

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

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22 **ABSTRACT**

23 Water supply and reuse through non-conventional water resources can significantly decrease
24 the stress on natural water resources. Decentralized systems can help not only to alleviate
25 issues of water security in arid areas, but also to create a sustainable framework within a

26 circular economy. Although these small-scale innovative technologies are able to achieve
27 ready-to-use, high quality of recovered/treated water on-site, the loop cannot be closed in
28 most cases due to legislative barriers. Similarly, the end-use of sewage sludge after treatment
29 in decentralized systems still lacks specific regulations that limit its valorization. This work
30 analyzes the current policy and legislation related to water supply, wastewater treatment,
31 water reuse, and resource valorization within the context of decentralized state-of-the-art
32 technologies applied in rural areas. The drawbacks in the current EU legislation that set
33 barriers to close water-related loops in European countries are highlighted. A regulatory
34 fitness check is applied to each type of loop to identify the key factors to accomplish the
35 legislative compliance, and financing pathways are further evaluated at the EU level. As a
36 possible solution, further development of an innovation deal approach is recommended to
37 address the environmental, regulatory, and financial gaps in water management through an
38 integrated framework, providing ad-hoc policies and prescriptions for the sustainable reuse of
39 all water resources.

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

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44 **1. Introduction**

45 The depletion of natural resources at a fast rate leads to a transition of the current society to
46 re-evaluate these resources in a sustainable manner. Water is a fundamental resource to
47 sustain life and irregularly distributed both spatially and temporally; furthermore,
48 anthropogenic activities continuously contaminate the limited water reserves (Voulvoulis,
49 2018). Consequently, water sustainability is among the most discussed sustainability issues in
50 the last years where every applicable sustainability principle has been adopted to water from

51 reuse to recycle (Sodiq et al., 2019). These issues are increasingly discussed by the European
52 Commission as Europe has become more and more vulnerable to water shortages and to the
53 social, economic, and environmental impacts deriving from increasing demand and global
54 climate change in recent times. In fact, in several areas of Europe, there's a critical issue
55 regarding the balance between the demand and availability of water. As a result, the reduction
56 of available water resources has been followed by a deterioration in the quality of water
57 caused by poor dilution of pollutants. Consequently, EC sets increasingly ambitious
58 objectives to cope with these environmental pressures (European Targets2020, 2020;
59 European Targets2030, 2020).

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

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

76 (OECD) and is based on population density (Brezzi et al., 2011). The OECD method
77 classifies areas with a population density below 150 inhabitants/km² as rural. Moreover, the
78 method also addressed the predominantly urban, intermediate, and predominantly rural
79 regions when the share of the population is below 15%, between 15%-50%, and higher than
80 50%, respectively.

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

90 Innovative technologies and concepts for water and wastewater systems already exist, but
91 they have been mostly implemented in pilot/demonstrative projects so far, mainly as a result
92 of the institutional barriers they face (Trapp et al., 2017). Although the technological,
93 ecological, and economical sustainability of decentralized water/wastewater treatment
94 systems are often promising; the adoption of decentralized systems often fails to go beyond.

95 In fact, crucial dynamics relating to how the water sector can shift towards decentralized
96 infrastructure are not well-understood where technological approaches are not sufficient to
97 promote more sustainable systems. There is no doubt that an innovation in the water
98 infrastructure takes place both at the technical and at the institutional or organisational level.

99 In order to replicate these technologies and close the water-related loops, these solutions
100 should be evaluated under the legislative/policy frameworks at the macro-scale. In most cases,

101 the European Union (EU) legislations are the starting-points for the EU Member States and
102 accession countries. At this point, we analyzed policy and legislative barriers that hinder the
103 adoption of alternative decentralized systems by seeking answers to the following questions:
104 What is the state of the art on small-scale water cycle facilities in Europe? Which legislations
105 are related to water loops at the EU level? What kind of barriers should be dealt with to close
106 water-related loops? What are the key considerations while developing projects which aim to
107 close the water loops? Is there any difference between rural and urban environments regarding
108 the limitations? What are the possible solutions for overcoming the existing barriers? To
109 address these questions, this work critically assesses the fitness within relevant EU directives,
110 on-going policy initiatives, and minimum requested quality standards, regulatory, and
111 financing frameworks.

112 **2. Technology readiness levels of solutions to close water loops**

113 Technologies on non-conventional water resources are becoming fundamental contributors in
114 the water loop such as desalination of seawater and brackish water, rainwater harvesting,
115 atmospheric water harvesting, and wastewater reuse. Today, we have technologies (e.g.
116 desalination of seawater and highly brackish groundwater via osmosis or distillation;
117 rainwater harvesting systems by means of micro/macro catchment areas or fog harvesting,
118 etc.), valorizing these water sources at high technology readiness level (TRL) which can be
119 implemented to partially alleviate water scarcity in rural areas where renewable water
120 resources are extremely scarce (Imteaz et al., 2015; Qadir et al., 2007). In addition to potable
121 water supply through non-conventional water resources, treated wastewater can be used for
122 different purposes such as irrigation in the agricultural fields or parks, restoration of water
123 bodies and wetlands, recharging in the aquifer for storage, etc. Over the last decade, many
124 researchers have studied various decentralized options for wastewater treatment and reuse
125 (Lijó et al., 2017), such as membrane bioreactor (MBR) (Tai et al., 2014), constructed

126 wetland (CW) (Nivala et al., 2019; Wu et al., 2015), or integrated systems (e.g., bioreactor +
127 CW) (Tanner et al., 2012). In small-scale decentralized systems (onsite systems, population
128 1-40), the resources recovered consist of water and nutrients, but at least one option exists for
129 energy recovery. Meanwhile, medium-scale (satellite) facilities can serve 20-47,000
130 inhabitants with a minimum capacity of 8 m³/d and maximum flow of 20,000 m³/d (Diaz-
131 Elsayed et al., 2019). Decentralized wastewater treatment systems favor water recycling and
132 reuse in the proximity of their location, while other resources can be readily recycled as bio-
133 energy and nutrients (Capodaglio, 2017). Considering sludge processing, co-treatment with
134 biowaste may offer a promising solution either by decentralized anaerobic digesters (Thiriet et
135 al., 2020) or composting systems (Panaretou et al., 2019). Some examples from Europe are
136 summarized in the **e-Supplementary file** to highlight the most commonly used decentralized
137 technologies at high TRLs. For instance, Meuler et al. (2008) used both decentralized
138 membrane bioreactors for the reuse of greywater and rainwater harvesting systems to produce
139 water for irrigation or as service water in households. The authors further confirmed their
140 findings' compliance with the national (German) requirements for treated effluent reuse. In
141 another study, Yan et al. (2018) set up a rainwater harvesting system in an office building on
142 the University of Exeter's Streatham campus with around 300 occupants. Although the
143 rainwater harvesting system aimed to reduce water consumption in the toilet flushing, the
144 system enabled to get water with a quality met with the criteria for the potable water in the
145 UK which can also be used for washing the building and drinking. Since there is no regulation
146 in the UK for such systems, there is a code for practice (BS 8515:2009) specifically for
147 rainwater harvesting covers design, installation, and maintenance of the system, water quality,
148 and risk management and rainwater collection systems encouraged in The Code for
149 Sustainable Homes. In Noorderhoek (Netherlands), a biogas plant serving 232 apartments is
150 under operation since 2007 (Bautista Angeli et al., 2018). An UASB reactor (2.5-7 m³) is

151 operated with blackwater, kitchen waste, and greywater under mesophilic conditions and
152 produces 13.8–12.2 m³ CH₄/cap/year which is equal to 133–148 kWh/cap/year heat with CHP
153 unit. The national regulations such as “Regulation designating sustainable energy production
154 categories (enforced 01.10.2014)” for definition of technologies and regulation for subsidies
155 and “Renewable Energy Production Incentive Scheme (enforced 16.10.2007, last recast
156 01.04.2017) for the market price of the electricity and biomethane must be followed for the
157 renewable energy projects in the Netherlands (Hermann et al., 2019). In the study of Starkl et
158 al. (2007), a policy-oriented approach was followed to develop an integrated assessment for
159 rural wastewater management in Austria based on a separation of the wastewater into its
160 constituent parts using various technologies. It was concluded that the co-treatment of black-
161 water in a regional biogas plant would be technically feasible, but it is not supported by
162 regulations in Austria as well as in my EU member countries. In fact, limitations in the ability
163 of governance structures to adapt was stated as one reason for the stagnation in the
164 implementation of novel water systems in Germany (Schramm et al., 2018). Although these
165 technologies bring innovative solutions to decrease water and energy stress in the regions they
166 are applied, most of them may face legislative obstacles for further reuse and/or valorization
167 of resources as analyzed in the following sections.

168 **3. Legislative framework and barriers**

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

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

177 **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)	Rainwater	Rainwater for: Irrigation, drinking water, and domestic uses
EC Best Environmental Management Practice in The Tourism Sector (Styles et al., 2013)		
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)		

178 **3.1. Water reclamation and sanitation for water safety**

179 When considering the implementation of any solution that aims at ensuring sustainable
180 management of water and sanitation (Sustainable Development Goal-SDG 6) in the EU, the
181 fitness check with the Water Framework Directive (WFD) 2000/60/EC cannot be overlooked.
182 In the WFD, the use of reclaimed water is considered as a means of increasing water
183 availability while ensuring a good quality status of water resources. Specifically, the Directive
184 (Annex VI(x)) refers to ‘efficiency, reuse measures, and water-saving techniques for
185 irrigation’ to help to achieve good environmental status. In this perspective, the
186 implementation of small-scale decentralized technologies could contribute to tackling the
187 problem of reaching a good status in Europe, as already highlighted in the Regulatory Fitness
188 and Performance program evaluation (REFIT) of the WFD by the European Environment
189 Agency (European Commission, 2019b). In this perspective, the WFD (Art.11(3-f)) allows to
190 artificially recharge the groundwater bodies with water that “...*may be derived from any*
191 *surface water or groundwater...*”, after the necessary authorization. Thus, no clear constraint
192 on the use of specific water sources is stated, as long as the water used does not compromise
193 the achievement of the environmental objectives for a good water status.
194 Furthermore, no explicit permission or prevention is detected for drinking water production
195 from rainwater, as the WFD referred only to conventional water bodies as sources for
196 drinking water production (Art.7(1) and (2)).
197 No specific barriers are identified even when considering the compliance with the Directive
198 2006/118/EC, “Groundwater Directive” (GD). However, a focus on national/local legislation
199 should be further assessed to evaluate how monitoring strategies are carried out in different
200 countries to ensure the safety of aquifer recharge regarding contamination (e.g. pesticides) by
201 the stormwater runoff.

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

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

220 During the consultation period of the EU, the consortium of the Innovation Action project of
221 HYDROUSA focused its evaluation of the UWWTD at the challenge of individual or
222 appropriate systems. The consortium commented that “*Despite the generally high level of*
223 *implementation of the UWWTD, a number of challenges remain, including the need for*
224 *further investments in the wastewater sector to increase or maintain implementation,*
225 *operating costs optimisation, individual or appropriate systems (IAS), stormwater overflows,*
226 *as well as improving coherence with other European Union water policy.*” And concluded

227 that “...IAS should be framed by specific regulations in the future. Specifically, the
228 requirements for designing, constructing, and maintaining IAS must be defined and
229 environmental protection must be ensured on the same level as a collecting system followed
230 by centralised wastewater treatment.”

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

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

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

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

252 It should be noted that for small-scale systems it is crucial to adopt the risk-based approach
253 outlined in the Water Reuse Risk Management Plans (WRRMPs), which are also included in
254 the proposal 2018/0169 (COD), currently under evaluation by the European boards. When
255 considering small-scale collection and treatment systems, human, technical, and financial
256 resources are often limited (WHO, 2006) and thus monitoring strategies of water resources
257 might be challenging. However, the hazard prioritization and risk ranking introduced by the
258 WRRPM could represent a valuable control strategy for a small-scale water system.
259 Specifically, control measures can be implemented for the minimum monitoring of
260 community supplies, by monitoring the essential parameters of water quality and thus
261 reducing the overall monitoring costs. Furthermore, a legal instrument that can be used as a
262 reference for technical, economic, and environmental aspects is represented in the ISO/TC
263 282: “Guidelines for Treated Wastewater use for Irrigation Projects” for decentralized
264 systems. Applying the water safety plan to water reuse was examined elsewhere (Goodwin et
265 al., 2015), indicating that similar to the WHO’s Framework for Safe Drinking Water, the risk
266 management framework for reuse would guide scheme managers in setting targets and
267 assessing management performance.

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

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

282 Regarding the systems aiming to produce drinking water, the “Drinking Water Directive”
283 (DWD) Council Directive 98/83/EC (and its revision EU 2015/1787) is the starting-point
284 legislation for setting actions at the national level. Despite the binding character of the
285 Directive, measures are mandatory to distribution systems serving more than 50 people or that
286 provide more than 10 m³ of water per day, while for small-scale systems some exemptions
287 can be applied (Art.3 (2)). Therefore, under the DWD, household and small-scale supply
288 systems (e.g. wells or local springs) for rural communities are not regulated as well as the
289 possibility to produce drinking water from alternative sources (e.g. rainwater and/or water
290 vapor). These aspects highlight how the existing EU regulatory instruments for drinking water
291 are not in line with the latest scientific knowledge of the WHO recommendations.

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

296 It should be noted that, even for small-scale collection and treatment systems, no exemptions
297 are allowed when potential risks to human health are evident. In this perspective, WHO
298 guidelines provide scientific support, by highlighting the need for a water safety plan (WSP)
299 risk-approach for public health protection when small-scale decentralized systems are applied
300 (World Health Organization, 2017). These guidelines (evaluated also in the Proposal EC
301 COM 753/2017 (01.02.2018)) provide prescriptions for the safe management, operation, and

302 monitoring of wastewater, excreta, and greywater in agriculture and drinking-water quality. In
303 most cases, the successful implementation of WSPs is limited by a number of factors such as
304 the lack of financial resources and the absence of legislation (Tsoukalas and Tsitsifli, 2018). It
305 should be noted that when considering small-scale solutions, economic sustainability is a
306 crucial factor. In addition, alternative water sources for drinking water production should also
307 be considered. In this regard, it is fundamental to introduce the main elements of the WHO
308 guidelines in the revision of DWD to provide an EU regulatory instruments which could be
309 fully implemented for both centralized and decentralized systems. This means mainly to
310 update the existing safety standards, introduce a risk-based safety assessment, and to include
311 measures for drinking water production from alternative sources. Since compliance with
312 water directive might not be sustainable from an economic point of view, enabling the
313 environment for decentralized systems needs to be analysed at national and local levels
314 considering a risk-based approach to water safety. In terms of aspects related to the water
315 supply from unconventional water sources, e.g. recycled and desalinated water, public
316 acceptance is also stated as one of the major barriers in Europe and all over the world(Adapa
317 et al., 2016; Hurlimann and Dolnicar, 2016).

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

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

334 **3.2. Sludge treatment and reuse for food safety**

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

344 When considering applications of small-scale treatment systems to decentralized contexts,
345 rural community or neighborhood-based solutions should be implemented for treating the
346 sludge. In these cases, fecal sludge could represent the relevant input for producing compost.
347 In this regard, the SSD sets limits on the concentrations allowed (in soil and sludge) for the
348 application of the residual sludges from septic tanks (Art.2 (a -i, -ii, -iii)). Consequently, no
349 explicit barriers are detected for the replicability of small decentralized systems. Despite this,
350 the European Legislative Framework lacks ad-hoc regulation for community-based
351 composting and co-composting systems to fully support and regulate the recovery and reuse

352 of sludge in small and rural communities. Furthermore, the SSD often receives criticism as
353 being outdated and does not include limits for pathogens and organic micropollutants in soil
354 and sludge.

355 Considering the compost production, a further aspect is to analyse the possibility of labeling
356 and marketing of the fertilizer as an EU product. In this perspective, the European Fertilizer
357 Regulation (2009b, No 1069/2009) limits the exploitation of small decentralized systems,
358 since compost derived from digestate and sewage sludge cannot be labeled and marked as EU
359 fertilising products (Annex II). A possible way to address this barrier is currently provided by
360 different valuable works and projects. In 2019, the report “Digestate and compost as
361 fertilizers: Risk assessment and risk management options” was published by Wood with
362 partners Peter Fisk Associates and Ramboll for European Commission (Corden et al., 2019).

363 In this work, no limitation on input materials or uses is detected for compost or digestate
364 when an environmental and human health risk assessment and a risk management options
365 analysis (RMOA) are implemented. In a JRC Science for Policy report (JRC, 2019) possible
366 legal framework for marketing fertilising products, derived from precipitated phosphate salts,
367 thermal oxidation materials and pyrolysis, gasification materials, and derivates (STRUBIAS),
368 is explored. The main attention in STRUBIAS material is given to phosphate salts, which can
369 be obtained from wastewater and sewage sludge from municipal WWTPs by AD or by
370 composting. This study shows how STRUBIAS can be considered as a valuable framework to
371 provide phosphorus in a safe way to reduce the demand for the primary raw material from
372 phosphate rocks. Hence, the compost produced within decentralized systems might decrease
373 the demand for synthetic fertilizers and reduce economic/environmental impacts associated
374 with fertilizer production and waste disposal also in rural areas. In Europe, the European
375 Sustainable Phosphorus Platform (ESPP) serves as a hub for information exchange and
376 facilitates communication between all cross-sectoral stakeholders. In fact, political interest in

377 phosphate sustainability has grown a lot at the European level. Incorporation in the EU
378 critical materials list is seen as vital in this respect (de Boer et al., 2018). European legislation
379 governing phosphorus recycling was critically reviewed by Hukari et al. (2016), where
380 legislation harmonisation, the inclusion of recycled phosphorus in existing fertiliser
381 regulations, and support of new operators were proposed to speed up market penetration of
382 novel technologies, reduce phosphorus losses and safeguard European quality standards.
383 When using compost produced from waste and/or irrigate the site with reclaimed water for
384 food crops, food safety is a crucial factor to assess. Namely, the fitness check with
385 Commission Regulation (EC) No. 1881/2006 on maximum levels for certain contaminants in
386 foodstuffs should be analysed. According to this regulation, no relevant barriers were detected
387 for the marketability of products irrigated with reclaimed water and/or fertilized with compost
388 from waste, as the compliance depends exclusively on the final product. Major constraints
389 were detected when considering organic farming. In fact, according to the Organic Farming
390 Regulation (EC) No. 889/2008 (and its revision Regulation (EU) No. 848/2018) no
391 information is provided regarding sewage sludge matrix for fertilizer production. Thus, the
392 sewage sludge cannot be used to improve soil quality. However, “composted or fermented
393 household waste” can be authorized as long as it contains only vegetable and/or animal waste.
394 For instance, in the study of Viaene et al. (2016), among the 28 identified barriers to on-farm
395 composting and compost application, the complex regulation was listed as one of the main
396 five barriers. In fact, the authors recommended a certain degree of flexibility in current
397 policies and institutional arrangements to stimulate compost production and application.

398 **3.3. Renewable resources exploitation for energy efficiency**

399 To close the loop of the Integrated Resources Management, the energy sector should also be
400 assessed. In this regard, small-scale decentralized systems can offer a valuable alternative to
401 methane extraction from natural deposits, such as upgrading methane from biogas produced

402 in anaerobic treatment. With the view to reuse methane in the transport sector, small-scale
403 decentralized systems are supported by the renewable energy directive 2018/2001/EU (EC,
404 2018) to meet the 10% of renewable resources used in transport. Specifically, in Annex IX(f)
405 sewage sludge can be used to produce biogas for transport and advanced biofuels. It should be
406 considered that biogas and biomethane should ensure the quality requirements as defined in
407 the technical standards for biogas EN 16726 and EN 16723 on Liquefied Natural Gas (LNG),
408 biomethane, and blends for automotive fuels. Concerning the investigated barriers for the
409 implementation of technologies promoting biogas reuse, many studies highlighted the lack of
410 institutional support and specific action programs to support biogas technologies (Nevzorova
411 and Kutcherov, 2019). In this regard, complex institutional and legal pathways could block
412 and prevent the implementation of such applications. Furthermore, Yaqoot et al. (2016)
413 analysed barriers to the dissemination of decentralized renewable energy systems. Among the
414 institutional barriers, the authors include the lack of a suitable legal and regulatory framework
415 for dissemination of decentralized renewable energy systems as a major institutional barrier,
416 together with the other sub-barriers such as the lack of agencies to disseminate information,
417 uncertain government policies, strict bureaucratic procedures, unstable macro-economic
418 environment, lack of stakeholder participation in decision making, clash of interests among
419 stakeholders; lack of R&D culture; insufficient professional institutions and lack of private
420 sector participation.

421 **4. Regulatory fitness check**

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

427 For each parameter, the reference documents were listed (see column “reference documents”).
428 Documents were grouped according to directives, technical standards, guidelines, manual (see
429 column “document type”). Finally, “relevant information” was reported to point out whether
430 the regulatory instruments “support” or “hinder” the recovery and use/reuse of specific
431 resources/by-products.
432

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

436
 437

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
From sewage sludge to compost	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

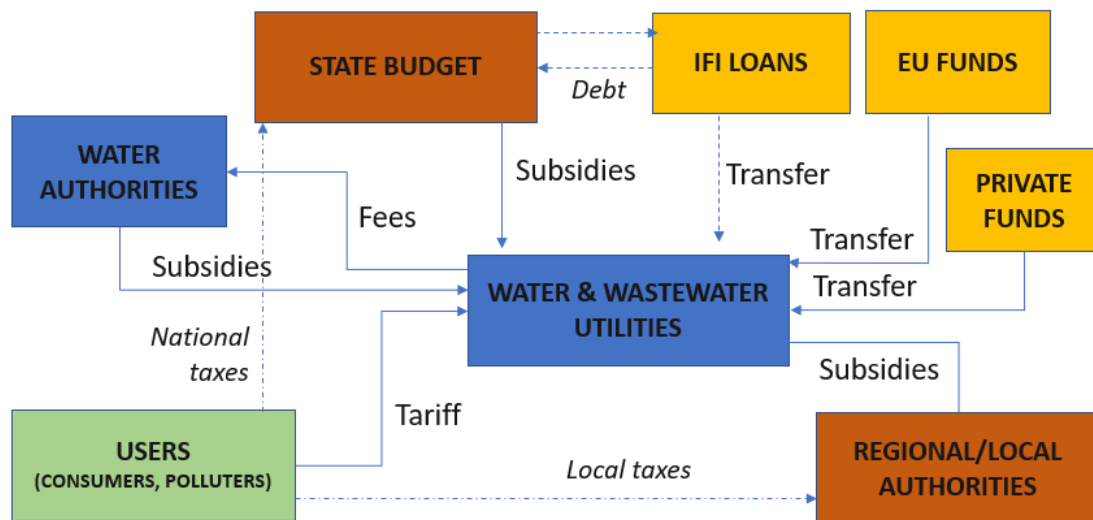
	Indicative treatments required for reaching water quality standard		Proposal 337/2018 and 2019 revision	A
	influence of flow quality on the final intended use		Proposal 337/2018 and 91/271/EEC and revisions	A
	Types of food regulated		1881/2006	A
	Limits for compliance in foodstuffs		1881/2006	A
	Amount 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		2000/60/CE and 98/83/EC and revisions	B
	Parameters to meet for potable uses	Directive	98/83/EC and revision; (Proposal 753/2017 EC)	B
	Permitted water source for drinking purpose		WHO Guidelines for drinking water quality	A
	Treatment for the purpose and monitoring/control measure	Guidelines		B
From rainwater and runoff from road to water for aquifer recharge and further irrigation	Type of water to aquifer recharge		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	Directive	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

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

457 **5. Financial analysis**

458 The choice for funding water infrastructure between a centralized and decentralized solution
459 in a rural and/or peri-urban area depends on several variables: method of economic
460 assessment (social discount rate), funding policy (funding rate), and users' self-organization
461 (cost-sharing) (see the paper, (Brunner and Starkl, 2012)). In fact, a successful
462 implementation of decentralized solutions relies on many critical factors such as public
463 acceptance, qualified maintenance, organizational support, and availability of financial

464 resources (Sousa-Zomer and Cauchick Miguel, 2018). The nature of financing arrangements
 465 that depends on the institutional structure was assessed to define a general structure of the
 466 mechanisms on which the water/wastewater management is based. The approach proposed by
 467 the Organization for Economic Cooperation and Development (OECD) focuses on the 3T
 468 (Taxes, Tariffs, Transfers) for regulating, increasing, and balancing finances in three forms.
 469 The structure of financing pathways for small-scale decentralized technologies was analyzed
 470 by highlighting the general framework for ensuring cost recovery (**Fig. 1**) of municipal water
 471 cycle services (e.g. wastewater and domestic water).



472
 473 **Fig. 1.** General structure of the financial framework in water service management.

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

- 480 • Countries with a specific water financing structure. In this case, the concept of “water
 481 pays water” is followed;

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

484 **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		

485
 486 It was also highlighted that for small-scale decentralized treatment systems, whose owners
 487 and suppliers could be either a public or private body, a blend of three financing strategies
 488 (e.g. Tariff, Subsidies, Transfers) could be implemented to cover the initial investment and
 489 thus reduce the Return On Investment (ROI) period. The details are shown in **Table 4** below.

490 **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		

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

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

501 **6. Possible solutions: a step forward in the context of the Innovation Deal and the** 502 **European green deal**

503 The aspects analysed in this study can be contextualized in a broader framework such as the
504 European Green Deal (European Commission, 2020). Achieving a zero-climate impact by
505 2050 will only be possible if measures to be adopted are supported by adequate European
506 regulatory instruments that can be applied both at large- and small-scale. In this context, the
507 European regulatory framework highlighted signs of disparity. Clear policy instruments
508 regarding sustainable solutions in small and rural communities or agglomerations are
509 currently lacking. The result of this gap is the achievement of quality standards that could
510 represent a challenge for the economic sustainability of decentralized systems.

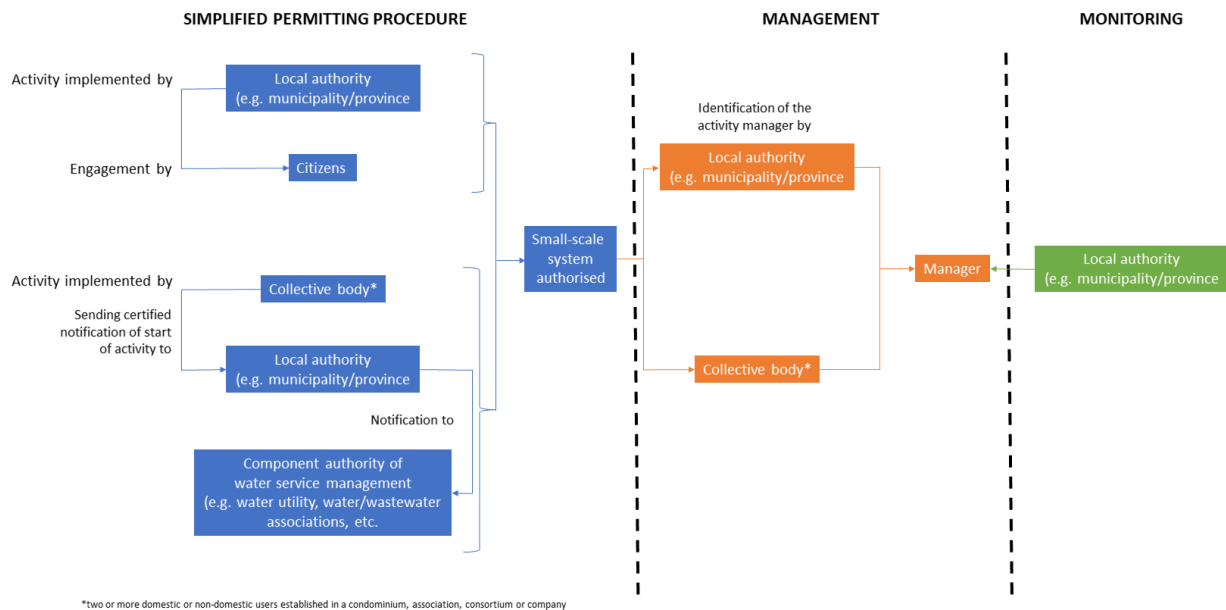
511 Moreover, according to the last revision of the UWWTD (91/271/EC), pollution from urban
512 wastewater systems to water and soil can still be avoided. Specifically, sources of pollution
513 are related on one side to unmonitored/untreated combined sewer overflows, small
514 agglomerations, and non-connected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

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

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

538 When considering the management of small-scale systems, the activity could be carried out
539 either by the municipality or by the collective body. Regardless of the manager, data
540 regarding the system treatment efficiency, amount of produced wastes, effluent characteristic

541 for quality monitoring should be registered. Monitoring strategies should be anyway carried
 542 out and supervised by the competent authority (e.g. province, municipality, etc.).
 543 Thus, the community composting based-approach could be implemented in the water and
 544 water-related sector to support the implementation of small-scale treatment technologies as
 545 according to the scheme represented in **Fig. 2**.



546

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

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

556

557

558 **7. Conclusion**

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

579 **Credit authorship contribution statement**

580 **Giulia Cipolletta:** Investigation, Methodology, Formal Analysis, Visualization, Writing -
581 original draft. **E. Gozde Ozbayram:** Investigation, Writing - original draft. **Anna Laura**
582 **Eusebi:** Project administration, Validation, Supervision. **Çağrı Akyol:** Conceptualization,

583 Writing - original draft. **Simos Malamis**: Project administration, Resources, Validation,
584 Writing - review & editing. **Eric Mino**: Conceptualization, Visualization, Writing - review &
585 editing. **Francesco Fatone**: Funding acquisition, Project administration, Resources,
586 Supervision, Writing - review & editing.

587 **Declaration of competing interest**

588 The authors declare that they have no known competing financial interests or personal
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595 **Appendix A. Supplementary data**

596 Supplementary data to this article can be found online

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