for the fertilizer	Directive	1009/2019	C
	Influence of sewage sludge for agricultural uses		219/2009	A
	Use of sewage sludge for organic farming		889/2008	C
	Compost parameters to be considered for agricultural uses at National Level	Report	ENV.A.2. /ETU/2001/0024 (Amlinger et al., 2004) Digestate and compost report JRC Report	A
	Use of sewage sludge for agricultural purposes		ENV.A.2. /ETU/2001/0024 Digestate and compost report JRC Report	A
From biogas to biomethane as automotive fuel	Biomethane characteristics for transport, distribution and use	Technical standards	EN 16726	A
	Characteristics of methane for use as automotive fuel		EN 16723-2	A
Agroforestry system	Categories of crops allowed	Directive	Proposal 337/2018 and 2019 revision	A

	Indicative treatments required for reaching water quality standard		Proposal 337/2018 and 2019 revision	A
	influence of flow quality on the final intended use		Proposal 337/2018 and 91/271/EEC and revisions	A
	Types of food regulated		1881/2006	A
	Limits for compliance in foodstuffs		1881/2006	A
	Amount of water required by crops	Manual	FAO Manual	B
	Permitted reuse of rainwater in relation to required treatments	Guideline	Guidelines and report from world-wide experiences	A
From rainwater to drinking water	Permitted water source for drinking purpose	Directive	2000/60/CE and 98/83/EC and revisions	B
	Parameters to meet for potable uses		98/83/EC and revision; (Proposal 753/2017 EC)	B
	Permitted water source for drinking purpose	Guidelines	WHO Guidelines for drinking water quality	A
	Treatment for the purpose and monitoring/control measure			B
From rainwater and runoff from road to water for aquifer recharge and further irrigation	Type of water to aquifer recharge	Directive	2000/60/CE	A
	Attention to water quality to maintain the "Good" status of groundwater		2000/60/CE and 2006/118/EC (2014/80/EU)	A
	Categories of crops allowed to be cultivated		Proposal 337/2018 and 2019 revision	A
	Indicative treatments required for reaching water quality effluent		Proposal 337/2018 and 2019 revision	A
	influence of water quality for irrigation use		Proposal 337/2018 and 2019 revision	A
	Permitted reuse of rainwater concerning required treatments	Guidelines	Guidelines and report from world-wide experiences	A
From brine to salt production	Salt quality parameters	Standards	CXSTAN 150-1985 (Codex Standard, 1985)	B
From water vapor to drinking water	Water source for drinking purpose	Directive	2000/60/CE and 98/83/EC and revisions	B
	Parameters to respect for potable uses		98/83/EC and revision; Proposal 753/2017 EC	B
	Treatment for the purpose and monitoring/control measure	Guidelines	WHO Guidelines	B

When considering irrigation for agroforestry, crop categories, indicative required treatments, and influent water quality need to be considered within the EU directives and the ISO/TC 282. The application necessities should be evaluated within the EC 337/2018, EC 271/1991, and EC 118/2006. Besides, the typical amount of water should be guaranteed according to the type of crop, as specified in the FAO Manual. When considering compost spreading, on the other hand, no unified EU regulation/legislation/directive is specified. However, quality parameters and/or presence of sewage sludge were evaluated in several Reports (Amlinger et al., 2004; Corden et al., 2019; JRC, 2019). Concerning biomethane production, quality parameters for automotive fuel applications are specified in EU level directives. In terms of rainwater and/or runoff treatment and reuse for irrigation, since no specific prescriptions are defined in the EU legislative framework, further analysis is required at the national/local level. Concerning the drinking water, quality standards cannot be applied to small-scale water supply and sanitation systems. When aquifer recharge is involved, the discharged water is regulated by the WFD in terms of quality to maintain a “good” status of groundwater. Regarding salt production, quality standards defined by FAO and WHO needs to be ensured when food-grade salt is considered. Since no information on the source of salt and the minimum treatment is provided, reuse is outlined as “not defined”, while national/regional regulations should be further analysed.

5. Financial analysis

The choice for funding water infrastructure between a centralized and decentralized solution in a rural and/or peri-urban area depends on several variables: method of economic assessment (social discount rate), funding policy (funding rate), and users' self-organization (cost-sharing) (see the paper, (Brunner and Starkl, 2012)). In fact, a successful implementation of decentralized solutions relies on many critical factors such as public acceptance, qualified maintenance, organizational support, and availability of financial resources (Sousa-Zomer and Cauchick Miguel, 2018). The nature of financing arrangements that depends on the institutional structure was assessed to define a general structure of the mechanisms on which the water/wastewater management is based. The approach proposed by the Organization for Economic Cooperation and Development (OECD) focuses on the 3T (Taxes, Tariffs, Transfers) for regulating, increasing, and balancing finances in three forms. The structure of financing pathways for small-scale decentralized technologies was analyzed by highlighting the general framework for ensuring cost recovery (**Fig. 1**) of municipal water cycle services (e.g. wastewater and domestic water).

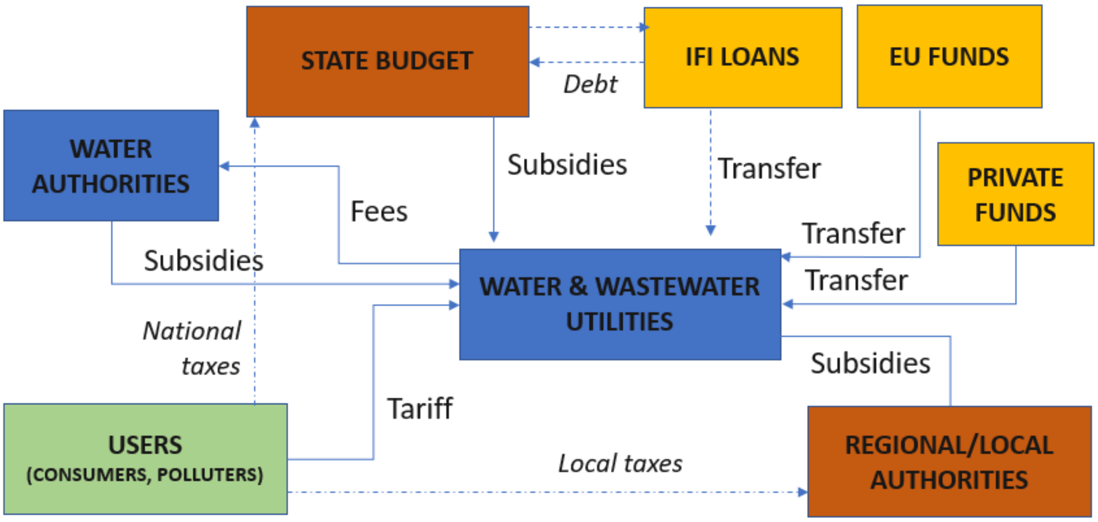

Fig. 1. General structure of the financial framework in water service management.

The analysis conducted for all EU member states highlighted that the cost recovery is mostly achieved through tariffs, whose affordability differs from between countries. Specifically, the majority of the Countries use the taxpayer's money to cover the Capital Expenditure costs (CAPEX), while few economically weaker Countries use foreign funds as "money transfers" for cost recovery. Moreover, the source of used subsidies for cost recovery can be divided into two main categories (**Table 3**):

- Countries with a specific water financing structure. In this case, the concept of "water pays water" is followed;

- Countries with financing strategies mainly derived from public budget at national or local/regional levels.

Table 3. Summary of subsidies source.

Countries	National administration	Water authority	Local / Regional authorities
Croatia	X	X	X
Spain	X	X	X
Cyprus	X	X	
France	X	X	
Germany		X	
Poland	X	X	
Belgium			X
Austria	X		X
Bulgaria	X		X
Greece	X		X
Italy	X		X
Portugal	X		

It was also highlighted that for small-scale decentralized treatment systems, whose owners and suppliers could be either a public or private body, a blend of three financing strategies (e.g. Tariff, Subsidies, Transfers) could be implemented to cover the initial investment and thus reduce the Return On Investment (ROI) period. The details are shown in **Table 4** below.

Table 4. Summary of financing sources.

Service delivered	Type of costs	Tariff	Subsidies (taxpayers' money)	Transfers
Wastewater treatment	CAPEX	X	X	X
	OPEX	X	X	
Domestic water	CAPEX	X	X	X
	OPEX	X	X	
Agriculture water	CAPEX	X	X	X
	OPEX	X		

In all these cases, in which the delivered service (e.g. water supply or wastewater treatment) does not involve any financial transaction, end users will be the payers of the "tariff" (e.g. a farmer will pay to maintain/operate its small-scale decentralized treatment system and the initial investment at least partly).

Furthermore, local, regional or national public bodies or water service operators can provide subsidies especially when costs for drinking water supply (e.g. tap water) and sanitation services through public networks are unaffordable. These measures can be applied to provide universal and equitable access to drinking water and sanitation to all. Transfers (in the form of foreign or EU funds) are mainly used to cover investment costs for building or revamping a water infrastructure, targeting vulnerable and less developed areas in the EU and worldwide.

6. Possible solutions: a step forward in the context of the Innovation Deal and the European green deal

The aspects analysed in this study can be contextualized in a broader framework such as the European Green Deal (European Commission, 2020). Achieving a zero-climate impact by 2050 will only be possible if measures to be adopted are supported by adequate European regulatory instruments that can be applied both at large- and small-scale. In this context, the European regulatory framework highlighted signs of disparity. Clear policy instruments regarding sustainable solutions in small and rural communities or agglomerations are currently lacking. The result of this gap is the achievement of quality standards that could represent a challenge for the economic sustainability of decentralized systems.

Moreover, according to the last revision of the UWWTD (91/271/EC), pollution from urban wastewater systems to water and soil can still be avoided. Specifically, sources of pollution are related on one side to unmonitored/untreated combined sewer overflows, small agglomerations, and non-connected dwellings and on the other side to possible toxic and emerging contaminants in sewage sludge used in farming.

The challenge is to consider the health and environmental risk related to the emerging contaminants (e.g. pharmaceuticals, micro-nanoplastics) while recovering and safely reusing water and raw materials. Therefore, the implementation of small-scale treatment solutions must be supported by ad-hoc regulations for small agglomerations and by a regional integrated health and environmental risk-based approach to sustainably manage solid and liquid non-zero-polluted residual streams. In this regard, innovation actions should be promoted, such as the Innovation Deal (Innovation Deal, 2017), to support European and national governments in proposing and adopting policies more oriented towards rural services. Recently, Jiménez-Benítez et al. (2020) assessed the reclaimed water reuse in fertigation via AnMBR technology within the EU Innovation Deal. The authors highlighted that in order to take full advantage of the benefits of AnMBR technology on water reuse, favorable and harmonized regulations among the EU States would need to be adopted.

Similar to the approach of the community composting regulation, Innovation Principle (Innovation Principle, 2017) can be implemented to design a policy framework that promotes the sustainable management of water and water-related services also in rural areas at a community-based level. For instance, similarly to the Italian community composting draft proposal, small-scale technologies could be formally implemented either by the municipality in co-creation with citizens or by a “collective body” (e.g. two or more domestic/non-domestic users established in condominium, association, consortium, etc.). Specifically, in the latter case, the implementation should start after the collective body sends a certified notification of the activity to the competent municipality, which in turn notifies the collective body with the management service.

When considering the management of small-scale systems, the activity could be carried out either by the municipality or by the collective body. Regardless of the manager, data regarding the system treatment efficiency, amount of produced wastes, effluent characteristic for quality monitoring should be registered. Monitoring strategies should be anyway carried out and supervised by the competent authority (e.g. province, municipality, etc.). Thus, the community composting based-approach could be implemented in the water and water-related sector to support the implementation of small-scale treatment technologies as according to the scheme represented in **Fig. 2**.

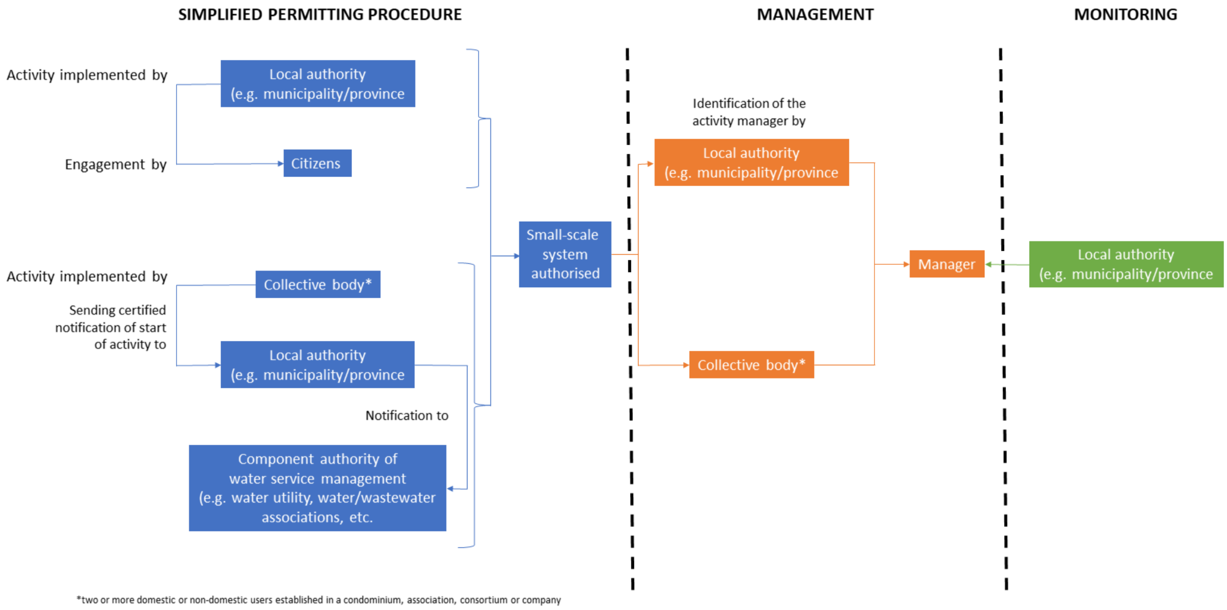

Fig. 2. Implementation of Community Regulation in the context of small-scale collection and treatment systems.

Furthermore, the regulatory gap that must be bridged to fully support the integrated management of resources should include measures aimed at providing quality standards and monitoring procedures suitable for small-scale collection and treatment systems as they are more vulnerable to breakdown and contamination than larger utilities. These systems are also the most sensitive in terms of economic sustainability. Therefore, the application of regulations for centralized systems may not be economically sustainable, thus representing a constraint or a barrier for further development.

7. Conclusion

Although no general barriers are detected for the reuse of reclaimed water in the EU legislation, there are some limitations on drinking water production from non-conventional water resources. On the other hand, major constraints are determined for EC-marked compost for organic farming. Since no relevant information is found for the community composting at the EU level, regulatory instruments for policy support should be analysed at the local level. As a result, the current EU legislative framework does not provide ad-hoc guidelines to close the water loops for a small decentralized system, highlighting a lack of the enabling environment for small-scale decentralized technologies at the community level. Moreover, some gaps are determined in terms of regulatory framework, institutional support, financing schemes for small and rural communities, which might hinder the implementation of decentralized systems. In this regard, possible blockages for the exploitation of small-scale treatment solutions could be the achievement of the quality standards, as set out in EU Directives, which might not be economically feasible for these systems. To deal with the European Green Deal challenge, sustainable growth in terms of social, economic, and environmental progress should be delivered by adopting Innovation Principle. Concerning the financial aspects, water tariff structures are mainly addressing urban environment and larger utilities' needs, and smaller service authorities have to find ad-hoc solutions for local service providers. To develop a full picture of water and water-related small and decentralized services to deliver regenerated closed loops, an innovation deal might be prepared to support European (and national) governments.

Credit authorship contribution statement

Giulia Cipolletta: Investigation, Methodology, Formal Analysis, Visualization, Writing - original draft. **E. Gozde Ozbayram:** Investigation, Writing - original draft. **Anna Laura Eusebi:** Project administration, Validation, Supervision. **Çağrı Akyol:** Conceptualization, Writing - original draft. **Simos Malamis:** Project administration, Resources, Validation, Writing - review & editing. **Eric Mino:** Conceptualization, Visualization, Writing - review & editing. **Francesco Fatone:** Funding acquisition, Project administration, Resources, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online

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