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Enhancing a Transition to a Circular Economy in the Water Sector: The EU Project WIDER UPTAKE

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Abstract: Wastewater treatment plants (WWTPs) require an urgent transition from a linear to a circular economy operation/design concept with a consequent resource recovery and more sustainable waste management. Natural resources have to be preserved, and wastes have to become an opportunity for recovering resources and materials (water reuse, energy, sludge reuse). However, the transition toward a circular economy is a complex and long process due to the existence of technical, economic, social and regulatory barriers. These existing barriers are critical challenges for a modern and sustainable WWTP concept. The recovery of resources must be considered a strategic target from the earliest process-design phase. In this context, the European Union's Horizon 2020 project "Achieving wider uptake of water-smart solutions—WIDER UPTAKE" aims to overcome the existing barriers (technological, regulatory, organizational, social and economic) toward the transition from a linear to a circular economy model for WWTPs. This study is aimed at increasing the awareness of the existing barriers to a circular economy and summarizes the key contributions of the WIDER UPTAKE project in terms of water reuse, sludge reuse and nutrient recovery.

Keywords: smart water; circular economy; wastewater treatment

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1. Introduction

In recent years, huge industrialization and development of urban areas produced a significant exploitation of natural resources, entailing a consequent production of large amounts of waste [1]. In this light, the huge recurrence of using fresh water for irrigation coupled with the large amount of sewage sludge produced during wastewater treatment pose a serious challenge in the context of sustainable development. The concurrent need to manage resources and produced wastes pushed communities worldwide to change their standpoint—wastes are no longer a problem, but an opportunity [2]. Concerning sewage sludge, severe population growth, expected to rise up to 9.7 billion by 2050 [3], coupled with the increased amount of treated wastewater, will lead to an extensive increase in production of sewage sludge that should be properly disposed. Kominko et al. [4] estimated a production of 13 million tons of sewage sludge (as dry solids) in the 27 member states of the European Union by 2020. Due to specific legislation on waste-management hierarchy [5] that limits sludge-disposal methods to landfilling and land application, in the last decades many efforts were devoted by researchers to develop methods for sludge reuse and recycling as possible sustainable environmental options [6]. On the other hand, alongside sewage sludge management, the reuse of treated wastewater represents another key factor for wastewater treatment plant (WWTP) operators, communities, decision-makers and stakeholders. Water reuse represents one of the most important alternatives to conventional fresh water sources, in order to address water scarcity [7], especially in low-income countries, as well as in arid or semiarid regions [8]. In this context, it is expected that the application of circular economy concepts would help to avoid severe freshwater stresses, while it also would contribute to the reduction of greenhouse gas (GHG) emissions related to sludge disposal, which are estimated at close to 40% of the total GHG emissions from WWTPs [9].

The concept of the circular economy has been gaining attention since the 1970s; its formulation was attributed to Pearce and Turner [10]. Investigating the linear and open-ended characteristics of contemporary economic systems, Pearce and Turner [10] described how natural resources can influence the economy by providing inputs for production and consumption while serving as sinks for outputs in the form of wastes. The circular-economy concept emerged as an alternative to the "Take–Make–Dispose" (linear) economic model and is based on the principles of cradle-to-cradle, regenerative design, industrial ecology, laws of ecology, biomimicry, looped and performance economy, and the blue economy [11]. According to the Ellen MacArthur Foundation (EMF): "Circular economy is the one that is restorative and regenerative by design and which aims to keep products, components and materials at their highest utility and value at all times" [12]. In this light, with the aim to promote reuse, recycling and recovery of wastes, the European Commission adopted an ambitious circular-economy package [13].

However, many countries are experiencing several difficulties with the implementation of solutions for the reuse of both treated water and sludge [14,15] due to the existence of technical, economic, social and regulatory barriers. The implementation of more conscious and sustainable reuse of sludge and treated water requires the identification and involvement of stakeholders in the whole process chain [16]. Some of the implementation barriers that might hamper the widespread reuse of wastewater and sludge are described in the following.

Regarding the technical aspects, despite the existence of several advanced technologies for resource recovery, few large-scale applications have been implemented [17]. This is mainly due to the lack of information possessed by the water-management utilities' decision-makers about the existence of such technical solutions. Furthermore, the possibility of creating a market based on recovered resources is also poorly known among politicians, decision-makers and water-utility managers. This is mainly due to an inability to estimate the economic value and the amount of the potential resources to recover [17]. In this regard, a transition of the role of water-management utilities is mandatory. Water-management utilities have to be not only the guarantor of the legislative rules, but also market actors promoting resource recovery within the WWTPs from a circular-economy point of view. Regarding the social aspects, users often have misconceptions (mainly based on absent and/or poor information) about the risks related to the adoption of resources recovered from wastewater. Therefore, there also is a need to invest in informing the users regarding this information in order to overcome such a barrier.

From a regulatory point of view, the reuse of treated wastewater as well as sewage sludge represents a challenging issue, and national and regional authorities in Europe have devoted many efforts in recent years; despite such efforts, uncertainties still exist [18]. Concerning wastewater reuse, the European Parliament recently released Regulation (EU) 2020/741 [19], establishing the minimum requirements for water reuse, in order to "*facilitate the uptake of water reuse whenever it is appropriate and cost-efficient, thereby creating and enabling framework for those Member States who wish or need to practice water reuse*". In Italy, in order to comply with article 26 of Legislative Decree N. 152/99, Ministerial Decree No. 185/2003 [20] was released. Several efforts were provided in order to regulate sewage-sludge reuse at either European or national levels. A number of directives were released in recent years, among which are Directive 1986/278/EEC (Sewage Sludge Directive) [21], 1975/442/EEC [22], 1999/31/EEC (Landfill Directive) [23], 1991/271/EEC (Urban Water Treatment Directive) [24], 2008/98/EC (Waste Framework Directive) [5]. In Italy, Legislative Decree No. 92/99 [25] was issued as transposition of Directive 1986/278/EEC [18], while Legislative Decree No. 152/2006 [26] regulates waste management.

Bearing in mind the above discussion, the main aim of the paper is to highlight and discuss the urgent need of WWTP transition from a linear to a circular economic model. Such a circular economic model is sustainable since it is based on circular use of resources; further, the circular model fosters the development and application of smart solutions in WWTPs to cope with population growth and improve standards of living. The transition of WWTPs into water-resource-recovery facilities will preserve the major aim of the WWTPs, which is to protect humans from sanitary risks and the receiving water bodies from the detrimental effects of polluted wastewater. In this context, the WIDER UPTAKE Project (grant agreement number: 869283) represents a promising and effective opportunity and a tool for enhancing this transition to circular-economy concepts, pushing the wastewater sector toward more sustainable development. Due to its complexity, the project is divided into seven work packages (WPs), each having the aim to break the existing barriers (technical, economic, social and regulatory). Specifically, existing and innovative technologies will be studied and applied at full scale at different demonstration sites with a view toward establishing connections between the technological sector and water management utilities in WP1. Five demonstration cases are considered to provide knowledge on the feasibility of the proposed solutions for overcoming the existing barriers. In WP2, the quality and health risks related to the use of recovered resources are evaluated. The circularities of the resources and the industrial symbiosis are tested and evaluated in WP3. In WP4, the governance and assessment tool are set up to establish a transition process toward a circular economy that involves all stakeholders, including resources users, policymakers, and water-utility managers. Water smartness and progress toward sustainable development goals are assessed in WP5. In WP6, a roadmap is co-developed for a widespread implementation of water-smart symbiotic solutions for wastewater reuse and resource recovery, including sewage sludge and biopolymers, basing on the principles of the circular economy. Finally, WP7 addresses project-management activities. The final goal of WIDER UPTAKE is to demonstrate that innovative solutions can be effectively implemented for the optimization of wastewater reuse, resource recovery and energy consumption; market utilization of resources are aimed to be achieved through a symbiotic interaction between utility and industry. This paper aims to summarize the main issues surrounding the application of a circular economy in the wastewater sector: barriers, bottlenecks, opportunities and challenges. Within this context, the way the Horizon 2020 WIDER UPTAKE project is aimed to contribute to push the transition toward a circular economy is also presented. The contribution of the present paper is to critically assess the existing regulation framework and the ongoing policy trend; analyze the minimum quality standard required, as well as the existing bottlenecks and barriers that should be overcome; and address how the WIDER UPTAKE can sustain this transition for the successful implementation of water-smart solutions in the wastewater sector.

2. Past, Present and Future Regulations

2.1. European Environmental Law Concept and Trend Evolution

Water and sewage sludge reuse policies are basic pillars of the European Union 2019 Green Deal [27] and 2020 New Circular Economy Action Plan [28], a concerted strategy aimed at a progressive, yet inevitable transition to a climate-neutral, resource-efficient, and sustainable competitive economy. In this landscape, an overview of current European and Italian legislation on water reuse and sewage-sludge management and treatment shows two main features: a remarkable complexity and a trend of increasing evolution.

Focusing on the first one, the institutional and regulatory framework clearly reveals a so-called multilevel system in the distribution of legislative and administrative competence in this field. In the context of the Italian system, Article 117, paragraph 2, section (s) of the Italian Constitution establishes the exclusive authority of the national Parliament and Administration for the "protection of the environment and ecosystem". Hence, the national competence in the wide area of water regulation is founded in this general provision.

However, this power is apparently full and unrestricted. Indeed, it is delimitated from two opposite directions. Firstly, from "the bottom", some regions with "special powers" can claim a legislative competence on public waters. This is the case, for example, for Article 14, section (i), of the Sicilian "Statuto Speciale". Second, from "the top", both national and regional legislation must respect duties deriving from the European Union (EU), according to Article 117, paragraph 1 of the Italian Constitution. EU member states, such as Italy, have given up to the EU the legislative and regulative power in the broad field of environmental law. However, the competence of the European Economic Community in environmental policies was introduced only with the revision of the original Treaty of Rome by the 1986 Single European Act. Then, the 1992 Treaty of Maastricht set the proper legislative power of the EU in environmental policies.

Nowadays, the general aims of European environmental policy are encapsulated by Article 3, paragraph 3 of the Treaty on the EU (TEU) in the "high level of protection and improvement of the quality of the environment"; and Article 191 of the EU Functioning Treaty (TFEU) in "preserving, protecting and improving the quality of the environment, prudent and rational utilization of natural resources". With particular regard to water regulation, the legislative power concerning quantitative management and the availability of water resources is assigned to the European Parliament (Article 192 of the TFEU). Precaution, preventive action, damage rectification and "polluter pays" are the fundamental and classic principles of European environmental law enshrined in Article 191, paragraph 2 of the TFEU. Principles and rules settled both by the European primary law (i.e., TEU and TFEU) and secondary law (regulations and directives) prevail on the national legislations of the member states as a tribute to the general principle of the primauté of European law. Evaluated as a unique regulatory body, these sources gave shape to European environmental law [29–31].

In European environmental law and, particularly, in the water and sludge reuse legislation, it is possible to observe the above-mentioned evolutionary trend. There are two tangible clues of this evolution: (1) a change of paradigm in environmental policies; and (2) increasing legislative production of European institutions.

The new Green Deal launched by the European Commission in December 2019 depicts an overall change of paradigm in European environmental policies; indeed, it was proposed as a system of investment plans called the "Just Transition Mechanism" to support a sustainable use of natural resources and environmentally friendly technologies aimed toward a circular-economy model. The European Green Deal strengthens a market-oriented philosophy in environmental policies [32,33].

2.1.1. Increasing Legislative Production of European Institutions

The increasing legislative production of the European institutions (Parliament and the Commission) around these topics is one of the key points of the environmental policies. Table 1 summarizes the key legislative production at a European scale for the fields of wastewater treatment/water reuse and sludge treatment/management.

In the following sections, a detailed discussion on the key issues of the new Regulation (EU) 2020/741 [19] and Sewage Sludge Directive 86/278/EEC [21] is presented.

Table 1. Summary of the main European legislation in the fields of wastewater treatment/water reuse and sludge treatment/management.

Wastewater Treatment/Water Reuse		
Legislative Reference	**Key Topic**	**Relevant Output**
Directive 91/271/EEC [24]	Urban wastewater treatment	Water for irrigation reuse
Directive 2000/60/EC [34]	Framework for community action in the field of water policy	Define actions for environmental recovery
Directive 2004/35/EC [35]	Environmental liability with regard to the prevention and remedying of environmental damage	Establish the risk connected with reuse
Regulation (EU) 2020/741 [19]	Minimum requirements for water reuse	Water for irrigation reuse
Sludge Treatment/Management		
Legislative Reference	**Key Topic**	**Relevant Output**
Directive 86/278/EEC [21]	Regulate the sludge application in agriculture	Introduction of criteria for environmental protection when sewage sludge is used in agriculture
Directive 2006/12/EC [36]	Waste recovery	Possibility of using sludge biodegradation in soils
Directive 2008/98/EC [25]	Waste recovery	Possibility of using sludge biodegradation in soils
Directive EU 2018/851 [37]	Waste recovery	Modifies Directives 2006/12/EC and 2008/98/EC; specifies that sewage sludge is not urban waste
Regulation (EU) 2019/1009 [38]	Resources market	Criteria definition to put sewage sludge in the market as fertilizing products

Regulation (EU) 2020/741 on Minimum Requirements for Water Reuse

Focusing attention on Regulation (EU) 2020/741 [19] of May 2020 on minimum requirements for water reuse, we can clearly distinguish the above-mentioned modernized market approach, which tended to trigger a circular economy between water reuse and sewage sludge recovery. This regulation is built on two European Commission communications related to the problem of water scarcity: (i) the 2012 Blueprint to Safeguard Europe's Water Resources [39]; and (ii) the 2015 EU action plan for the Circular Economy [13], which has committed to a series of actions to promote the use of treated wastewater, and to a legal proposal setting out minimum requirements for water reuse. Limited awareness of potential benefits among stakeholders and the general public and the lack of a supportive and coherent framework for water reuse have been identified as the two major barriers preventing a wider spread of this practice in the EU. Indeed, the purpose of Reg. EU 2020/741 [19] is to guarantee that reclaimed water is safe for agricultural irrigation, thereby ensuring a high level of protection of the environment and human and animal health, through promoting the circular economy (Article 1). The reuse of properly treated wastewater (for example, from urban WWTPs) is considered to have a lower environmental impact than other alternative water supply methods, such as water transfers or desalination. The regulation recognizes that the main reasons for the low uptake of water reuse in the EU are the high investment needed to upgrade urban WWTPs and the lack of financial incentives for practicing water reuse in agriculture. The strategy for addressing these issues is to arrange innovative legal tools and schemes and promote economic incentives. The latter is necessary to take appropriate account of the costs and the socioeconomic and environmental benefits of water reuse, and to develop a circular economy by recovering nutrients (such as nitrogen, phosphorus and potassium, in natural biogeochemical cycles) from the reclaimed water and applying them to crops, using fertilization techniques, linking water reuse to sewage sludge recovery.

With particular regard to legal tools, the regulation sets out minimum requirements for water quality and duties of water-quality monitoring imposed on the reclamation-facility operator. The reclamation-facility operator must ensure that reclaimed water intended for agricultural irrigation complies with: (i) the minimum requirements for water quality set out in Annex 1 of the regulation—covering microbiological elements (such as levels of *E. coli* bacteria) and monitoring requirements; (ii) any additional conditions concerning water quality set by the competent authority in the relevant permit issued (Article 4). Besides, the relevant national authority must ensure that a water-reuse risk-management plan to produce, supply and use reclaimed water is prepared. The reclamation-facility operator can draft the water-reuse risk-management plan with other parties in the water-reuse project or the end users, as appropriate, and it must identify the risk-management responsibilities of all parties in the water-reuse project (Article 5).

The basic idea behind Regulation 2020/741 [19] is to enhance public confidence in water reuse and mechanisms of traceability and transparency. To ensure transparency, the regulation also sets out rules on raising awareness, information to be provided to the market and disclosure of the implementation monitoring. National contact points also must be established to facilitate cross-border coordination where necessary (Articles 8–11).

This new water-reuse regulation undoubtedly represents a step forward for European environmental law in the Green Deal transition to a green sustainable economy. Nevertheless, it displays some significant limitations, due to the general and minimalistic nature of the provisions that allow deviations in member states' legislation. Actually, an EU country can decide that it is not appropriate to reuse water for agricultural irrigation in one or more of its river basins on the basis of specific criteria: (i) the geographic and climatic conditions of the basin or parts thereof; (ii) the pressures on and the status of other water resources; (iii) the pressures on and the status of the surface water bodies in which treated urban wastewater is discharged; and (iv) the environmental and resource costs of reclaimed water and other water resources (Article 2). This peculiarity can jeopardize the whole purpose of the unification of European law and the development of the common market of water reuse.

Sewage Sludge Directive 86/278/EEC

The impact of the new policy context, resulting from the above-mentioned Circular Economy Action Plans [13], requires an update of the existing European legislation on sewage sludge, which shows evident obsolescence dating back to the 1980s. Indeed, Sewage Sludge Directive 86/278/EEC [21] seeks to encourage the use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and human health. To this end, it sets rules on how farmers can use sewage sludge as a fertilizer to prevent it from harming the environment and human health, by ensuring that the nutrient needs of the plants are considered, and that the quality of the soil and the surface and groundwater is not impaired. It also prohibits the use of untreated sludge on agricultural land unless it is injected or incorporated into the soil. Treated sludge is defined as having undergone "biological, chemical or heat treatment, long-term storage or any other appropriate process so as significantly to reduce its fermentability and the health hazards resulting from its use". To protect against potential health risks from residual pathogens, sludge must not be applied in soil where fruit and vegetable crops are growing or grown, or less than 10 months before fruit and vegetable crops are to be harvested. Due to the growing scientific knowledge and technological developments, in 2014 the EU Commission started a process of evaluation to revise this directive. A first result was the new Regulation (EU) 2019/1009 [39] on the market of fertilizing products.

Sewage Sludge Reuse: The EU Vision and Updates

In Europe, the proper management of sewage sludge represents a great challenge that is becoming increasingly difficult to address. Over the years, the European Commission has issued a number of laws aimed at protecting the environment as well as human health. This has led WWTP operators to face a series of considerable challenges to limit the pollutant concentrations in the treated water and manage the sludge produced by biological water-treatment processes [40].

Although the scientific community has been committed over the years to develop and promote innovative technologies to reduce the production of sludge [41], on the other hand, waste reuse is an important aspect to be encouraged through the diffusion of the concepts of circular economy [9].

Concerning sewage sludge in particular, several studies have been carried out with the aim to assess the feasibility of resource recovery with special reference to sludge reuse in agriculture [42]. Field-scale studies have shown that reuse of sludge, when properly treated and stabilized, leads to better soil fertility without promoting significant biological and chemical contamination [43]. In general, Europe has seen an increase in the reuse of sludge in agriculture. Some European countries, first of all Ireland, Lithuania, Estonia and Norway, have arranged, through internal policies, an almost total recovery of the produced sludge through reuse in agriculture [44].

However, this kind of policy cannot always be applied, since there are a number of legislative barriers, both at the European and national levels, which limit the reuse of sludge. The European Commission therefore took action for an initial intervention aimed at revising the 1986 Sewage Sludge Directive [21], giving rise to an initiative to assess the risks and opportunities of using sludge in agriculture.

Citizens and stakeholders were involved in a first event, from 16 June to 25 August 2020, aimed at gathering feedback on the roadmap created for the sludge directive review.

By analyzing the feedback received in more detail, the most critical and agreed-upon themes are the following:

- The revision of the directive is necessary and extremely important to adapt an old law to today's needs.
- Community and social aspects must be considered, as well as the development of new technologies.
- The theme of sludge reuse in agriculture was appreciated. Great attention was paid to the levels of pollutants for the environment protection. A hierarchy of sludge could be created in view of a more targeted reuse in specific contexts.
- There is a need for coordination between the various current directives (SSD, UWWTD, etc.) to avoid legislative contradictions that would make any changes appropriately made to a specific directive in vain.
- Improve communication between the EU and member states, which very often have completely different policies on sludge recovery.

Public consultations were opened from 20 November 2020 to 5 March 2021, in which citizens and stakeholders were invited to express their opinions via a questionnaire before the commission finalizes its proposal to revise the directive.

2.1.2. Italian Legislation

A comparable path in the Italian legislation can be found, both in general regulations about the preservation/protection of water resources against pollution and the reuse/management of sewage sludge (the so-called "Testo Unico dell'Ambiente", Legislative Decree n. 152/2006 [26]), and in specific rules on sewage sludge reuse in agriculture (Legislative Decree n. 99/1992 [25], implementing Directive 86/278/EEC [21]). The above legislation exhibits an outdated approach of considering sludge as waste, while the possibility of recovery and reuse is very limited. Indeed, many controversial issues have risen in national courts around the interpretation and implementation of their provisions. The need for an overall review has come to light, and the Italian Parliament is currently debating a proposal for a new uniform statute intended to set a renewed notion of sludge as "end of waste" and reviewed technical standards for the recovery and treatment of sewage sludge.

3. Barriers, Bottlenecks and Challenges for Wastewater and Sludge Reuse

As discussed in Section 1, the existence of social, technical, economic and regulatory barriers can hamper the widespread implementation of wastewater and sewage-sludge reuse. Concerning wastewater reuse, the most critical factor for the sustainability of the reclamation scheme is not the technology itself, but public acceptance [45,46]. Indeed, if on one hand there is good support of reclaimed wastewater for agriculture, public utilities and low-contact purposes, the majority of objections concern projects where humans may come in close contact with recycled water [14]. Therefore, there is a need to increase public awareness in order to evaluate the potential for acceptance of wastewater reuse in the different European member states. Moreover, the cost of reclaimed water might be another great concern that is limiting support of the reuse of wastewater. From a regulatory point of view, a main issue that should be addressed to reduce the health and environmental risks related to wastewater reuse is that the different member states' standards and guidelines can be significantly different, even at the regional level. Therefore, there is a need for regulation at the European level; in this light, Regulation (EU) 2020/741 [19] released by European Parliament might contribute to improving clarity on wastewater reuse at the European level. Concerning sewage-sludge reuse, the main barriers are related to either legislation or public acceptance, depending on the type of sludge utilization. First, one of the main options for sludge reuse that is mostly adopted in many European countries is represented by sludge composting; however, the main limitation related to sludge composting is represented by compliance with the requirements for organic fertilizers, as well as the acceptance of this matrix by final users. Moreover, the direct use of sludge in agriculture is becoming more complicated due to the adoption by some EU countries of stricter limit values for contaminants compared to that reported in the Sewage Sludge Directive (SSD) [9]. Nevertheless, even if agricultural use of sludge remains one of the most suitable options from an environmental point of view, due to the nutrient content in sludge that can be recovered [47], it strongly depends on acceptance by farmers, as well as on the specific agricultural production.

4. The WIDER UPTAKE EU Project

"Achieving wider uptake of water-smart solutions—WIDER UPTAKE" is an international project financed by the European Union's Horizon 2020 Research and Innovation Programme focusing on innovative circular-economy solutions co-developed by water utilities and private businesses from industry sectors. The project aims to overcome the existing barriers (technological, regulatory, organizational, social and economic) toward the transition from a linear- to a circular-economy approach in the water sector. The project represents an excellent step toward the aforementioned transition process. Specifically, WIDER UPTAKE's ambition is to develop and implement new industrial symbioses based on water-smart solutions linking water and wastewater treatment, resource extraction, energy supply and product development for the agriculture and building/manufacturing materials industries. The project has a four-year duration starting from 1 May 2020.

WIDER UPTAKE involves a strong team composed of Stiftelsen for Industriell og Teknisk Forskning (SINTEF) and Norges Teknisk-Naturvitenskapelige Universitet (NTNU) in Norway, Technische Universiteit (TU) Delft in the Netherlands, Czech Technical University and The University of Chemistry and Technology Prague in the Czech Republic, University of Palermo in Italy and the Council For Scientific and Industrial Research (CSIR) in Ghana, 6 water utilities, 5 companies and 10 stakeholders. WIDER UPTAKE is organized in seven work packages (WPs) (Figure 1).

The activities performed during WIDER UPTAKE aim to: (i) demonstrate innovative technical solutions that optimize water reuse, resource recovery and energy utilization; and (ii) facilitate wider uptake of water-smart solutions. In this regard, five demonstration case studies (Ghana, Italy, Norway, the Czech Republic and the Netherlands) in WP1 are considered within the project to implement innovative solutions for wastewater reuse and resource recovery. In view of facilitating the application of water-smart solutions, cross-cutting activities addressing common barriers will be studied in WP2 to WP5. A roadmap will be developed within the project in WP6 and will be made available in an open-access virtual learning and sharing center.

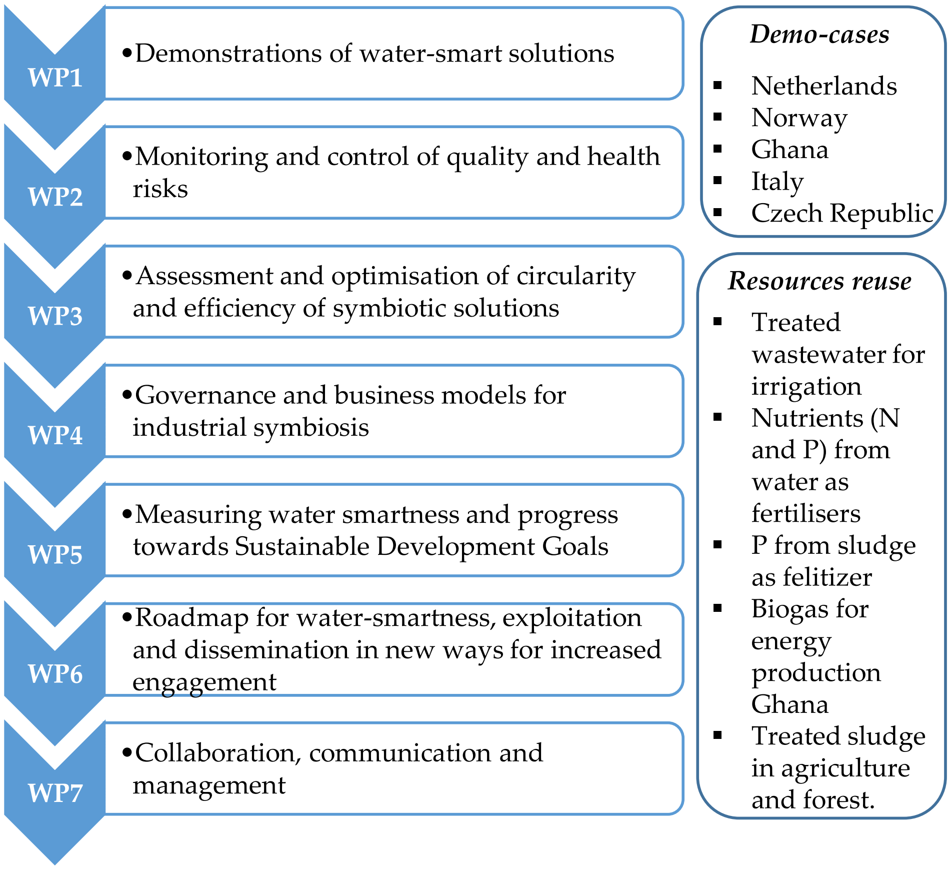

Figure 1. Summary of WIDER UPTAKE WPs, demonstration cases and resources recovery.

University of Palermo, the leader of WP6, is also responsible for one demonstration case in Italy (Sicily), which will be developed at the full scale WWTPs of Corleone and Marineo (12,000 and 7000 inh, respectively). Further, a water-reuse demonstration case at the Palermo University campus has been planned, with a final aim to provide an example of environmental sustainability in the water sector to students and the educational field, promoting the awareness of the value of water reuse.

The main objectives of the team at University of Palermo are: (i) material and resource recovery/reuse; (ii) plant optimization in view of reducing both direct and indirect greenhouse gas emissions; and (iii) proposal of new regulations for sewage sludge and water reuse. In order to achieve the aforementioned objectives, several activities (grouped into experimental, modeling and risk-analysis activities) will be performed both at laboratory and full scales in the two demonstration sites (Corleone and Marineo WWPTs). All the aforementioned activities are tightly connected to each other, and some will benefit from input provided by the cross-cutting activities in WP2 to WP5. Table 2 summarizes the main objectives and sub-objectives of the Italian demonstration case in WIDER UPTAKE underlying the main activities and the contributions of the transition toward a water-smart condition.

Table 2. Summary of the main objectives and sub-objectives of University of Palermo within the Italian demonstration case in WIDER UPTAKE underlying the main activities and contributions of the transition toward a water-smart condition.

WIDER UPTAKE—University of Palermo			
Objective	**Sub-Objective**	**Main Activity**	**Contribution toward the Transition**
Material and resource recovery/reuse	Polyhydroxyalkanoates (PHA) recovery/reuse	Experimental activity at laboratory and demonstration scales, and mathematical modeling	Possibility to trigger bioplastic production/market
	Nutrient recovery/reuse Water reuse Sewage sludge reuse	Experimental activities; quality and health-risk analyses related to water reuse and sludge; evaluation of plant and soil quality	Promote the market and the use of the recovered resources
Full-scale plant optimization	Direct and indirect greenhouse gas reduction Reduction of sewage sludge production	Full scale monitoring and mathematical modelling; application of automatic control technologies and metabolic techniques to reduce sludge production	Reduction of plant operational costs and environmental impact
Proposal of new regulations	New "Sludge Regional Law" New "Water Reuse Law"	Study and round tables aimed to identify the criticalities of the existing legislation	Overcome the existing regulatory barriers

In the following sections, attention will be focused on the main activities related to water and sludge reuse, and nutrient recovery.

4.1. Water Reuse

The sub-objective represented by water reuse will be accomplished in a twofold way: (i) setting up a reuse facility on the University of Palermo campus; and (ii) start-up of a water-reuse facility at the Corleone WWTP. Regarding the reuse station within the campus of the University of Palermo, the wastewater produced within the campus will be treated by means of a pilot plant (expressly set up for the WIDER UPTAKE project) adopting advanced technology. The treated water will be used to irrigate the green areas of the campus, thus reducing the consumption of fresh water.

The Corleone WWTP is equipped with membrane modules for final effluent filtration and a distribution network for water reuse (irrigation) of local agriculture and green urban areas (i.e., green gardens). The membrane modules have never been operated; one aim of the project is to carry out the membrane maintenance and the consequent start-up in view of producing water to be used for irrigation in agriculture and/or green urban areas. In order to improve the quality of the treated water, several pilot and batch tests will be performed at the University of Palermo by implementing different operational conditions and technologies.

4.2. Sludge Reuse

Minimization of excess sludge production and GHG emissions will be implemented at the Corleone WWTP. In this regard, the current plant layout will be upgraded by using one empty tank as an anaerobic sludge reactor, according to the oxic-settling-anaerobic (OSA) configuration. To pursue circular-economy concepts, the excess sludge that will be produced will be subjected to composting processes and reused as an agricultural soil fertilizer/conditioner. In this regard, aerated piles of sludge mixed with bulking agents will be monitored under different operational conditions in order to achieve a good compost quality. The interaction of water, soil and plants will be analyzed for both water and sludge reuse, in order to avoid negative effects in terms of plant growth and soil quality. Moreover, the production of polyhydroxyalkanoates (PHAs) from sludge will be studied in view of overcoming technical and socioeconomic challenges. PHAs are bio-based and biodegradable polyesters with thermoplastic properties comparable to some petroleum-based plastics, and could replace conventional polymers on the plastics market [48]. Mixed microbial cultures (MMCs) commonly used in biological wastewater treatment have the potential to intracellularly accumulate PHA. Therefore, integrating the PHA production process with wastewater treatment allows WWTPs to recover carbon from wastewater by reducing the amount of sludge to be disposed [49]. The PHA production process, when integrated with wastewater treatment, usually takes place in three distinct process elements: (i) sludge fermentation for volatile fatty acid (VFA) production; (ii) culture selection to produce biomass with a high PHA accumulation potential; and (iii) PHA accumulation using the biomass produced in the second process unit and the VFA rich stream produced in the first. The feasibility of producing PHA-rich mixed-culture biomass from municipal wastewater treatment using this scheme has been widely demonstrated at the pilot scale [50–52]. The integration of the PHA production process in full-scale WWTPs would be a step toward a change of paradigm in wastewater management: from WWTPs as end-of-pipe environmental-protection infrastructure to the concept of wastewater biorefineries; in other words, from a linear-economy model to a circular one. As proved in the first full-scale demonstration case [53] the whole WWTP can operate as a process unit for the production of PHA-accumulating biomass, with no or minor modification of the wastewater-treatment process. In this way, all the surplus activated sludge produced can be harvested and used to accumulate PHA, while the fermentation of primary sludge from the same plant can provide up to 40% of the VFA-rich feedstock needed to maximize the biomass PHA content [54]. Therefore, the integration of MMC PHA production in WWTPs could be a concrete solution to recover carbon from wastewater by biopolymer synthesis, with the concurrent benefit of sludge minimization. Nevertheless, there are still challenges that need to be addressed in order to make this technology ready for widespread application. Economic sustainability of the process is one of the main barriers to overcome, in which a major role is played by the downstream processing for PHA extraction from biomass. The extraction of the polymer is also a pivotal step with respect to material quality. Along with technological developments and optimization of product reliability in supply and consistency of properties, despite the variability of waste streams used as feedstock, it is important to establish a viable chain between the PHA producers and stakeholders in order to promote upscaling efforts [55].

4.3. Nutrient Recovery

The Marineo WWTP represents the demonstration case intended for material recovery, by implementing a deviation line for PHA production/extraction, as well as the installation of column filters for nutrient recovery. In particular, the deviation line for PHA production and extraction will be characterized by a fermenter unit for volatile fatty acid (VFA) production, a sequencing batch reactor (SBR) for the growth of PHA-accumulating organisms (namely, SBR 1) and another SBR for the accumulation of PHA (namely, SBR 2).

Nutrients (phosphorus and nitrogen) will be recovered from the effluent flow rate by means of adsorption columns. Specifically, two adsorption columns will be built and filled with adsorbent material (biochar and zeolites), with the aim to recover nutrients from the effluent streams.

4.4. Microbiological Aspects Related to the Innovative Solutions

In the modern concept of a biorefinery associated with WWTPs, microorganisms play a key role in those processes in which pollution removal and water recycling are coupled with resource recovery [56]. In WWTPs, activated sludge acts as a consortium that comprises different kinds of prokaryotic (i.e., bacteria and archaea) and eukaryotic (i.e., yeasts, molds and protozoa) microorganisms with complex and interconnected trophic relationships. In fact, the biochemical and metabolic capabilities of the activated sludge microorganisms determine WWTP performance and, conversely, the characteristics of operational conditions can shape the quantitative and qualitative (i.e., structure) composition of activated sludge [57,58]. The structure of the complex microbial community in WWTPs is being increasingly studied by using culture-dependent and culture-independent approaches. Uncultivable microbial species are the most abundant in various types of activated sludge [59]. Therefore, in the era of high-throughput sequencing methods, metagenomic-based approaches are powerful techniques that allowing comprehensive information to be obtained on microbial taxa, their abundance and their metabolic capabilities [60]. The study of microbial-community structure could be performed by: (i) amplicon sequencing of the 16S rRNA gene and ITS region—for prokaryotic and eukaryotic microorganisms, respectively—and by (ii) whole-genome shotgun metagenomic sequencing [60]. In this context, bioinformatic tools are required to identify metabolic processes associated with genetic or genomic information obtained from the microbial community. Indeed, information obtained from an activated-sludge microbial community could be crucial in order to: (i) to clarify the relationships between WWTP process parameters and nutrient removal/recovery effectiveness; and thus (ii) to drive decisions for process optimization.

Therefore, either at the pilot or full-scale plants, metagenomic studies will be carried out on activated sludge samples to investigate changes in the microbial-community structure by comparing different operating conditions—spanning from suboptimal to optimized ones—with the aim to highlight microbial community features associated with improved nutrient recovery (Marineo WWTP) and minimization of excess sludge and GHG emissions (Corleone WWTP).

4.5. The Effect of Water and Sludge Reuse on Soil Properties and Health Aspects

Treated wastewater (TWW) and sludge will be used for irrigation of agricultural and green urban areas and to improve soil fertility. Use of TWW is possible, but its impact on crop production and maintenance of good soil physical properties, as well as on public health, have to be taken into account [61]. By providing water, minerals and nutrients (mainly nitrogen and phosphorus), as well as organic matter to soil, TWW may have beneficial effects on soil microbial communities, and in turn on soil fertility [62]. However, the potential addition of heavy metals, pharmaceuticals and even pathogens into the environment and into the food chain may directly affect soil microbial diversity and activity, as well as public health [63]. TWW from the Corleone WWTP will be used only for irrigation of agricultural crops. Its effect on soil properties will be assessed by monitoring chemical and biochemical soil properties. Furthermore, its effect on horticultural crops will be monitored by evaluating some biometric parameters.

With regard to the sludge, its application as fertilizer or as an amendment to agricultural and forest soil represents an attractive disposal method. In particular, sewage-sludge application to forest soils can improve their physical, chemical and biochemical conditions, as well as fertility, while avoiding the risk of human food-chain contamination by sewage-borne heavy metals [64]. Moreover, the spreading of sludge on soil will counteract the continuous decline of organic matter, especially in soils in arid and semiarid environments [37]. However, the sustainability of amended soils might be threatened by contaminants in the sewage sludge, such as heavy metals, micro-pollutants and pathogens [65]. Thus, within the WIDER UPTAKE project, to reduce organic contaminants and pathogens, sludge will be applied to soil after composting. Different bulking agents (pruning residues, zeolite, biochar) and the sludge-to-bulking-agent ratio will be investigated to determine the optimal condition.

4.6. The Juridical Contribution of WIDER UPTAKE

From the juridical point of view, the WIDER UPTAKE project aims toward two different goals: (i) "*de lege lata*", to obtain clarity in the allocation of legislative competence at the European, national and local levels through a deep analysis of the problematic issues arising in the described multilevel framework; and (ii) "*de lege ferenda*", to suggest a set of new legal and economic tools of regulation for the common market aimed at the growth of the industrial symbiosis between water reuse and sewage-sludge treatment.

In this last perspective, we opted for a strong choice of method: the studies of behavioral economics known as the "nudge theory", conceived by Thaler and Sunstein (Thaler was awarded the 2017 Nobel Prize in Economic Sciences) [66]. According to this doctrine, nudges are tools designed to influence individual behaviors in a predictable and desirable direction for the policymaker. A public policymaker is considered as the "choice architect", building a context that promotes individually desired choices that are efficient to community welfare. It looks for the appropriate combination of context ingredients in such a way that individual decisional processes spontaneously are aimed at the desired result. The economic model proposed is defined as "libertarian paternalism", because the public policymaker identifies the common good and provides incentives for individuals and groups to adopt behaviors oriented to this target, without restricting private freedom and autonomy of choice.

The implementation of this theoretical approach to the specific field of European environmental law could represent a revolution against the traditional paradigm founded on the rationale of prohibition and fines expressed by the principle "polluter pays" [67,68]. In the specific context of the water- and sludge-reuse market, the design of incentives and benefits set by the public policymaker at the proper level of intervention, aimed at operators, stakeholders and users, can allow a transition to a green and sustainable circular economy that is truly able to convert waste into a resource.

In conclusion, the proposed concept seems to be perfectly matched and consistent with the new vision of the European Green Deal, which pursues human health, environmental protection and economic growth as "common good".

4.7. Community of Practice and Roadmap

As discussed above, the transition from a linear to a circular economy in the WWTP field is not easy, due to the existence of cultural, regulatory, financial and sectoral blocks and barriers [69]. Furthermore, the lack of a clear governance model is accompanied by the need of social acceptance; indeed, health and safety concerns drive public opinion to oppose the adoption of the technology. This requires the development of stronger multilevel regulatory frameworks, risk-based regulatory approaches and additional communication and consultation tools to build public support [70]. Public opposition is currently the primary barrier to the implementation of water-reuse projects [71]. Once the new regulatory framework is established, public support for the technology increases. This enables large-scale adoption of the technology [70]. Therefore, the first step for achieving the circular economy aim is the creation of a community of practice (CoP), which is a powerful form of support network containing different interests [72]. The concept of the CoP has its roots in the work of Lave and Wenger [73] on situated learning, and is defined as communities sharing a common framework of knowledge, skills, beliefs and practices [74]. The CoP will be used to share the perspectives of water utilities, solution providers and stakeholders from different industry sectors and to jointly develop the technical, marketing and commercial aspects of smart water systems in alternative scenarios for the future. Within the WIDER UPTAKE project, this information exchange will be carried out through semistructured interviews, which are the main form of data acquisition, and will be submitted to the CoP partners and stakeholders. This process of sharing and comparing ideas and experiences among participants often produces data and insights that would be less accessible without the interaction found in a group [75]. The results of the interviews will be shared, as it is essential to ensure the identification of the main actions to apply for achieving the circular-economy condition. Furthermore, the results of the interviews and the involvement of partners and stakeholders at different levels will allow the creation of a roadmap for a wider uptake of water-smart solutions, which will include objectives, key results, targets, timelines, potential risks, dependencies and resources that will be included in a database for further use of the roadmap in future projects and scenarios. In this light, the memorandum of understanding signed in July 2020 between the special Italian commissioner on wastewater depuration and the Sicilian president of the National Association of Italian Municipalities (ANCI) represents a useful tool in order to overcome EU infringements in the wastewater-depuration field, promoting the transitions of conventional WWTPs toward the concept of water-smart utilities. At the same time, education represents a powerful tool to sustain the transition to a circular economy at the academic/university level. Several events will contribute to disseminate the results of the WIDER UPTAKE project, including a European Researcher's Night and a final project conference (to be held in Palermo).

5. Future Perspective: A Nudge toward a Circular Economy

The transition toward a circular economy in the water sector, which entails economic activities and environmental sustainability, is a challenging and long-term process [76]. Within this process, the nudge paradigm for behavioral change and improving social acceptability has been given particular attention in environmental policymaking. Nudging represents the idea of altering people's behavior without restricting their freedom of choice [60]. In a circular economy applied to the water sector, the nudging process has several aspects: technological, social, economic and legislative. In terms of technological aspects, for the near future, it is desirable to design new plants and upgrade the existing ones by applying advanced technologies that are able to: (i) improve the effluent quality and recover water for beneficial reuse; (ii) reduce the amount of resources to be used (e.g., energy, chemicals, water); (iii) reduce the amount of waste (e.g., sewage sludge) produced; and (iv) allow recovery of resources (such as phosphorus and nitrogen, energy, etc.) In terms of social aspects, the social acceptability of using recovered resources derived from wastewater has to be increased by implementing several encouraging actions (e.g., information about the quality of the recovered resources or economic incentives). The legislative nudging process starts by overcoming the existing legislative limitations in favoring the adoption of resources recovered from wastewater. In this regard, the proposal of new laws and economic-support actions have to be encouraged in the near future. In this context, the ambition of the WIDER UPTAKE project is to cover the above aspects, and demonstrate the feasibility of water-smart solutions in WWTPs, thus representing a useful example that will favor the transition from a conventional approach to a more sustainable one, in agreement with the concepts of the circular economy.

6. Conclusions

Several barriers still exist for a widespread application of water-smart solutions (technological, regulatory, organizational, social and economic). These barriers should be considered as challenges to guide water-management utilities and policymakers toward future resource-recovery-oriented decisions. In the complex process of the transition from a linear to a circular economy, the role of water-management utilities is crucial; indeed, they must change their traditional vision of a utility manager and transform into actors in the market for recovered resources. Within this context, the Horizon 2020 project WIDER UPTAKE represents a great opportunity to push the water sector toward more sustainable development, according to the well-known concepts of the circular economy. The roadmap created within the project represents an innovative tool based on a decision-support system, not yet proposed in this sector, to guide designers/operators/researchers in the water sector to support the transition toward a circular economy. Innovative tools will be developed in the future (such as a dashboard) to guide WWTP operators toward the circular-economy approach to meet local opportunities for market-resource recovery. The WIDER UPTAKE project represents an opportunity to highlight that the existing barriers should be perceived as a challenge and not as an obstacle in the transition scenario, and that the recovery of resources needs to be considered as a strategic target from the earliest process-design and planning stages of new facilities.

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