Sophie Marie Hohenwarter

Institutional barriers to realizing the potential of nature-based solutions for a broader circular economy for water and nutrients in the EU

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Evaluator

Em.Univ.-Prof. Dr. Marina Fischer
Alpen-Adria-Universität Klagenfurt
Institut für Soziale Ökologie (BOKU)

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Sophie Marie Hohenwarter m.p. *Graz, 27.08.2021*

Abstract

The long-standing dilemma of society's unsuccessful ability to metabolize the nutrients released into the natural environment is the main problem addressed in this thesis. Regenerating water and nutrients could contribute significantly to closing nutrient cycles within society's metabolism, but their wider adoption is hindered by social and institutional barriers. The research explores these barriers, focusing on nature-based solutions (NBS) as a key strategy. For that, key informant interviews, literature review, and MaxQDA, a qualitative coding software, were the main methodologies used. The current state of knowledge reveals significant barriers, most of which are found in institutionalized systems and prevailing infrastructure. However, social barriers such as social engagement and responsibility are not frequently mentioned. This is confirmed by the results of this research. Nevertheless, the most important newly discovered barriers belong to the social dimension, namely lack of awareness and availability of examples of best practices. It can be concluded that more attention should be paid to NBS systems because of their primary function as regenerative wastewater treatment technology, but also because of their various co-benefits. Furthermore, these decentralized wastewater treatment systems are of particular interest to those countries that are directly and permanently affected by water stress. Finally, these changes in wastewater treatment can lead to a more sustainable long-term change in linear input-output patterns through increased awareness and institutional support.

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List of abbreviations

C2C Cradle to Crave
CAP Common Agriculture Policy
CAPEX capital expenditure
CE Circular Economy
DWD Drinking Water Directive
EC European Commission
EDC endocrine disrupting chemicals
EU European Union
K Potassium
N Nitrogen
NBS Nature-Based Solution
OPEX Operational expenditure
P Phosphorus
PhAC Pharmaceutically active compounds
UWWTD Urban Wastewater Treatment Directive
WFD Water Framework Directive
WRR Water Reuse Regulation

Introduction

The research of this thesis was conducted to contribute to the European Union (EU) Horizon 2020 HYDROUSA project in collaboration with alchemia-nova GmbH, an institute for innovative phytochemistry and closed loop processes (alchemia-nova 2020). The main goal of the HYDROUSA project, funded by the EU, was to develop a new circular business model for the Circular Economy (CE) of water and nutrients within the EU, which shall be suitable for water-scarce regions in Europe and worldwide. This circular business model aims to provide innovative solutions for water scarce regions in the form of decentralized (waste)water management for water and nutrient recovery (HYDROUSA 2020). Another aim is to reduce energy-intensive water management, thereby contributing to emission mitigation and climate change adaption, returning water and nutrients to the human system, as well as conserving resources by introducing nature-based and nature-inspired water management solutions for different types of water bodies Further, in 2020, the EU policy-makers showed interest in the circularity of water and nutrients by introducing the new European Circular Economy Action Plan (EC 2020, 98 final), which primarily aims to implement CE concepts to reduce greenhouse gas emissions as part of the long-term plan to become climate neutral in 2050 (EC 2019, 640 final) and secondarily emphasizes the issue of water scarcity. The research I conducted for the HYDROUSA project is embedded in this framework.

The aim of this thesis is to examine institutional and social barriers realizing the potential of Nature-based Solutions (NBS) for a broader CE for water and nutrients in the EU. The following hypothesis served as the starting point for this research: Even though nature-based (waste)water treatment technologies are available and could significantly contribute to closing water and nutrient cycles in the EU, their wider implementation is hindered by social and institutional barriers. Based on this, I elaborated the following main research question:

- Which social and institutional factors are hindering the wider uptake of NBS for resource recovery and reuse in the EU, and what are the potentials to overcome existing barriers?

During the research process, several additional questions arose that proved to be important for answering the main research question and trying to verify the hypothesis. Thus, I gradually tried to locate and answer the following questions along the analysis concept:

- What are first steps that could be taken to catalyze the transition to a circular economy for water and nutrients in the EU?
- How do social and institutional barriers interact?
- What can different stakeholders do to facilitate the transition?

Consequently, in order to answer these questions, I conducted a qualitative research by carrying out key informant interviews with project managers and practitioners of best practice case studies for water and nutrient recovery in different European countries. I faced a major challenge due to the outbreak of the Covid-19 pandemic and the start of the summer holiday season during 2020: receiving answers from case study managers and practitioners proved to be particularly difficult. Therefore, I could only examine six case studies in more detail and interview six practitioners and/or managers. I decided to further interview experts in the field in order to gain more comprehensive insights, which led to four additional interviews. In total, I carried out ten interviews to answer the research question emerging from the hypothesis. Furthermore, to complement the findings of these interviews and embed them in a theoretical framework, and I conducted literature research on the topic of CE and NBS, thereby giving the state of the art.

In general, this thesis is structured in six chapters: The first chapter introduces an old and prominent topic in environmental science, the disruption of the nutrient chain in the wake of industrial development. Further it explores the role of water and introduces the topics wastewater and nutrients. In chapter two, I address the relevant framework, namely Circular Economy (CE), as well as the specific EU CE strategy in connection with the relevance of (waste)water and nutrient management, in which the chosen case studies operate. The third chapter discusses NBS as a suitable technique to recover water and nutrients in more detail. Further, it presents the state of the art of NBS in water and nutrient recovery in the EU and its barriers for further dissemination. I emphasize the focus of this thesis: barriers and potentials of implementing NBS for water and nutrient recovery. In the fourth chapter, marking the practical part of this thesis, I elaborate on the developed research design and methodology I applied to conduct this research. In chapter five the research findings are presented. In chapter six I provide a discussion within the framework of the designed analysis concept as well as further prospects on what can be learned from them by answering the research questions.

Lastly, a conclusive part will summarize the main findings of the research and state what can be learnt.

This thesis focuses on the recovery of water and nutrients from wastewater by applying NBS in the context of CE concepts. Now, the following chapter aims at giving a brief overview on the disruption of the nutrients cycle in social ecological tradition, background information on water, thereby emphasizing the significance of wastewater for nutrient and water recovery in water scarce regions in Europe.

The background reasoning: closing the nutrient and water cycles

Now, by introducing the first chapter I will briefly explain the underlying problem of closing the nutrient cycle in the intersection of society and nature since the Neolithic. The Earths service of acting as a sink for emissions has been disrupted since the start of the transition towards an agrarian society. Amongst other things, this determines the era of the Anthropocene, which is characterized by human interventions that have contributed to the domination of important Earth system features in a shorter time than any other species before (Fischer-Kowalski et al. 2014). Ever since, in particular the nutrient output in the social metabolism has significantly influenced the biophysical metabolism. Along with the rapid development of wealthy countries, living standards improved, patterns of life and work changed fundamentally and socioecological regimes shifted towards a high input (e.g. extractions) and output (e.g. emissions) society (Fischer-Kowalski et al. 2007) in which we are living today. One might even argue that systemic linearity in the socioeconomic sphere has become the status quo. Therefore, the need to develop alternative ideas based on circularity rather than linearity, to regenerate nature as well as to reuse what we put into the system instead of emitting, is of greater importance than ever before.

The dilemma of closing the nutrient cycle

Since the Neolithic revolution and the associated beginnings of agricultural food production, the nutrient chain and the use of nutrients have become of interest to mankind. With the onset of the industrial age and its regime that is based on the use of fossil resources, the impactful human interventions in the global biochemical cycles have begun (Fischer-Kowalski et al. 2007). With the onset of the industrial revolution, the discharge of chemicals during mechanized processes of production and consumption into the natural environment and their dispersion have grown tremendously and is still increasing. One major problem within this spectrum is the closing of the nutrient cycle, thus the disruption of the nutrient chain is the main underlying problem perpetuated by this thesis. This issue has been perpetuated over and over again. Since chemical fertilizers received resurgence during the Second Agricultural Revolution In the 19th century - most notably through the work of chemist Justus Liebig - the interaction between society and nature has changed irreversibly (Foster 1999). Hence, the abundance of nutrients after being applied for agricultural productivity increase has led to the disruption of the soil nutrient cycle (Foster 1999). Thus, creating the great dilemma of closing the nutrient cycle. Later on, even Karl Marx has spoken about the insoluble problem of the nutrient cycle in the social metabolism, with postulating the “metabolic rift”. As the “metabolic rift” theoretically the ideological separation of ecology and economy is understood. Practically this means “when capitalist production subverts its own social metabolism” (Salleh 2010). Consequently, the abundance of nutrients influences biophysical metabolism, f.i. in form of fresh water eutrophication, thus further impacting the social dimension. Therefore, taking circularity as a basis for tackling this problem in an ecologically and socially sustainable way, is an appealing notion.

The following subchapters follow that thought with the focus on the important role of water and its potential for the recovery of freshwater and nutrients for further use. Especially in regions that are affected by water stress.

The importance of water

Water and water management systems have become an important part of human interventions since the transition to an agrarian society. Archaeologists even found remains of structures of a simple irrigation and water storage system in southern Jordan, which was built approximately 9,500 years ago. From that time on, global water infrastructure and management solutions have continued to progress and create the basis for the water systems of today (Gerten 2018). During the time of industrialization, the settlement of riverine landscapes contributed immensely to overall social and economic prosperity and, furthermore, enhanced population growth (Gerten 2018). The growth of the world’s population was accompanied by steadily increasing water consumption[1]. Only in 1990, a process of relative decoupling of water consumption from population growth began. According to the United Nations Environment Program 2019 on the future of natural resources (UNEP 2019), approximately 30 percent of the global river basins have been under water stress[2] since 2010 due to the increase of global water consumption. Between 2000 and 2011, water stress related impacts increased by a factor of 1.2, drawing attention to the threats to sustainable freshwater supplies for people's needs and ecosystems (UNEP 2019). According to the UNEP report, the increase of these impacts is associated with increased production and consumption (e.g. in the agricultural, industrial and household sector). These negative effects and developments result in predictions stating that agricultural sites as well as cities will have to be innovative in order to adapt to potential future water and nutrient supply challenges. This can be particularly challenging for cities due to high population density and growth. According to the UNEP report (2019), 685 million people will live in over 570 cities by 2050 and face a continuing decrease in fresh water availability of at least 10% because of climate change. Furthermore, the global demand of water is predicted to increase by 55% by 2050 (UN WWDR 2020). However, not only urban or agricultural fields are threatened; also, the industrial sector, including the energy sector, that extract 19% of the world's freshwater resources, will have to search for alternatives, because its global water demand is projected to increase up to 24% by 2050, with Europe among the largest absolute increases (UNEP 2019). Consequently, water challenges such as floods, drought and water stress, especially water scarcity[3], will impact food production, its supply chains and heavy water users (UNEP 2019). In European regions already affected by water scarcity (e.g. Lavrnic' et al. 2017) the availability of freshwater will continue to deteriorate as global warming and climate change increase (Gerten 2018). An UN report (2017) on wastewater reuse states that 2/3 of the world's population are already living in areas where water is scarce for at least one month a year. Therefore, with the reduction of unnecessary water consumption and water losses as well as the efficient (re)use of water and the regeneration of nutrients, lower energy consumption and thus lower emissions and adaptation to water scarcity can be achieved (UN WWDR 2020). Hence, water and nutrient recovery from wastewater is becoming more valuable as it increases available freshwater

[1] Water consumption = opposed to the actual amount used. Either it does not flow back into the water system at all, only much later or only at some distance via the evaporation and precipitation cycle (Gerten 2018).

[2] Water stress = the reliability of water supply in terms of availability (quantity), quality as affected by pollution and accessibility (allocation, competition and conflict) (UNEP 2020).

[3] Water scarcity is defined with a water demand that exceeds the available water resources under sustainable conditions (UN 2017).

resources, as well as reclaimed water and nutrients. Furthermore, it can create new sources of revenue for wastewater treatments (UN WWDR 2017) and positively impacts the efforts of transitioning to a more circular socioeconomic system. In the next subchapter wastewater will be discussed as an interesting source for reclaimed water and nutrients.

,Wastewater and its potential nutrients

The definition of wastewater varies slightly depending on the perspective of each discipline. For the purpose of this thesis, the United Nations' definition of wastewater (treated and untreated) as *"water that has been contaminated by anthropogenic activities"* was chosen (UN WWDR 2017). The term wastewater can be differentiated in industrial, agricultural and domestic wastewater. Agricultural and industrial wastewater is defined as wastewater being produced in agriculture and industrial processes, without further subcategories. On the contrary, domestic wastewater contains grey- and blackwater. Greywater is the wastewater produced by domestic uses such as bathing, doing laundry or dishwashing. Blackwater is the wastewater that flows out of the toilet and contains solid and liquid human excrements in combination with rinse water (Nolde 2000). In most sewage systems around the world, greywater is combined with blackwater in a single domestic wastewater stream. The question of sustainability (and efficiency) of wastewater treatment requires innovation due to constantly new pollutants emerging from society (Villarín et al. 2020). Zraunig et al. (2019) state that recently there has been a dramatic increase in concerns about organic micropollutants in water and the environment (such as pharmaceutically active compounds – PhACs, and endocrine disrupting chemicals - EDCs). These usually occur in low concentrations, making their removal with conventional wastewater treatment technologies difficult (Zraunig et al. 2019). This intensifies the destruction of important ecosystem functions, such as climate cooling, better air quality or depression decrease among others (Garfi et al. 2017). Nevertheless, wastewater contains P (phosphorus), N (nitrogen) and K (potassium), which are nutrients that could be recovered and serve as fertilizer in agriculture. Despite their positive functions, P, N and K, if not treated properly, pose an environmental threat to terrestrial and aquatic ecosystems. Hence, giving an example for the "metabolic rift", Marx was talking about. Because the receiving ecosystems can hardly compensate for all pollutants, leading to a vicious cycle of imbalances, which ultimately impacts climate change, thus the loss of biodiversity, eutrophication and eventually food security (Mavhungu et al. 2020). In addition to recovering rich nutrients for fertilizer and reclaimed water for irrigation in agriculture, toilet flushing and various other purposes, wastewater also carries resources such as carbon, which can be processed into biomethane as an energy source (EC 2020). Wastewater treatment technologies must become more integrative and in the best-case scenario use technologies based on nature in combination with traditional technologies in order to treat all components in an effective and sustainable way (Boano 2020). Furthermore, the reuse of water and recovered nutrients can contribute to the creation of green jobs in the water-related industry, which the European Commission (EC) considers to be an important sector in the EU eco-industrial landscape. The global water market is growing rapidly. It was estimated to have reached €1 trillion by 2020 and, therefore, a 1% increase in the growth rate of the water industry in Europe could create up to 20,000 new jobs (EC 2020).

In conclusion, wastewater and its treatment hold an enormous potential for water and nutrient recovery and recycling for reuse and eventually brings us closer to closing the gaps in the social metabolism, and, thus, tackling the problem of disruption in the nutrient cycle. Further, the reuse of water and recovered nutrients can have various co-benefits for the natural environment, such as reduction of water stress on ecosystems and its biodiversity (Nolde 2000). So, closing water cycles successfully, meaning as far as possible with ecologically and socially sustainable solutions might reduce challenges and ideally mitigates emissions. However, wastewater treatment plants are mostly centralized systems, which lead to difficulties in recovering most of the water and nutrients. Therefore, expert researchers in this field also support decentralized treatment systems (Villarín et al. 2020, Zraunig et al. 2019, Nolde 2000). In this regard, the EU proposed systematic changes in water-based waste disposal and management. In addition, the EC is working to establish standards for coordinating the efforts of its member states to improve European water quality and quantity, to protect wetlands and to promote and secure the use of community waters (Smol et al. 2020). Thus, different strategies are being applied. One of these strategies focuses on the closing of the water and nutrient loops by applying the framework of CE using NBS.

In the following chapter two, the concept of CE will be elaborated on in the context of water and nutrient recovery from wastewater. Focus will be on the EU's implementation of CE.

Framework: CE, wastewater and EU

With the urgent need of adapting to climate change and extreme weather events, such as droughts especially in Europe´s Mediterranean region (IPCC 2021), strategies within the CE framework are being applied in the EU. The EU considers CE as a concept that counteracts the linearity of the input and output society, and enforces a more sustainable economy. This section will briefly present the concept of CE, tackle its limitations, and link it with the EU CE strategy in the context of regaining water and nutrients from wastewater.

CE is widely perceived as an economic system that aims to eliminate waste and the continual use of resources as well as to create a closed-loop system (Geissdoerfer et al. 2017). From the 1970ies onwards, CE experienced widespread enthusiasm. Putting it simple, CE means to close the cycle, meaning the loops within a cycle, of input and output in a system. Closing loops essentially implies creating circularity in the entire process of production-consumption-disposal of each product or service (Hobson 2019). Five decades ago, the idea of looking at material input and output in society in a more circular as opposed to linear way just started to grow slowly (Geissdoerfer et al. 2017). Nowadays, CE is considered as a significant concept in society and its institutions such as the EC and companies. Winans et al. (2017), citing Robert Hunt and William Franklin, concludes that companies in Europe are applying the CE concept in particular with the aim of improving recycling programs and conducting life cycle studies at product level. Nancy Bocken et al. (2017) and Korhonen et al (2018) state that, unlike traditional recycling, CE is a concept that extends conventional waste and by-product recycling with the goal of keeping products and materials at their highest value at all times. This is intended to make more efficient use of the life cycle of resources through multifunctionality (Bocken et al. 2017). The underlying essential idea is that everything is metabolized by society and nature (Braungart 2013). In this regard, CE is often presented as "the solution" to all challenges that society and its natural environment are facing currently as well as in the future. Nevertheless, factually speaking there are clear limitations to the CE concept (Korhonen et al. 2018). One limitation is linked to the cradle to crave (C2C) paradigm, especially with various aversive effects, such as an overflow of nutrients, that can't be processed by nature and lead to eutrophication, and particularly relevant in terms of the nutrient chain. In contrary to the at the beginning introduced problem of nutrient abundance, the C2C assumes that society and the biosphere are in equilibrium; nature continuously processes industrial waste and emissions and, thus, provides for society, which can cause a rebound effect (Korhonen, et al. 2018), especially when transferred to economy. Korhonen et al. (2018) therefore argue that 100% complete "natural economic cycles" will not be achieved in the foreseeable future. According to them, the challenges of sustainability within the economic system persist due to the inherent growth paradigm. Further, Anne Velenturf et al. (2019) argue that the outcome of CE actions may not yield the desired net economic, social, and environmental gains due to a lack of consideration of the biophysical limits of circularity and other dimensions of life in the conceptualization of CE. Another limitation mentioned in literature is framed by the fact that CE as it is seen from the institutional side is catering to sustainable development, which has become a main focus for the EU since the last two summits on climate change (Korhonen et al. 2018). However, the contribution of CE projects to sustainable development is being critically reflected within the scientific community, since it is often argued that the cycles should rather be maintained and well managed than questioning waste at all (Korhonen et al. 2018). This means that some dimensions of the interrelation of the social and biophysical metabolism are left out of the general discourse when talking about the adoption of CE concepts. Thus, the lack of a "holistic view" on the three dimensions of sustainability in CE research, since the concept of the CE is frequently simplified to resource input, waste and emission output (Geissdoerfer et al. 2017). This is also confirmed by the research on CE definitions by Julian Kircherr et al. (2017), whose findings show that only 13% of the definitions refer to all three dimensions and usually do not take the social dimension into account. However, for any kind of CE application, it can be stated that social as well as ecological and economic aspects can achieve positive results, as shown in Fig. 3 (Korhonen et al. 2018). Positive outcomes such as the relocation of property, community spirit and employment opportunities can be achieved (Korhonen et al. 2018; Winans et al. 2017).

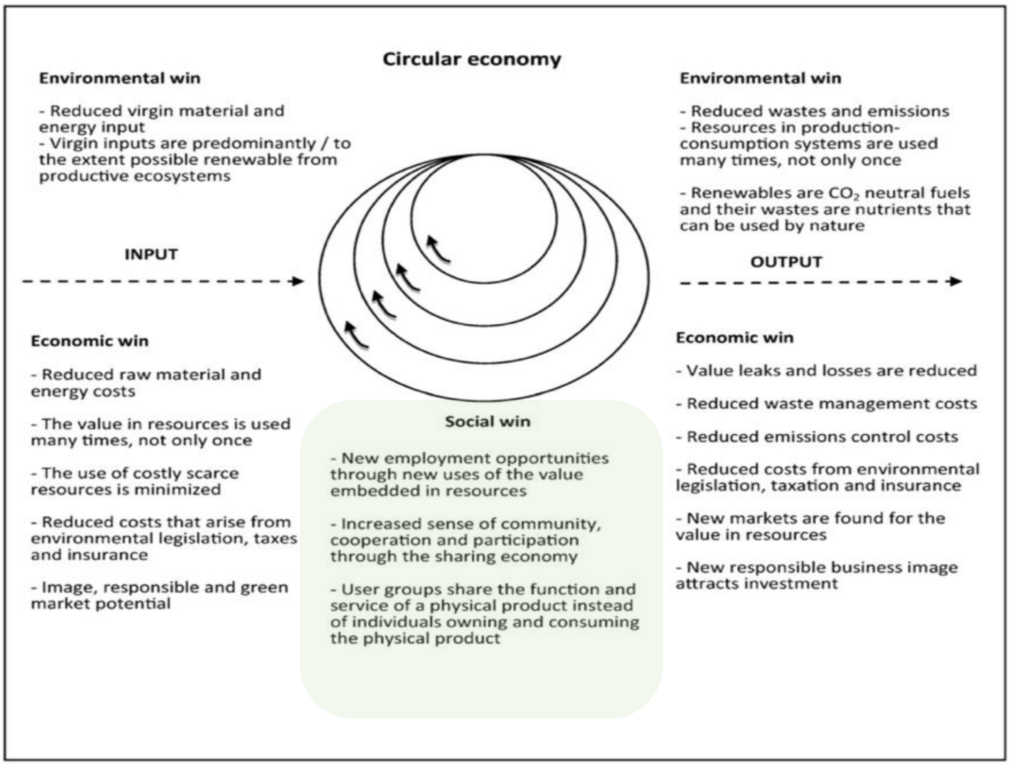

Figure 1, The win-win-win potential of circular economy, if implemented successfully, drawn from the thought of CE within a sustainable development framework as it is anchored in the EU (Korhonen et al. 2018).

The study by Korhonen et al. (2018) appears to be the first attempt to start building a scientific basis for a more comprehensive CE, as the CE concept was mainly founded by politicians, business organizations, and practitioners. It is of utmost importance to state, that policy instruments such as subsidies and fiscal incentives for CE projects only work efficiently if there are clear short- and long-term government goals for policy processes that are evaluated, regulated and based on a comprehensive scientific basis. Nevertheless, it is also important to mention that bottom-up support from industries and communities is needed to support CE reforms towards more social and ecological sustainability (Winans et al. 2017). Based on that the EU is adopting the CE concept in various fields of private and public lifes. In the following parts this strategy will be elaborated on more precisely, especially focusing on circular water management and wastewater for water and nutrient recovery.

The EU's CE strategy

The degree of material circularity within the EU economy is twice the global average; renewable biomass flows are lower than the global average of 32%, with 28% of processed materials (Haas et al. 2015). Moreover, the metabolism of EU countries is characterized by material throughput and the gap to closed material cycles seems surprisingly large. Hence, both the global and the (back then) EU-27 are still far from a circular economy and closing the loops (Haas et al. 2005), which has urged the EU to implement CE in their policy making. In 2014, a CE concept was introduced by the EU: "On the way to a circular economy: a zero-waste program for Europe" (Smol et al. 2020). In 2015, the European Commission published an extended version – the Circular Economy Action Plan (EC 2020, 98 final) - with a strong focus on measures covering the entire product life cycle. This includes actions for water and reuse aimed at integrated water planning and management, water reuse in irrigation and industrial activities, research and innovation in water reuse and more EU investment in water reuse, and the need for water quality regulations (WBCSD 2017). In 2018, the Circular Economy Action Plan was adapted for plastics and a communication on waste legislation, a monitoring framework and a report on critical raw materials in CE. Further, the new agenda for sustainable growth – the 2020 European Green Deal[4] – adapted the Action Plan, focusing on strengthening competitiveness while protecting the environment and granting new rights to consumers (EC 2020). The 2020 European Action Plan for Central and Eastern Europe states that global consumption of materials such as biomass, fossil fuels and others is expected to double in the next 40 years, while annual waste generation is projected to increase by 70% by 2050 (EC 2020, 98 final). As a consequence, the demand for water and nutrient recycling is increasing both in the energy sector and in agriculture. In order to respond to the growth in consumption and waste generation, which is accompanied by a high consumption of freshwater, CE strategies appears to be a sustainable framework.

CE & wastewater

Due to the multiple socio-economic shifts over the last four decades, rapid ecological and social changes have occurred that affect the overall sustainability of the present and future. The complexity of the institutional structure and the lack of policy measures often leads to conflicts among users in areas exposed to water stress, such as the Mediterranean (Iglesias et al. 2007). In general, little social and political attention is paid to wastewater management in terms of regaining water or nutrients, usually it focuses on challenges of water supply (UN WWDR 2017). However, there are many reasons for reusing wastewater, e.g. wastewater is produced

[4] The European Green Deal = the EU's plan to make its economy sustainable. The goal is to reduce net emissions to zero by 2050 and to decouple economic growth from resource use (EC 2020).

permanently and remains largely untouched (Lavrnić et al. 2017). Implementing alternative technologies such as NBS for closing the loops in a wastewater treatment technology and its positive co-benefits are rarely discussed (Nesshöver et al. 2017). Furthermore, the recovery of nutrients and water for further use is considered an important part of circular wastewater management (Smol et al. 2020). The Ellen MacArthur Foundation has published a white paper, which describes three design principles that should underlie circular water management: (1) design out waste externalities, (2) keep resources in use and (3) regenerate natural capital (see Fig. 2). The quintessence of these three principles is to establish a long-term sustainable relationship between humanity and nature, where the aim is to reduce, maintain, optimize, and restore.

Circular Economy Principles ***(Ellen MacArthur Foundation)***	**Water Systems Management**
Principle 1: **Design out waste externalities**	• Optimise the amount of energy, minerals, and chemicals use in operation of water systems in concert with other systems. • Optimise consumptive use of water within sub-basin in relation adjacent sub-basins (e.g. use in agriculture or evaporative cooling) • Use measures or solutions which deliver the same outcome without using water
Principle 2: **Keep Resources in Use**	• Optimise resource yields (water use & reuse, energy, minerals, and chemicals) within water systems. • Optimise energy or resource extraction from the water system and maximise their reuse. • Optimise value generated in the interfaces of water system with other systems.
Principle 3: **Regenerate Natural Capital**	• Maximise environmental flows by reducing consumptive and non-consumptive uses of water. • Preserve and enhance the natural capital (e.g. river restoration, pollution prevention, quality of effluent, etc.) • Ensure minimum disruption to natural water systems from human interactions and use.

Figure 2, Interaction between Circular Economy Principles and Water Systems Management (Ellen MacArthur Foundation, , ARUP, AnteaGroup - White Paper Draft 2018).

Since water itself is a raw material and cannot be "produced" from recycled materials, but only "recovered", these other aspects of circularity must be considered (Nika et al. 2020). For example, in the EU more than 40,000 million m^3 of wastewater are treated annually, but only 964 million m^3 of this treated wastewater are reused. The EU notes that there is great potential as it could use six times the amount of treated water currently in use (EC Factsheet 2020). However, the increase in the amount of reused water or regaining nutrients is not yet a common practice (EC 2016). A circular perspective on this promotes the reuse of treated wastewater, as wastewater is considered a material and energy source (EC 2016). It is therefore essential to develop and implement more effective technologies for the reuse of water and the recovery of nutrients (Smol et al. 2020). Furthermore, for a better social integration of the CE concept and knowledge about the wastewater potential, the links between the two need to be further elaborated and passed on to practitioners (Smol et al. 2020).

The European legislative framework on circular water management and wastewater

According to the EC (2020), treated wastewater can be considered a reliable water and nutrient supply. Thanks to its independence from seasonal drought and weather cycles, the treatment of wastewater is able to cover peaks in water demand and opens up new fields for the generation of nutrients (e.g. for fertilizer). This naturally has many advantages for the agricultural and industrial sector, but also for households, as it provides more reliable water supply, reduces emissions, might even save costs for nutrients as well as various other co-benefits. Regarding the nutrients, if P, N, and K, are recovered, the use of synthetic fertilizers can generally be reduced with positive impacts on the natural environment, states the EC (2020). However, wastewater reuse and nutrient recovery in the EU is currently being applied far below its potential (EC 2020). First, this is primarily due to a lack of innovative ideas in the field of wastewater treatment, even though the effort of introducing CE principles are supporting such ideas (Smol et al. 2020). Second, it is due to a lack of societal awareness of the potentials and benefits of water and nutrient reuse. Furthermore, several calls for stronger regulatory and financial incentives to support European water reuse, which could increase reuse to more than 6,000 million m3 of water per year by 2025 (EC 2016), became louder. This led the EU to introduce a suitable supporting framework for water reuse. In the EU, water and wastewater are governed by a set of Directives, such as the Water Framework Directive (WFD), the Drinking Water Directive (DWD), the Urban Wastewater Treatment Directive (UWWTD), the Waste Framework Directive, as well as Directives on bathing water quality and, above all, the Water Reuse Regulation (WRR). The WRR is a series of standards aimed at re-purifying polluted water and ensuring that all waters are preserved in this form. It was implemented in 2000 and updated in 2006. The WFD was first published in 1998 with the aim of ensuring the quality of water intended for human consumption and has been updated several times since then. The UWWD was adopted in 1991 and updated on several occasions until 2014. Its aim is to protect the water environment from the effects of wastewater effluents and from certain industrial discharges. After a process of revision in 2006, the original 1975 Waste Framework Directive became a legally binding version in 2008. It aims to establish the basic concepts and definitions related to waste management and lays down the principles of waste management.

Since the 1970s, the bathing water policy has focused on the protection of public health and clean bathing water. It is complementary to the WFD and is regularly updated. Recently, in 2020, the new EU 'Regulation on minimum requirements for water reuse for agricultural irrigation' entered into force, as a measure situated in the context of the new European Action Plan for Circular Economy (EC 2020). EU Directives are legislations addressed to member states, with the background that the goals of these Directives are to be achieved. The member states must then adapt their relevant national legislations within a specified time period in order to put the provisions of the Directive into legal effect (Hassler et al. 2019).

In 2014, 18 countries agreed on the requirements for wastewater collection, seven countries agreed to the obligation for secondary treatment, but only four countries approved the need for more stringent treatment of wastewater in sensitive areas, Villarín et al. (2020) conclude. Furthermore, only Austria, Germany, and the Netherlands fully agreed to all requirements (Villarín et al. 2020). Previously to the existence of the WRR, several EU countries applied national reuse legislation. Cyprus, France, Greece, Italy, and Spain have adopted water quality standards for reclaimed water in national legislation (JRC 2014). As a result of the above-mentioned EU Directives, a significant improvement in water quality in European inland and coastal waters was achieved over the last four decades (Smol et al. 2020). Despite the progress made, "improvement actions in the water management should be proposed, but also—in the management of water-based waste to recover raw materials and energy occurring in it" (Smol et al. 2020). With the aim of recovering nutrients from wastewater, the EU published a proposal in 2018 to make recycled fertilizers (mostly P) ready for the market. In 2019, it was extended by certain rules on how the market availability of EU fertilizers should work. Fertilizers that meet all quality requirements will therefore be embedded in CE marketing and freely traded within the EU (Smol et al. 2020). In addition, the 2020 EC report on the state of implementation of the UWWTD in the broader context of achieving climate neutrality by 2050 shows that the wastewater sector contributes to CE through wastewater reuse, energy recovery, and recycling nutrients (EC 2020). Several different technologies are suitable to recycle or recover water and nutrients. Amongst these technologies are nature-based solutions (NBS), which can present an eligible alternative to conventional treatment technology (Boano et al. 2019).

This thesis puts the focus on NBS as a treatment technology to recycle water and nutrients from wastewater. The following chapter introduces this technology as a potential solution for recovering nutrients and water from wastewater.

Nature-based solutions (NBS) as a strategy

With regard to this thesis, the question of why NBS can be a suitable technology for recovering nutrients and water from wastewater is explained by briefly approaching the definitions of NBS. Furthermore, I will discuss the state of the art in research on barriers and potentials of the application of NBS for wastewater treatment, hence nutrient and water recovery.

The International Union for Conservation of Nature (IUCN 2016) defines NBS as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". The aim is to ensure human well-being, achieve the sustainable development goals, and enhance the resilience and capacity for renewal of ecosystems and their services (IUCN 2016). Furthermore, Pauleit et al. (2017) define NBS as technologies whose objective it is to use nature to overcome challenges such as climate change. In addition, the EU accentuates NBS within the framework of the EU research and innovation program *Horizon 2020*[5] in order to establish Europe as a global leader in their implementation. NBS are therefore defined as solutions that "aim to help societies address a variety of environmental, social and economic challenges in sustainable ways". This refers to actions that are inspired by, supported by or copied from nature (EC 2020). Moreover, it is in the interest of the EC to raise awareness of nature and to address social challenges. However, NBS are rarely mentioned as a key strategy in wastewater treatment (EC 2020). There are numerous co-benefits such as ambient air cooling, reduced flood risks or even just the aesthetics of the natural elements and their positive impact on human well-being (Boano et al. 2019). NBS are neither widespread nor well known as non-conventional soft impact technologies (Depietri et al. 2017). On the timeline of the technological development of wastewater treatment, NBS are a fairly new approach and have a broad scope of definition. NBS in wastewater treatment are also associated with a broader concept of nature and participatory processes (Emilsson et al. 2017). Beyond that, they are transdisciplinary by nature, while the institutional implementation and dissemination are rather isolated (Frantzikaki et al. 2019). They are mostly implemented to restore dysfunctional ecosystems, either where there is already a high pressure on an ecosystem or it is on the verge of tipping (Krauze et al. 2019). As a result, NBS are often considered a public good, resulting in

[5] Horizon 2020 = an EU funding program for research and innovation, running from 2014 to 2020, tendered by the European Commission (EC 2020).

an unrecognized economic value. Consequently, their true economic value is not reflected in societal decisions and legislation (Langergraber et al. 2020). However, NBS can be assigned a great responsibility by society, after all, ecosystems and their functions are needed for human well-being. Further, the expectation that NBS could restore all lost ecosystem services may be too high. In fact, NBS technology must always give priority to one ecosystem service over another, as the application is expected to sustain itself, nature, as well as society (Krauze et al. 2019). Within NBS an important distinction can be made between mimicking and manipulating nature. Mimicking nature is a process by which natural capital is enhanced, whereas the manipulation of nature is based on the implementation of external agents (Krauze et al. 2019).

The definitions addressed above fall within the broader definition of NBS, which provides the framework for this research. Specifically, in the present thesis, NBS are defined as *technologies in which the key agents are plants*. These key agents can be used to manipulate the course of a treatment, but also to improve the function of the local ecosystem. Thus, the water treatment trains and resource recovery systems within the scope of this thesis must contain a technology with plants as key agents. The availability of different wastewater treatment technologies, conventional or non-conventional, is fairly extensive and varies both globally and historically. NBS are thus a valuable and suitable alternative in recovering water and nutrients from wastewater, since they have plenty of co-benefits for the human well-being, are cost-efficient and dynamic by nature, as well as easily implementable.

The status-quo in research is presented in the next chapter and answers one of the main research questions of this theses, namely: What are the hindering factors for the implementation of NBS in the EU?

State of the art – wider adoption of NBS and its barriers

With regard to water reuse technologies in general, several academic and public sector publications addressed the question of institutional and social barriers to their wider adoption in Europe. The JRC Science and Policy report on water reuse in Europe (2014), for example, examined such obstacles in order to advocate for a wider diffusion of innovative water reuse technologies on a European level, including NBS. In these programs, also research on barriers to the deployment of NBS technologies has increased lately from the previously moderate attention during the last 10 years (Kabisch et al. 2016; Frantzeskaki et al. 2019; Somarakis et al.

2019; Kisser et al. 2020; Kasou et al. 2020). The current state of knowledge reveals significant barriers that hinder the wider adoption of NBS for water and nutrient recovery from wastewater. However, knowledge of these barriers can be used as a driving force to overcome them, elaborate on potentials, and promote the planning and implementation of NBS (Somarakis et al. 2019). I reviewed the current scientific literature and reports to extract some of the already scientifically identified barriers. Tables 1 and 2 below classify the barriers identified in the literature into the following categories: “infrastructure”, “economy”, “bureaucracy”, “social engagement” and “technology”. As shown, most of the barriers were found in institutionalized regimes and predominant infrastructure; social barriers, such as social engagement and responsibility (which is subcategorized under “social engagement”), were not frequently mentioned. These broad categories serve as a basis for the analysis in chapter six.

According to the ThinkNature Nature-based solutions Handbook (2019), NBS are more cost-effective than traditional wastewater treatment technologies. However, the barriers for implementation are more complex and related to managing change, training, transdisciplinary cooperation, and securing investments (Somarakis et al. 2019). Kisser et al (2020) divide barriers into "lack of awareness, current legislation, regulations and the organization of infrastructures as well as technical barriers" and argue in favor of the need for further technical and social innovation. There exists a difficulty in communicating the financial benefits of NBS due to limited data, little research on quantified benefits, and a lack of coordinated knowledge transfer (Somarakis et al. 2019). Since NBS is not one of the conventionally widely used technologies, and consequently often not fast and easy to install, small NBS projects may incur higher costs at the stage of implementation. Therefore, expensive technology can be an obstacle in the cross section of the technical and market economy sphere (Somarakis et al. 2019). Frantzeskaki et al. (2019) identified a lack of finance and investment as a major obstacle to the introduction of conventionalizing NBS. Most investments in NBS have so far been either fully or partially supported by public funding (Frantzeskaki et al. 2019). However, dealing with funding opportunities is often a challenge, as all criteria for conventional waste management must be met - at household level or in larger recycling plants - even if it may not make sense in every single NBS case (Kisser et al. 2020). Furthermore, technical barriers, such as available technical infrastructure in terms of design implementation (Somarakis et al. 2019), are also frequently addressed. For instance, the space requirements of the most common NBS wastewater treatment technologies, e.g. constructed wetlands, create difficulties in areas with high population density (Kisser et al. 2020). Beyond that, Somarakis et al. (2019) mention capacity related barriers such as knowledge gaps, meaning a lack of skills, which hampers the selection and effective implementation of the most appropriate NBS. This is based on inadequate education and poor technical knowledge of planners, developers, and construction experts. Moreover, key figures who have the necessary knowledge are often excluded from the decision-making process (Somarakis et al. 2019). Thus, this can be identified as a major institutional barrier. Further, it is mentioned that there exists a lack of adequate and safe handling practices in nutrient recovery, especially when it comes to faeces (Kisser et al 2020). For example, the recovery of N and P as product for further use can become problematic when recovery technologies are insufficient or lacking the proper wastewater treatment (Kisser et al. 2020). NBS can offer high nutrient recovery with substantial additional benefits, but for commercialization as fertilizer further processing is usually required to ensure product purity (Kisser et al. 2020).

In the following tables, a summary of the literature review on barriers of implementing NBS technologies is presented.

BARRIERS FOUND IN LITERTURE					
Communication/ Acceptance/Trust	**Infrastructural (techn. & social)**	**Economically (e.g. funding opportunities)**	**Bureaucracy (e.g. policies)**	**Social engagement**	**Technical knowledge/advances/ difficulties**
Poor public perception and education of NBS	Inconsistent and unreliable methods for identifying and optimizing appropriate wastewater treatment technologies for reuse applications	Lack of financial incentives for reuse schemes	Inconsistent or inadequate water reuse regulations/guidelines	Low levels of public and government enthusiasm for water reuse	Difficulties in specifying and selecting effective monitoring techniques and technologies for the whole system
fear of the dangers of consuming food irrigated with reclaimed water	Significant challenges in reliably assessing the environmental and public health risk	NO Long-term economic viability for reclaimed water (often priced just below the consumer cost of drinking water to make it more attractive to potential users, but this may also affect the ability to recover costs)	Limited institutional capacity to formulate and institutionalize recycling and reuse measures		Practitioners and public entities often lack the know-how to identify the optimal biorefinery design and choice of secondary products in their individual cases.
lack of trust in NBS, even in industry	Poorly developed business models for water reuse schemes, and markets for reclaimed water	uncertainties of new system financing (new business models, etc.) and the legislation in place	uncertainties of new system financing (new business models, etc.) and the legislation in place		Finally, many of the technologies that enable recovery of products other than energy are still in development and applied so far only at lab and pilot scales.
the implementation of water reuse as a drinking water source is less likely to be accepted by society	Bad network, e.g. the authority of the water supply sector is not connected responsible for wastewater management → inaction, disagreements, negotiations etc.	lack of finance and investment to the uptake and mainstreaming of nature-based solutions	Lack of state regulation and EU guidelines (overly strict standards have led to a high number of illegal - and thus unmonitored - reuse practices in some countries) → the difference in standards between EU Member States can cause confusion		The diffusion of gaseous pollutants and associated removal inefficiencies, which can be mitigated by active airflow through plant substrate, e.g., active green walls

Table 1, Collection of Barriers highlighted in literature (Boano et al. 2019, Frantziskaki et al. 2019, Kier et al. 2020, Nika et al. 2020, Policy Report on Water Reuse 2014, Villarín 2020).

Communication/ Acceptance/Trust	Infrastructural (techn. & social)	Economically (e.g. funding opportunities)	Bureaucracy (e.g. policies)	Social engagement	Technical knowledge/advances/ difficulties
	Big surface area required (e.g. constructed wetlands)		For research and non-research installations, the lack of standards, existing legal frameworks and lack of awareness of public administrative bodies make it very difficult to obtain building permits for these non-conventional systems.		Many secondary commercial products that can be derived from microalgae require further R&D to become profitable
	NO availability of "NoMix" toilets. Several models have been removed from the market due to problems during use.		The decentralized microscale for biogas production requires further research and development and is often confronted with legal barriers.		lack of sufficiently safe handling practices in the case of nutrient recovery from faeces or DTM
	The existing sanitation infrastructure due to source separation (e.g. double pipe system)		The legal framework is limiting the possibilities of reusing products from wastewater in agriculture (quality, safety reasons)		
	Lack of expertise in health and environmental risk assessment and mitigation		Once a resource becomes waste it has to fulfil all criteria for waste management (legislative hurdles)		

Table 2, Collection of Barriers highlighted in literature continued (Boano et al. 2019, Frantziskaki et al. 2019, Kisser et al. 2020, Nika et al. 2020, Policy Report on Water Reuse 2014, Villarín 2020).

Generally speaking, the multifunctionality of NBS shows benefits, but can also reveal itself as challenging, in particular for people with insufficient skills and experience to implement such technologies (Langergraber et al. 2020). On the one hand, there is an underdeveloped and general lack of applicable technologies, since many recovery technologies are still under development at laboratory and pilot scale (Kisser et al. 2020). On the other hand, however, there is also little willingness among key actors to apply new scientific findings, which renders the implementation of NBS more complicated (Somarakis et al. 2019). Finally, technical development often encounters an awareness and acceptance barrier, because the establishment of a solution always involves the existing consciousness and will of the people (Somarakis et al. 2019). Public awareness and social acceptance are strongly linked to the successful implementation and dissemination of NBS for water and nutrient recovery (Katsou et al. 2020). Moreover, legal frameworks repeatedly prevent the adoption of innovative sustainable approaches due to their complexity, unclear communication, and rapid change (Nika et al. 2020). Nevertheless, policies and legal frameworks can act as accelerators for the transition to more circularity (Katsou et al. 2020). For the implementation of a CE based on increased use of NBS, various stakeholders are of high importance (Katsou et al 2020). In this context, it is important to show how the planning of the NBS is embedded in governmental structures. Thus, Somarakis et al. (2019) highlight the benefits of promoting knowledge about NBS and its applications at the decentralized level. Political barriers and drivers were identified as the most common obstacles. This suggests that the issue of policy frameworks is fundamental to a broader diffusion of NBS, which should be reviewed across all policy areas to provide the necessary support for a shift towards more sustainable nutrient recovery technologies (Somorakis et al. 2019).

Many of these revealed barriers are systemic by nature and embedded in cultural practices and processes. Therefore, they are difficult to overcome. As the scope of NBS is broad and complex, there have been general difficulties in integrating them into regulations and policies (Katsou et al. 2020). In conclusion it can be stated that regulatory and technical barriers have been studied in more detail than others, such as social engagement (e.g. Oral et al. 2020, Martínez-Hernández et al. 2020, Pearlmutter et al. 2020). Hence, this shows potential for improvements and further research on the topic of NBS for reclaiming water and nutrients from wastewater (Kisser et al. 2020).

In conclusion, not only is there potential for further research about NBS, thanks to the various positive co-benefits as the function of natural systems itself, it is assumingly an interesting solution to recover resources from wastewater.

Design, Research question and methodology

My first step in order to tackle the hypothesis that available NBS could significantly contribute to closing water and nutrient loops in the EU, but that their wider adoption is hindered by social and institutional barriers, was the design of my research, which will be presented in the following section. Afterwards, I introduce the case studies, the interview partners and the empirical data processing.

Research design

As a framework for this research the insights on the role of water and nutrients in the context of the EU circular economy concepts, as discussed in chapter 1 and 2, were used for the greater understanding and for embedding the topic of NBS, presented in chapter 3. NBS are therefore seen as an interesting solution to tackle future obstacles for water scarce regions, such as the Mediterranean, to have enough clean water and nutrients for further (re)use reclaimed from already used water, namely wastewater. On that note, NBS are identified as those *technologies that use plants as key agents*. The research aims at analyzing the institutional and social factors hindering the implementation of these NBS in resource recovery, focusing on wastewater treatment. For this, Institutional barriers are defined according to the sociological tradition of thinking. In particular, they are based on the definition of institutions, which is a phenomenon that causes regularity by supporting certain structural characteristics and behaviors. In this context, institutions not only refer directly to social behavior, e.g. in family, university or mass media, but to the entire structure of a society. They are furthermore linked to decision-making power and governance (Hasse et al. 2008). Further, the definition of the term "social" goes back to socio-ethnological traditions of thinking, where e.g. Émile Durkheim uses "social facts" to describe the interaction of values, social structures, and norms in a society (Abels 2020). The "social facts" act as fixed rules, so that a society can exist in a controlled way (Abels 2020). Of course, the social interactions and behaviors, everything related to human activity, is complex and strongly linked to the institutions that arise from it. Nevertheless, a distinction is made and social barriers are considered as such when referred to human action around the institutions.

This thesis examines the following research questions:

- Which social and institutional factors are hindering the wider uptake of NBS for resource recovery and reuse in the EU, and what are the potentials to overcome existing barriers?
    - What are first steps that could be taken to catalyze the transition to a circular economy for water and nutrients in the EU?
    - How do social and institutional barriers interact?
    - What can different stakeholders do to facilitate the transition?

Empirically, the thesis is based on qualitative primary data collected in summer 2020. Due to the outbreak of a pandemic, the majority of the interviews had to be conducted online. Six interviews were conducted face-to-face online. Two interviews were conducted in written form online. Further, two field visits were undertaken, where the last two interviews were contacted face-to-face. The empirical study focuses on the EU, with case studies located in the Mediterranean countries Greece and Spain, and in the Central European countries Austria and Germany – generally regions that are facing water stress. Within the HYDROUSA project, alchemia-nova and I developed an evidence-based matrix for collecting suitable case studies. This evidence-based matrix contains 150 cases of circular water management that use NBS to recover resources, such as water and nutrients. The selected case studies for my thesis were drawn from that evidence-based matrix. To approach the topic itself I started with a literature research, which I expanded throughout the research process. The keywords used for the search were "NBS", "water scarcity", "water management", "closed loop economy", "closing water loops", "wastewater treatment", "blue-green infrastructure", reclaimed water, “nutrient recovery”, “water recovery”, circular water” and "circular economy". The topical overview led to the development of the structured interview guide (see Appendix) and the research design. After the Interviews were carried out, they were transcribed using ExpressScribe (a free and open source transcription software). For further processing, the transcripts were inserted into the qualitative data analysis software MaxQDA. The notes of the field visits were reviewed and also inserted into the software. For processing data in MaxQDA categories were established.

For this, I conducted a literature review to find out the current research state of the art on barriers for implementing NBS, focusing on water management. Based on the review as well as on the results of the COST Action Circular City (a multi-stakeholder workshop to determine barriers for NBS dissemination, within the HYDROUSA project, facilitated in collaboration with alchemia-nova in 2019), categories for allocating the interview sections and field visit notes were established. The coding results of MaxQDA were extracted and manually prepared as the major findings into a coherent text. Next, I was analyzing and discussing the prepared findings with regard to the research questions and hypothesis along a three-level analysis (micro, meso, and macro) scheme.

Case studies

For my research I have chosen different case studies in various European countries to gain a broader picture of the distinguished NBS technologies and their implementation. Therefore, urban residential buildings, a big hotel, a wine processing facility, as well as rural buildings are concerned. They will be presented in the following section, before elaborating on the methodology applied and its data processing.

HOUSEFUL (Spain, Austria)

HOUSEFUL is a project that aims to design innovative interventions for the efficient management of materials, waste, water, and energy along the entire value chain at the household level. This is done by demonstrating the feasibility of an integrated systemic approach for resource recovery, consisting of 11 circular solutions, to be demonstrated in five different buildings in Vienna, Styria and near Barcelona, Spain. The demonstration sites in Spain are "El bloc del Mestres" and "La Grípia"; in Vienna they are "Baumgartenstraße" and "Donaufelder Straße", and the community living space called "Cambium" in Southern Austria. The buildings were selected according to the following criteria: geographical distribution; differences in social, cultural, and current housing practices; differences in national regulations for construction and renovation; common European building archetypes, size and population per building; climatic differences; common challenges for construction companies, similar professions and regional/national housing associations. In addition, three of the selected buildings are social housing, as one of HOUSEFUL's objectives is to improve the level of recycling through solutions that are also applicable to low-income groups.[6]

ROOF-WATER-FARM (Germany)

ROOF WATER-FARM is a transdisciplinary research project initiated by Dr.-Ing. Grit Bürgow and Dr.-Ing. Anja Steglich, which aims to make a valuable contribution to multifunctional, sustainable infrastructure development, and urban resilience. The concept adds two further dimensions to the urban landscapes and city gardens that have been established in Berlin for two decades: fish production and the connection to urban water infrastructure systems. It is a blue-green infrastructure that actively protects from detrimental effects of climate change by managing rainwater in and around buildings. Plants are used for evaporation and CO_2 storage. With the broad implementation of the concept, houses and neighborhoods would be able to produce high-quality process water and fresh food instead of wastewater in the future. The site is located in Berlin-Kreuzberg, a densely populated area in Central Europe which, according to Grit Bürgow, also has to contend with water shortages since Brandenburg is the driest region in Central Europe. Cultivation techniques of hydroponics and aquaponics are combined with decentralized water treatment technology of rainwater, greywater, and blackwater. Furthermore, technologies for the production of urban liquid fertilizer for hydroponic cultivation and design for rainwater utilization, evaporation, and infiltration were demonstrated. It is a holistic approach to close urban resource cycles and to recover nutrients for multifunctional use and to counteract linear nutrient flows.[7]

DemEAUmed (Spain)

The DemEAUmed project developed innovative technologies for the demonstration of an optimized closed water cycle in a tourist facility in the Mediterranean region. Involving industry representatives, policy-makers, a wide range of technical and scientific experts, and other stakeholders, it is a transdisciplinary project. The demonstration object is a resort in Lloret de Mar, Catalonia, Spain, where all water flows are characterized, treated, and reused with the appropriate innovative technologies to finally reduce the total water consumption and the carbon footprint in terms of water management. DemEAUmed addressed two major

[6] For further information: https://houseful.eu
[7] For further information: http://www.roofwaterfarm.com.

challenges: The importance of the tourism industry and water scarcity in the targeted region. The use of greywater is an ecologically and economically feasible alternative for applications where drinking water quality is not required. With the aim of using nature as a model to make ecosystem services more understandable, a vertically arranged wetland, called the vertECO, was developed. The greywater (building wastewater e.g. from showers, bathtubs, hand basins, etc., i.e. excluding wastewater from toilets - brownwater) is used as a source of reclaimed water.[8]

WETWINE (Spain)

WETWINE is a transnational cooperation project to promote the conservation and protection of the natural heritage of the wine sector in regions of different south-western European countries (SUDOE area). It derives from the need to manage the waste generated by the wine industry during the wine-making process and to control its environmental impact, as well as to promote the efficient use of fertilizers based on the development of an innovative pilot project, using anaerobic digestion and sludge treatment, as well as a constructed wetland. Based on the results obtained, the WETWINE project offers solutions to the problems of waste production in the wine industry by treating wastewater and reusing recovered resources as fertilizers, thus reducing the environmental impact of wine production by 90%.[9]

GROWGREEN (Spain)

GROWGREEN's demonstration project for NBS aims to combat heat stress in the Benicalap-Ciutat Fallera neighborhood in Valencia, Spain. The city has a high level of unemployment, an aging population, and deteriorating infrastructure. Several NBS are currently being tested there: a vertical garden, installed at a local school, is used to regulate the temperature and provide sound insulation and also filters the wastewater from the school's sinks and showers; a local senior center is now also equipped with a green roof, which helps reduce the heat in the building and stores rainwater, which is being reused in a small forest with near-natural solutions for rainwater management, as well as a green-blue corridor connecting existing green areas. These solutions are providing shade, improve ventilation, and facilitate the penetration of rainwater into the ground. A mobile app helps local people learn more about plants and wildlife

[8] For further information: http://www.demeaumed.eu/.
[9] For further information: http://wetwine.eu/en/.

in Valencia, and a "solidarity basket" connects food producers and consumers. All these ideas are designed and implemented in collaboration with the residents of the neighborhood. Their results are being monitored for the next few years. The results of these demonstration projects and an analysis of existing plans and strategies will be used to develop a new strategic approach to NBS throughout the city.[10]

HYDROUSA (Greece)

HYDROUSA is an international collaboration between 27 partners, which will focus on innovative and nature-based solutions for water management and water treatment from July 2018 to December 2022. The demonstration sites within the project are addressing issues of water supply, wastewater problems, biodiversity, and nutrient losses (mainly during the peak tourist season), the extent of the difficulties faced by the infrastructure at the peak of the tourist season, leading to unsustainable water demand, as well as job creation. The existing use of non-conventional water resources, such as rainwater for low-purity water needs (toilet flushing, irrigation, washing machine, etc.), cistern storage in winter to reduce the load on the aquifer during the tourist season, low water consumption devices (e.g. ultra-low flush toilets, air-injected tabs or local irrigation), and communal wastewater treatment and reuse of water and nutrients for irrigation (fertigation water). HYDROUSA's main objective is to offer a range of solutions to these problems that can be easily adapted and reproduced to other possible circumstances around the world. The overall goals are to demonstrate that circular, nature-based technologies work for the supply of freshwater from non-conventional water sources; that nature-based technologies can recover water and nutrients from wastewater for safe reuse, while creating further environmental and societal benefits; that the applied technologies are feasible within existing (legal) restrictions and generate an economic return, can create jobs, and stimulate the economy; as well as to involve the community and stakeholders in all parts of the value chain from the very beginning; prove that craftsmanship combined with modern ICT solutions create resilient and attractive, durable systems; establish Nexus Water-Energy-Food Employment and work with real cost accounting as a tool for evaluating the recycling economy; replicate this concept with additional resources in as many other places as possible and spread the good news; and finally to effectively address the demand side of

[10] For further information: http://growgreenproject.eu/.

unsustainable water consumption by using unconventional water resources in agriculture and for domestic use.[11]

Empirical Data

For the initial data collection, I used an evidence matrix, assembled in collaboration with alchemia-nova. This matrix included a listing of 150 innovative circular water projects in Europe, with Technology Readiness Level (TLR 6 and above)[12]. All cases are residing amongst the broader spectrum of resource recovery from wastewater using biological technologies (microorganisms as primary agents), but not all are NBS according to the definition I applied in this thesis. Based on the NBS definition I used, geographic location, and size of demonstrational scope (micro, meso, and macro – which influenced my analysis scheme), I selected 14 cases. As a next step, I conducted the project managers of these 14 cases. However, due to the summer season and the pandemic, direct contact proved to be difficult. By the end, six case leaders were able to act as my interview-partners. In order to get a better picture as well as more expert insights on the topic, I decided to move ahead and change my initial plan of interviewing only case managers, and added also general experts in the practical as well as in the theoretical spectrum of resource recovery, NBS, and Wastewater treatments. Thus, I was able to conduct four more interviews. In the end, this decision proved to be positive, since it was important to gather the perspectives of project leaders or managers, and people who have practical knowledge about the entire project implementation (technology installation) process. Nevertheless, for the sake of avoiding bias, it was also essential to learn from experts in the theoretical field. Since the projects are case studies, the goal was to conduct an on-site excursion to each demo site. However, due to the circumstances traveling was only possible under limited conditions. This led to two field research trips in Austria, Fehring (HOUSEFUL) and Vienna (vertECO). During these excursions, I took notes to better understand the interactions as well as the NBS technology itself. For the interviews which I conducted online, I used either jitsi.org or skype.com, both open source platforms for video calls. On these platforms, I recorded and stored the interviews after previously obtaining the consent of the

[11] For further information: https://www.hydrousa.org/.

[12] TLR = Technology Readiness Level scale was introduced into the EU funded projects arena in 2014 as part of the Horizon 2020 framework program, for further information: https://enspire.science/trl-scale-horizon-2020-erc-explained/ (2020).

interviewees in order to proceed with the transcription. I processed these transcriptions using the ExpressScribe software.

Interview partners

The project leaders and/or practitioners interviewed are as followed:

HOUSEFUL

I conducted a 90-minute in-depth interview with project manager Tamara Vobruba, who coordinates all activities related to the HOUSEFUL Vienna (Baumgartenstraße) and Fehring (Cambium) demo sites, in Vienna.

ROOF-WATER-FARM

I conducted an in-depth 80-minute interview with Grit Bürgow, focusing in particular on institutional and social barriers she experienced during her research at ROOF-WATER-FARM. Due to the online format of the interview, the setting may have set limits to the scope of the insights I gained.

DemEAUmed

At the time of the research, the project in the Spanish hotel had already been completed and was in the phase of evaluating the results for communication purposes. I conducted an interview in person with Heinz Gattringer and another interview partner, who preferred to remain anonymous, Consequently, I use the pseudonym of Andrea Meister in this thesis.

WETWINE

I conducted a 90-minute in-depth interview with Rocío Pena Rois of AIMEN[13], who was the technical coordinator of the WETWINE project. Due to the difficulty of conducting an online interview, parts of the interview were not well recorded.

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[13] AIMEN is a Spanish private non-profit organization with an **Innovation and Technology Centre**.

GROW GREEN

I conducted this 90min in-depth interview online with a member of the Climate Emergency and Energy Transition Service in Valencia City Council who preferred to remain anonymous, and will be referred to in this thesis as Juan Diez.

HYDROUSA

I conducted a 50-minute online interview with Dimitris Kokkinakis, one of the co-founders and co-directors of the Impact Hub in Athens. The role of the Impact Hub within HYDROUSA is the communication and dissemination through community building.

In addition, four experts were interviewed: Günter Langergraber from the Department of Water, Atmosphere and Environment (WAU) at BOKU Vienna. Johannes Kisser, trained chemical engineer and technical director of alchemia-nova GmbH. Gianluigi Buttiglieri, researcher at ICRA (Catalan Institute for Water Research) and scientific coordinator of the European project demEAumed. Finally, Nicolas Bedau, landscape designer and architect, co-owner of ELT (Tinos Eco Lodge), who is also involved in HYDROUSA. I interviewed both Nicolas Bedau and Gianluigi Buttiglieri by means of a written questionnaire. I interviewed Johannes Kisser and Günter Langergruber personally via an online platform. Both expert interviews lasted between 40 and 50 minutes.

MaxQDA – a tool for qualitative research

To perform the data processing, I transcribed and coded the contents of the qualitative interviews (see Appendix) with the MaxQDA coding software. First, I used the methodology of open coding. I inserted the transcriptions into the software and thoroughly examined them before starting the allocation process. Based on the literature and the Circular City COST Action, I established 16 categories and allocated around 400 sections of the interview protocols to these categories (see Fig.3-5).

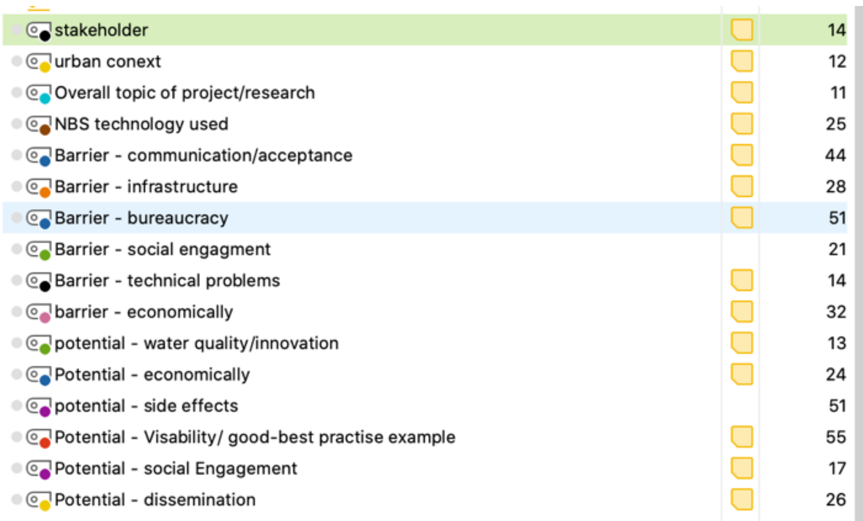

Figure 3, An excerpt of the coding: divided into barriers, potentials as well as urban context and stakeholder categories. (Not visible on this picture other categories, such as NBS technology and trade-offs).

Figure 4, An example of aggregated codes for institutional and social barriers, where the sections have been allocated to.

As can be seen in Fig.6, the originally built codes were systematically divided into social and institutional barrier categories - (1) to (8). In order to realize this, I conducted an assessment based on these aggregated categories - (1) to (8) - with each of the more than 400 coded sections being assigned the number of the built category.

institutional - lack of tec...	Expert_Intervie...	Günter_L_done	all codes\Barrie...	59	59	3	In a lot of if you...
institutional - decentraliz...	Case_Interview...	DemEAUmed_H...	all codes\Barrie...	78	78	3	We know that It...
social & institutional - th...	Case_Interview...	Grow-Green_N...	all codes\Barrie...	35	35	3	the market is u...
institutional - insurances ...	Case_Interview...	DemEAUmed_H...	all codes\Barrie...	230	230	3	Because then t...
institutional & social & c...	Expert_Intervie...	Expert_Johann...	all codes\Barrie...	94	94	3	And of course, ...
social & institutaional - la...	Case_Interview...	Grow-Green_N...	all codes\Barrie...	58	58	4	You you should ...
social & institutional - sy...	Expert_Intervie...	Expert_Johann...	all codes\Barrie...	107	107	4	I think they sho...
institutional - also media ...	Expert_Intervie...	Expert_Johann...	all codes\Barrie...	102	102	4	Definitely in sc...
social - circular systemic ...	Expert_Intervie...	Expert_Johann...	all codes\Barrie...	105	105	4	From kindergar...
institutional - goverment ...	Expert_Intervie...	Expert_Johann...	all codes\Barrie...	102	102	4	the ministry sh...
social -& institutional - k...	Case_Interview...	Dimitris_hydrou...	all codes\Barrie...	43	43	4	And also there i...
institutional - class on N...	Expert_Intervie...	Günter_L_done	all codes\Barrie...	27	27	4	They have to d...
institutaional - ethical sta...	Expert_Intervie...	Expert_Johann...	all codes\Barrie...	104	105	4	If you don't like...
social - lack of qawarene...	Case_Interview...	Dimitris_hydrou...	all codes\Barrie...	41	41	4	It is more that it...
social - technology that d...	Expert_Intervie...	Günter_L_done	all codes\Barrie...	80	80	5	And so it took t...

Figure 5, An example of the sentence/section allocation in the green scope.

The result clearly shows the most and least frequently used words and aspects. Overlaps signify those sections that can be allocated to more than one category or are cross-categorial by nature, f.i. due to the narrative of the interviewed person. Therefore, I had to repeatedly revisit these overlaps in order to ensure the quality and integrity of the coding. At this point, I want to state, that the researchers bias and subjectivity influences all stages of the research. Even when trying to avoid this, objectivity will never fully be reached. In a final step, I exported all codes via MaxQDA's Smart Publisher feature, which systematically orders all selected codes and transfers them into a Word document for further processing according to the constructed code system. Then, I textualized all findings and created a table to get a fast overview. I will present both in the following chapter.

Findings

In this part of the thesis, I summarize and present the findings of the interviews. First, I explain the barriers identified as institutional, followed by those identified as social. The findings are limited by the fact that based on these case studies no universal validity can be claimed. However, they can contribute to existing research on the barriers to the diffusion of NBS applications.

All insights gained from the interviews, literature review, and site visits were processed and finally categorized as "infrastructure and fixed procedures," "legal barriers (and solutions)," "economic and financial barriers," "knowledge barriers," and "behavioral barriers." First, I provide a table overview of the barriers, possible solutions, stakeholders involved, and the scope of action. This is followed by a textual more elaborate presentation of the findings separated into institutional and social barriers and potentials.

Infrastructure and fixed procedures

Barriers found	Stakeholder groups	Space of action	Social strategy (up to now)	Suggested solutions/ strategy	Interaction with social barriers
Infrastructural conditions Building infrastructure → in most EU countries no double pipe system installed → higher costs, if rebuild	Esp. Cities	EU (macro)	Rebuilding the pipe system, taking higher costs into account	Clear EU regulations for new buildings build to have double pipe systems installed (black and grey water separation)	Resistance to new practices, lack of education and skills
Rigid practices & bureaucracy set in stone procedures for waste water treatment & bureaucratic processes	Private households, industries, cities, agriculture, research, municipalities	EU (macro) and national governments (meso)	-	Debureaucratization and faster processing of applications as well as campaigns to educate and counteract misinformation	Willingness for opening up to new processes is hampered due to complicated and bureaucracy

Regulatory barriers (and solutions)

Barriers found	Stakeholder groups	Space of action	Social strategy (up to now)	Suggested solutions/ strategy	Interaction with social barriers
National Regulations *#1* Transparency of centralized water treatment data not obligatory	Decentralized water treatment facilities → communities, private households, municipalities, …	national governments	-	mandatory disclosure for the public of centralized water treatment data	Some people are earning well within the current system → resistance to new practices
National Regulations #2 High Insurances tariffs due to NBS's non-commercial usage	Private household, agriculture, small-scale treatment facilities	national governments	the acceptance of increased costs (due to idealistic principals)	A cost cap for insurance tariffs for NBS technologies → thus, it cannot become too expensive to hinder	Primarily people with an idealistic drive do not allow themselves to be hindered by this barrier
EU Regulations Higher taxation for	Decentralized water treatment facilities →	EU (macro) and national governments (meso)	Disadvantageous for wide distribution → focusing on co-	Shift of water taxation (eco-taxing) and clear	Lack of Awareness and Engagement to

decentralized water recovery	communities, private households, municipalities, …		benefits for economic benefit	regulations from the EU (within the idea of circular economy) on the lower taxes for decentralized recovered water and nutrients	pressure → bottom-up
Design Standards & permits Lack of design standards for the various NBS technologies → Restricted (building) permits	Decentralized water treatment facilities → communities, private households, municipalities, …	EU (macro) and national governments (meso)	Especially through research trying to co-create standards with authorities	Harmonization and collection of design standards EU wide (or even globally) to eliminate uncertainties.	Linked with uncertainties → distrust in NBS

Economic and financing barriers

Barriers found	Stakeholder groups	Space of action	Social strategy (up to now)	Suggested solutions/ strategy	Interaction with social barriers
Economic factors (yield, return of investment) Awareness/ knowledge or: a high CapEx → much lower OpEx.	Private household, agriculture, small-scale treatment facilities	Municipalities, cities, industry and agricultural unions	Creating data on this for further dissemination	Providing basic knowledge of the yields and returns of investments (e.g. from municipalities when entering the building permission process)	-
Public funding modalities - financing Little to no EU or national financing/funding opportunities (apart from for research projects → however, even there additional funding is needed & never sufficient)	Private households, industries, agriculture, research	EU (macro) and national governments (meso)	Dependency on private investment or additional fundraising/ EU subsidies	Decentralizing EU financing conditions and increasing the money spent for sustainable technology in waste water treatment → Provision of national financing opportunities for NBS in waste water treatment, esp. for nutrient- and water recovery (esp. making more EU money available for countries with higher water stress in the EU, for that purpose)	Linked with capacity of knowledge and skills as well as with time available (especially for non-research projects)

Knowledge barriers

Barriers found	Stakeholder groups	Space of action	Social strategy (up to now)	Suggested solutions/ strategy	Interaction with social barriers

Capacity of knowledge and skills No sufficient knowledge & interdisciplinarity in planning and/or construction/ implementation of NBS technology in waste water	Private households, industries, agriculture, research	NGO's, educational institutions, Sustainability movements and organizations, …	Revision/Research of NBS → raising awareness and building knowledge	Creation of standards as well as establishing a custom of working interdisciplinary	Higher costs due to longer processes and check ins (water quality, …) and more difficulties in obtaining permits
Educational framework "the more sterile, the better" is taught to be an underlaying approach to life (kindergarten to university).	Private households, industries, cities, agriculture, research, municipalities	EU (macro) and national governments (meso)	Alternative education, extramural courses/trainings	Revision of the school system and curriculum, inclusion of ethics and nature-society understanding	Linked to the general distance of nature and the lack of awareness
Lack of *dissemination* NBS generally lack diffusion and dissemination → lack of Awareness and Engagement	Small circles of interested and engaged people so far → Private households, industries, agriculture, research	Decentralized waste water treatments facilities	Research projects for replicating it	More replication of NBS technology for water- and nutrient recovery within the EU	Linked with funding opportunities and easy access of the knowledge

Behavioral Barriers

Barriers found	Stakeholder groups	Space of action	Social strategy (up to now)	Suggested solutions/ strategy	Interaction with social barriers
Perceived risks Uncertainties in construction (malfunction) or unwanted side-effects (smell)	Private household, agriculture, small-scale treatment facilities	Everyone	Creation of good/best practice examples	Raising awareness, special trainings/ courses & creation of standards as well as establishing a custom of working interdisciplinary	Linked with the educational system and public representation of NBS
Resistance to new practices No confidence or willingness to invest in new technologies	Farmers, industries	(Educational systems) governments, cities and municipalities	Talking to representatives of the agricultural sector and industries	Providing subliminal access to NBS: free further training, funding opportunities, less bureaucracy, competence support, …	Linked with intransparent organizational structure
Distance from the natural world Less interaction with nature (especially in	Everyone	Cities	Educating and Awareness raising	Revision of the school system and curriculum, inclusion of ethics and nature-society understanding as well as	Linked to the educational institutions as well as the public information sector

urban areas) → distance to the natural environment and it's skills				more campaigning for nature (media)	

Institutional barriers & potentials

Financing

According to the information provided by the interviewees, there is little to no financing for NBS technologies in the municipalities and countries, particularly in Greece and other Mediterranean countries. In Austria, for example, the national financing framework is also less favorable because the topic of wastewater utilization is generally not considered a priority. In the field of water, it is mainly the renaturation of river landscapes or energy production from hydropower, where the national financing is directed to. In general, it is easier to obtain funding for research projects in the individual countries, since explicit funding pools are available for this exact purpose. However, these are not available a comprehensive application of NBS for private individuals or communities. The research funding pools are provided by the EU and are tied to central EU regulations and goals, i.e. which criteria a project proposal fulfills and, accordingly, how much funding is made available is then decided. These criteria must be met by the respective country. It has been pointed out remarkably often by the interviewees that this superordinate centralization of funding would stand in the way of strengthening local governments and administrations. If local projects were then to receive funding from EU funds, this would involve a great deal of bureaucracy. This bureaucracy is understandable for all interviewees due to the size of the projects; but it is criticized that the effort is sometimes not related to the funding, because in most cases additional funding is needed for a full project/solution realization.

Transparency, as well as resulting and "hidden" costs

According to the interviewees, the lack of transparency is mentioned as a further challenge in the area of financing. The price for public water in Europe, particularly mentioned in the example of Germany, is actually substantially more expensive than recovered water (from greywater). In Germany this is based on the value-added tax, which is 7% for centralized public water. For decentralized operators, it is 19%. This means that the price per cubic meter of recovered water would be 3€, and the price per cubic meter of public water would be 5€. However, this profitability cannot be communicated because the central water management does not disclose its figures. The projects have to make all their figures transparent, which means that they would always have "more problems" than public centralized and established institutions, which is a massive barrier in the final operating and commercialization step of the NBS applications on the free market and leads to a clear financial disadvantage.

Minor aspects, as for example in Austria, the sewer connection fee, which co-finances the communal sewage treatment, must be paid in the municipalities even if one does not use the water from the centralized water system, as soon as a connection is present and usable. However, this is, according to the interview partners, a point that can be a drop in the ocean when it comes to decentralizing water in the private sector, whereas other barriers are more impactful. Furthermore, if NBS applications are used in a building environment, insurances also become an obstacle. Most of these insurances are based on norms and standards. So, if you adhere to norms and standards, you get very low insurance rates. On the other hand, if it is a novelty and there are no norms or standards, then the tariffs increase significantly. Moreover, if NBS is applied in agriculture, the insurances become even greater challenges, since the regulations for food and beverage production are stricter due to its potential health impacts.

Structurally speaking, the interviewees agree that the EU is doing fairly good work in this specific area. Nevertheless, a start should be made on truly internalizing the externalized and socialized secondary costs of unsustainable technologies, agricultural practices, mobility infrastructure, and the construction sector.

Public funding modalities - Bureaucracy and Time

The EU Commission has long-term agendas, which set targets for 2050, and related strategy papers, which propose regular regulatory measures. The interviewees recognized that the Commission pursues a science-based policy and its processes can therefore be considered sound. There is, of course, the disadvantage that funding policies and legislation have to go through the European Council and the European Parliament, which is still made up of member states, with national representatives participating in the process; thus, involving various interests of the different country representatives, which is often a long-drawn-out process.

The factor of time and perseverance in the complete realization of projects of NBS for resource recovery was mentioned many times. Whenever there is a research project idea for which funding could be obtained - be it in Spain, Germany, Greece or Austria - one has to deal with the applications to the EU. Even in the field of research funding, the previously mentioned bureaucracy is a barrier to this. It can take up to two years to go through all the different steps of the application process, because it is often a multi-stage process, until the realization and implementation of the idea can start. In this process of course also EU bureaucracy independent steps are taken, such as finding a suitable location or a suitable team for the implementation. However, it requires a solid foundation of knowledge about the process and perseverance, which may be too great a barrier for laypersons or private individuals to apply NBS. This is also reflected in the agricultural sector, where, according to one interviewee, it seems that farmers, because of these hurdles, are following the conventional path they are familiar with in order to obtain funding. This means that they are less inclined to use innovative applications under these conditions.

Permits, standards, and regulations

Most interviewees positively recognized the very clear water quality and water re-use legislation, on European and national level, for example, to measure certain aspects such as pathogens and microbial parameters to ensure that the water can be reused safely. Since NBS are a somewhat new procedure and not yet established, this step to obtain permits for these procedures can be very difficult. On the one hand, one must follow the regulations just mentioned, but on the other hand also other national ones, such as the Ö-Norm in Austria, when carrying out any kind of construction work, which is necessary most times when implementing a nutrient and water recovery technology. Almost all interviewees criticized the lack of internal cooperation within authorities, i.e. the different departments do not know about each other and are not well connected, which makes the integration of several sectors (e.g. water and food sector) correspondingly difficult for practitioners.

The poor networking also affects the creation of standards. Since NBS technologies are not commercially used, new standards for widespread implementation must be created. Due to the fact that the authorities are not well networked, this becomes difficult.

Standards for NBS are proving to be both a hindrance and a benefit according to the interview partners. If there are no design standards for a solution, the problem could be that the permit for operation is only granted for a certain time. Using the example of Austria and a constructed wetland for instance, in Upper Austria permits are issued for 15 years if the process is commercialized, in Lower Austria for 30 years. It is thus very different in all regions of Austria. That alone is complicated, said one interviewee. If it is an innovative, non-commercial process, the authorities could say that they will only grant approval for two to three years for the interim period, so that they can evaluate how the system works and decide whether to continue the permission. This leads to a systemic inclusion or exclusion of certain actors within the field. The same applies to nutrient and water recovery in agriculture; the Common Agricultural Policy (CAP) is a set of rules for agriculture, governs the EU agricultural subsidy structure and implements market measures and rural development measures (EC 2020). However, the administrative effort involved in dealing with the CAP is a great burden for small farmers, both in terms of time and money. This means that large farmers are more likely to deal with it and thus receive the benefits of the CAP.

On the one hand, the lack of e.g. construction standards makes it difficult to get permits, which in turn discourages designers and builders from building, as they don't appreciate building something for which there is no clear guidance and approval, wary of running into problems with authorities. On the other hand, the lack of standards also opens up the possibility to define them together with the authorities and thus to make recommendations on behalf of the NBS. However, setting new standards is a very tedious job and usually takes multiple years. "Negotiations over every single comma and every single sentence, every single word. It's a very exhausting process”, says one Interviewee.

The reuse of water is connected to safety regulations for the reclaimed water. The Spanish legal framework gives e.g. institutional investors like hotels, a lot of security in this aspect, which is still missing in countries like Austria or Germany, but will come into place as soon as the new Water Reuse Regulation legally applies from 26 June 2023 (EC 2020). According to the interviewees, there is a grey area here that scares away many of the institutional investors. If the investors do not have a good, clear framework in which they can work, they will not touch it. The water reuse regulation governs only water reuse for agricultural irrigation and no other reuses (e.g. street cleaning, industrial process water etc.). In addition, the costs for water quality measurements have to be borne by the operators themselves, which is also a hindering factor as these controls are mandatory. However, this does not only concern NBS, but all technologies for water treatment. Proof must be provided that the water is safe for its intended use. In contrast to innovative solutions, the procedure of commercial solutions is already established and there are no uncertainties in this process. In comparison, there are uncertainties in innovative solutions, especially on the part of the authorities, which can lead to a higher number of mandatory measurements.

Set priorities

At the centralized level, NBS are still rarely applied (sometimes only as third-party treatment), and there are generally no economic incentives from the central administration. In addition, there is nothing in the SDG's (Sustainable Development Goals) about circularity of water and nutrients, which indicates prioritization of other environmental interventions. In the area of decentralized water treatment, some EU countries are quite advanced, e.g. Italy and France, whereas Greece is against decentralized water treatment. According to the interviewees, this could be due to structures where there are simply some people and companies that profit well from the current system and therefore do not have any desire for change. The fear is that this is why the priority of sustainable water treatment technologies is not yet so high (although climate change is pushing the issue).

Furthermore, many of these sustainable technologies tend to focus heavily on energy savings (funding opportunities for solar panels), next in line are often health-related issues, and perhaps water comes in third place. NBS technologies are therefore disadvantaged in that other technologies account for the lion's share of the EU framework. According to this, NBS technologies are inherently disadvantaged.

Misinformation and lack of knowledge

False information based on profit-oriented actions of companies involved in wastewater treatment is common. Usually companies want to build a system that they can rebuild right away, so it is cheaper. This is accompanied, according to the interview partners, with the fact that, for example, constructed wetlands are communicated with false information; that they would not work well in principle, or that their plants do not work in winter, when there is snow. However, microorganisms are still present and do this work. This false information hinders the demand and implementation of NBS. Because usually it concerns thereby the microorganisms in the filter, which function so similarly as the microorganisms in the technical treatment plants. They also work in winter, although slower, but well enough to ensure required effluent quality. Thus, it is not a technical question, but rather the feeling or awareness of the people, especially in the administration or in companies, that these kinds of systems do not work in winter.

Moreover, it was mentioned that the level of institutional knowledge varies across Europe. For example, there is still a lack of wastewater treatment in Eastern Europe, especially for small amounts of wastewater. According to the people interviewed, this is due to a lack of knowledge about the technologies and their implementation, especially at the administrative level. The available standards vary widely in the EU countries, e.g. in Austria or Denmark standards for constructed wetlands are established, but in Poland or the Czech Republic there are no national standards for constructed wetlands or similar treatment solutions.

Organizational and structural factors

From an organizational point of view, the development and capacity of knowledge was identified as a potential barrier to the widespread establishment of NBS. The different systems, knowledge dissemination, and knowledge generation are important cornerstones here, as there are no standardized regulations concerning that (e.g. from the EU). In the long run, the aim is to move away from the traditional grey solutions to those based on nature. Efforts have already been made in research to achieve this, but this has not yet been internalized in the overall institutional structure and organization, says one interviewee. Furthermore, the entire structure of how knowledge is disseminated is not sustainable, for example, it could be that the market is not yet ready because it is simply a long-term transition that could not take place in a month, but institutions, authorities and legislators are in a position to create the structural conditions for this process in the best possible way.

The participatory involvement of the population is identified as another problem. For example, people in urban areas are not even asked whether they prefer a centralized or decentralized water treatment system. Thus, they do not know what their taxes are spent on, how much energy is used to pump water into the city or to pump drinking water from natural wetlands and forests, among other things. In the infrastructure system of urban water treatment, there is neither ambition to pass on knowledge to consumers, to research about their desires and needs nor transparency about how wastewater is currently treated. In general, the entire structure of the sector is criticized; “If you think about creating more green systems, you fail because of the barriers.” Those who are not sufficiently informed always take the easy way out, according to the interviewees.

Educational capacity provided

Docking on to the structural barriers, it was mentioned several times that the education system was of no help at all in disseminating NBS or generally soft, environmentally friendly technologies for wastewater treatment. The fact that people are taught that wastewater is pollution and must be removed was perceived as problematic by the interview partners. In our system, decontamination is the first priority. This starts at kindergarten, where children are able to understand bigger pictures, e.g. how nitrogen and phosphorus could easily be cycled: “eating in, poo out, into the soil, into the food (…) - it is very easy, you don't need much to really understand this nitrogen and phosphorus cycle”, and continues all the way to the universities, where people learn “the more sterile, the better”. One learns about synthetic chemicals, which, when used individually, are much easier to understand. And thus, mankind is looking for the synthetic as opposed to the natural processes. Moreover, students are not taught to take care of small systems themselves and thus learn by experimenting, but are given the ready-made familiar solutions to imitate. Additionally, the existing knowledge is trapped in the academic world, which is not a publicly accessible domain, using its own language and platforms.

Furthermore, the lack of widespread openness towards NBS is mainly attributed to the fact that there are no introductions to ethics in the European conventional education programs. The assumption is that the understanding of natural processes and the awareness and way people see nature as something greater is strongly linked to ethics. Next to Ethics, another aspect that has been addressed is awareness raising itself, which involves campaigns, workshops, information websites, etc., that are currently not widely available. Those target groups, who basically never get this knowledge, are simply forgotten. In some regions of Austria there is a mandatory course for all those who want to implement a decentralized wastewater treatment system. They learn about NBS technologies or other innovations in this area much too late, namely only after they have obtained their permits (when the design is already done) from the relevant authorities. However, these administrative and communication activities vary from municipality to municipality, which presents enormous challenges to NBS widespread use.

Infrastructural factors

The explicit barrier of the constructional infrastructure was always mentioned by the interview partners, since in many European countries additional piping is required for a functioning wastewater treatment as well as nutrient and water recovery by NBS.

In grey- and blackwater recycling it makes sense to install double pipe systems, which is of course easier to install when building a new building, rather than replacing the old infrastructure in existing houses. Most of the time this is very expensive. Grey- and blackwater should be separated to allow the highest rate of recovery. In southern countries, such as Spain, the structural implementation of double-pipe systems is historically more common than in Central, Eastern or Northern Europe. Greywater is generally easier to treat than blackwater. According to the interviewees, the value of water is disregarded when constructing buildings, and simple measures, such as a double-pipe system, which would in principle be inexpensive to implement in a new building, are not legally anchored and thus not applied. Furthermore, there are few companies on the European market that build NBS systems for wastewater treatment, hence, there are not enough available technologies for the normal user. These infrastructural factors act as a major barrier for the application of decentralized NBS wastewater treatment technologies.

Social barriers & potentials

Knowledge and competence capacity

NBS for waste water processing must be adapted to each individual case in order to function in the most optimal way. This requires knowledge and skills in design and implementation, which also demands a higher cost input. In addition, the user needs to understand the basic and more comprehensive aspects of his system in order to execute them correctly. Since these are not yet established, highly researched, and tested systems, it happens that problems gradually emerge. This risk is an obstacle for many consumers. Of course, this varies from country to country, for example, the constructed wetland in Austria is relatively well established and therefore there are competent experts for design, implementation or if something is not going according to plan. According to the interviewees, this established state of the art technology has enormously minimized the obstacles to the construction of constructed wetlands in recent years. However, it still depends on what kind of technology they use and which company they work with. Often it is a case of "my neighbor recommended his treatment solution to me, so I had it built by the same company". The problem of the treatment plant, if e.g. with the building of houses necessarily, is something that humans want to have solved fast, with it they do not want to be occupied for a long time, because it is only a small part in the large building project. It was also mentioned by the interviewees that there were companies that built and sold systems without maintenance requirements. Of course, these cannot work, and people started to lose acceptance.

Another obstacle is a lack of interdisciplinarity, for example in Poland, where biologists, (who obviously have basic knowledge about Nature) have built NBS technologies for wastewater treatment, but they lacked the engineering knowledge, and thus non-functional systems were on the market. This has worsened the reputation of NBS in Poland, and the trust in this type of wastewater treatment systems has been set back by years, so it took 15 to 20 years before these technologies were accepted again. This chain of lacking knowledge, too little cooperation between different specialists and the resulting non or badly functioning systems is one of the biggest for a wider uptake of NBS.

Furthermore, it is much easier to find conventional knowledge to any problems in the wastewater treatment sector than the NBS alternatives, if you, for example, want to integrate and develop it into a new urban area or a new block with houses. Usually the social demands are answered on a political level, but there is no real social demand in this respect because people do not have the knowledge about it. They do not know very much about the technical aspects or how to use a green roof, the sewage plant or the biogas plant to recover water and nutrients.

Lack of dissemination

According to the interviewees, due to the sparse availability of NBS applications for resource recovery, someone who wants to install an NBS often lacks reference cases and may not have access to experience. This makes any new installations more difficult, especially for available enhanced, innovative solutions, e.g. for a normal consumer to access practical information about e.g. biogas production from his blackwater. “If a thing has been done hundreds of times, you can google it”, says one interviewee. In this case, it is hard to go beyond the pilot projects.

In Greece, for example, the NBS systems are discussed in an exclusive small circle because they are not popular solutions yet. There are case studies where everything worked well that can be looked up, but the neighbor around the corner would simply not do it because there is no proper access. The lack of dissemination of the NBS itself, but also of all pilot projects, is itself a massive hurdle.

Distrust and fear as factors

Many professionals do not trust NBS because there is too much uncertainty. With exact sizes and numbers, there are fewer uncertainties in both maintenance costs and function. This is one of the reasons why not only consumers, but also installers or civil engineers prefer more homogenous, context-independent, “grey” technical solutions. Civil engineers in particular have no confidence in NBS and are reluctant to resort to NBS because they do not know how to handle plants, or how to quantify the aesthetic benefits, the cooling effect, etc. They do not like the perhaps additional moisture in the air. They sometimes like it in winter when the air is too dry, but they do not like it when it starts to condense in the walls. From this point of view, it is therefore a great barrier to convince the civil engineers.
Since NBS needs such a variety of different professionals, consumers would be frightened if they had to talk to all of them individually, when implementing an NBS system. Therefore, it needs people who are familiar with all the expertise related to the solution to act as a one-stop-solution to not scare off consumers. In addition, people do not believe that a non-human made system can work. And this is a very common misconception that only people can invent technologies that do a good job, or if they don't use a lot of energy, they might not work properly.

Another aspect often mentioned is the fear of negative side-effects, such as smell, water quality or insects. Especially when it comes to facilities such as hotels, smell and insects are an issue where fear is expressed, thereby excluding NBS by principle. Furthermore, water quality is often mentioned in this context. The fear for safety when it comes to wastewater is a constant companion. The idea that the blackwater is used to process one's own faeces and produce a product that could be used to fertilize the tomato plant in the garden irritates or even repels many people. This is a classic social barrier, as it is about awareness of cycles and the relationship to humans’ outputs.

Resistance to new practices

In the interviews, resistance to innovative ideas was mentioned as an obstacle, especially for farmers, who often have no confidence or willingness to invest in new technologies (e.g. sensor technology, where data can be tracked on a smartphone). The sensibility towards water is one that has changed significantly in the last decades, mainly because farmers are increasingly struggling with the effects of climate change. However, according to the interview partners, it is clear that farmers are attached to old knowledge (which is not a barrier because it is fundamental knowledge) but are not adapted to the current and future situation. For example, in Greece, farmers like and know the land they cultivate, but many still use the 250m deep boreholes to get fresh water for irrigation. These techniques are partly maintained, which is a barrier to innovative solutions. Of course, there is knowledge among farmers about weather and water changes, but often there is also no will to find out the exact figures; how much fertilizer has been used, how much water has fallen through rain or how they could optimize production. So, there is - not with all, but with many - a fundamental resistance to technologies which are then also brought into connection with NBS. Generally, it appears that people don't want to deal with things that get too complicated, people usually take the easy way out. Therefore, they need to be motivated to take the hard way and see that the system is already being used successfully many times. According to the interviewees, this concerns both younger and older people.

Economic factor – yields, return of investment, and additional costs

The knowledge about a smart implementation of NBS, i.e. that a higher CAPEX is required, which is difficult to amortize in the current economic situation, has not penetrated yet. People do not know that in the beginning a high CapEx is needed, but then a much lower OpEx results (So you have more capital expenditures, but lower operating expenses). The idea is that the plants will grow over time. In the first two to three years, neither the maximum yield nor the maximum capacity is reached. So, in order to really work properly in wastewater treatment with nature-based solutions, one has to work with the life cycle of the plants. This is seen as a major obstacle. When NBS are applied, it is still attributed to purely ideological reasons.

In terms of financing these costs, there are possibilities for subsidies, but in many areas, there is not enough time and energy to deal with the additional work, i.e. an external person must be paid to collect the information and prepare the necessary documents for an application.

These additional costs can be a hindrance right before the implementation of NBS for wastewater treatment.

It was also mentioned that unexpected costs could be added during operation, which might create barriers to implementation – but this applies to all forms of wastewater processing, not only NBS. For example, it would happen again and again that especially constructed wetlands, which usually take up larger areas, would be polluted with waste that people dispose of there. To clean this waste and to ensure the best possible processing of the wastewater additional costs would incur. In addition, it was mentioned in this context that the recovered nutrients do not always find a market. For example, in an urban project in Berlin, a NBS systems was used to recover fertilizer-liquid from wastewater, but the demand was not there, resulting in costs that could not be amortized. The same was explained by another interviewee, how important it is to know exactly what kind of recovered resources are really needed in order to make a good balance sheet, so that costs are not left behind. On top of these costs come smaller ones, such as the maintenance work or the laboratory costs to check the quality, if you cannot do it yourself or if the system is implemented on a larger scale. Since it is a living cycle, these are necessary for maintenance and continuation. Basically, of course, it depends on the NBS technology itself, some are more expensive in the development phase but perhaps more efficient in wastewater treatment, and others just the other way around - it always depends on the needs. However, these additional costs keep people from using NBS in wastewater treatment.

The fact is that there have been several investments in conventional wastewater treatment systems, whether at the household or municipal level. For this purpose, loans were taken out and plans were made to get the invested money back. One example of this is salt water desalination, which has been implemented on a large scale in Mediterranean countries at the municipal level. For private customers this is even worse, because the smaller units process less water, but the basic costs (planning, installation etc.) are the same. So, for those who are within the water network, there is really no economic benefit there yet.

Fear of losing income

Many people do not feel the urge to act, which one interviewee explained on the basis of a Greek island: It is a very touristic island, where it would be unthinkable to reduce water consumption. In the eyes of the local entrepreneurs, it is not possible to tell a tourist who spends €1,000 a day in the local economy to reduce the water. Likewise, they assume that tourists are not interested in whether the water in the shower is the clarified greywater, rather the opposite, that it discourages tourists. The fear of losing customers and consequently income is great. According to the interview partners, especially in European countries that are still troubled by financial crises, the desire to counteract climate change with NBS exists, but often cannot be prioritized.

Lack of awareness and engagement

The understanding of nature and technologies based on natural mechanisms often came up in the interviews. According to this, NBS frequently encounters a lack of understanding among people. The awareness of the nature-human relationship is often not very well established. Reasons for this can be the previously mentioned priorities, but also a lack of examples and cultural education. According to one interviewee, the awareness of this is greater in the northern countries of Europe than in the southern countries. This could perhaps be due to the fact that there are different levels of technological and cultural development within Europe. Here again, an example is given with a water supply company and wastewater treatment on a Greek island. A major obstacle for many water supply companies to work in this way is, above all, that people are not aware that solutions from nature can do the same job.

In the context of engagement, it can be seen that mandatory maintenance is an obstacle for NBS systems. According to the interviewees, this does not occur as frequently for greywater as for blackwater – because more maintenance tasks tend to be carried out in this area. A non-European example was also used to explain the lethargy of maintenance. In Africa, NBS systems are supposedly in great demand, but the commitment to deal with them is lacking because the means to do so are non-existent. In areas where resources are lacking, the network and commitment to apply NBS is also lacking a system of circular processing (e.g. to produce fertilizer from wastewater, to have it collected by a company that resells it on the local market, etc.). This obstacle for the application of NBS systems in wastewater treatment is of course also attributable to the aspect of awareness.

Distance from the natural world

Correlating to the lack of awareness, the distance to nature, which one respondent described as a classical phenomenon, was frequently mentioned. Many cities have a small stock of trees, or they leave little space available for green zones or places with soil, that people can associate with nature. Furthermore, there are the supermarkets where everything is packed in plastic and very far away from what is actually the natural process that operates behind it. The understanding that humans are part of the whole earth system, and that we should work with the natural environment rather than against it, is not widespread, according to a interviewee. Since many people do not pay attention to nature, it is also a discouraging factor when, for example, walls are greened, such an ecosystem is brought closer and attracts insects, birds, and other animals. Since NBS is often not just about technologies based on natural processes, but explicitly uses elements from nature, incorrect maintenance can lead to unfavorable side effects. So as an example, harmless mold or the falling off of leaves was mentioned, this again releases an aversion in many humans, although it is a completely normal part in the natural cycle. Understanding nature and the human relationship with nature is considered a significant barrier to NBS technologies.

Analysis & Discussion

In this chapter the results are analyzed by allocating them to three action scopes, see Fig. 6. The macro Scope of Action refers to the European framework conditions, such as regulations and policies, and explores the question of how the EU can foster broader dissemination of NBS through a top-down approach. The micro scope of action, in contrast, refers to the bottom-up approach and addresses, in addition to the social views of NBS, the question of how society can support the dissemination. The meso scope of action is of particular importance, as it represents a key position between macro and micro. As a bridge between the two, national as well as municipal framework conditions and possibilities for action are addressed here. Beyond that, the three scopes are used to demonstrate that a top-down and bottom-up approach is necessary for a sustainable transformation to circularity in nutrient and water recovery from wastewater in the EU, that enhances a wider adaption of NBS. Based on the parameters of the individual scopes, the results were manually assigned to these three scopes during the analysis process.

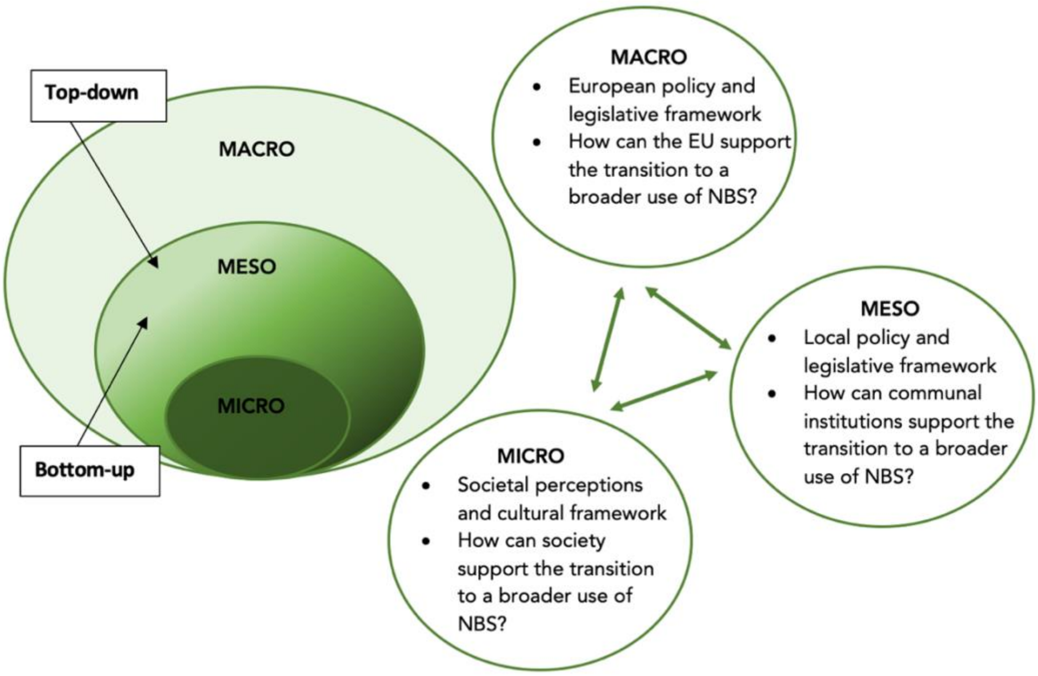

Figure 6, the visual model of the "scopes of action" used for the analysis.

It is important to emphasize the reality that these three scopes of action interact strongly in practice. Therefore, it is a useful technique to take a step back during the analysis in order to understand and correctly locate the links and interactions. Based on an iterative process during the extraction of the findings, the barriers as well as the potentials of NBS for nutrient and water recovery are discussed in the following part.

Institutional and social barriers, as well as conducive institutional and social conditions experienced by stakeholders

At the macro level, the following four fields of potentials and barriers could be identified: Regulations (including standards), financing, organizational structures, and education, all of which are interconnected. The findings reinforce the conclusions of e.g. Kabisch et al. 2016, Frantzeskaki et al. 2019, Somarakis et al. 2019, Katsou et al. 2020 and Kisser et al. 2020 that EU regulations have an important influence on the further dissemination and implementation of NBS in nutrient and water recovery in Europe. Complexity and bureaucracy are still considered the biggest barriers to pushing innovative and sustainable approaches. Furthermore, the lack of regulation, the resulting additional costs as well as the knowledge capacities provided were especially emphasized. A common legislation and the harmonization of national laws on various aspects of wastewater treatment are needed (e.g. for secondary resource recycling, such as the production of biogas: there are regulations for large biogas plants, but not for the domestic or agricultural sector) (e.g. Kisser et al. 2020). So far, it is still not completely transparent to which water and nutrient recovery application which regulations apply. The lack of intra-agency cooperation, thus the integration of several sectors (e.g. water and food sector) (Somarakis et al. 2019) makes it difficult for NBS practitioners to apply them, as the poor networking effects enhance the harmonization of national laws. In contrast to innovative solutions, the procedure of commercial solutions is already established with no uncertainties in the area of water or nutrient quality. Innovative solutions have the image of great uncertainty, especially among authorities, which leads to a higher number of mandatory measurements and long processes to undergo. According to Nesshöver et al. (2020) managing for increased resilience can help to cope with uncertainties.

A barrier not addressed in other research is that sustainable water treatment technologies are still weakened by actors that benefit from current structural systems. As a result, false information is spread, resulting in a negative and incorrect picture of NBS, but feeding conventional applications and therefore demand, which is reflected in the national representation before the EU Commission. According to the stakeholders, this is equally experienced in urban, industrial, and agricultural NBS applications.

Moreover, the lack of design standards is coupled with time-limited operating licenses, slowed down or even prevented permits (e.g. building permits). Thus, for example, planners and builders are discouraged from constructing NBS technologies. Which created even more uncertainties, that cause additional effort and higher costs in application. However, this problem also offers great potential for restructuring how standards are produced. Transdisciplinary teams of practitioners, researchers, and experts are to develop new harmonized design standards and thereby making policy recommendations on behalf of the NBS in wastewater treatment (e.g. Somarakis et al. 2019). Another important aspect is the adaptation of policies, especially for resource recovery in agriculture for example. Umbrella regulations such as the CAP lead to the systemic inclusion or exclusion of certain actors within the field (e.g. VC 2020). This also applies to nutrient and water recovery in agriculture, because the administrative burden of dealing with the CAP is too big for small-scale agriculture. The direct payments are largely bound to the size of a farm, hence directly favoring large farms. The new CAP (adopted 2020) binds 30% of direct payments to ecological measures implemented by farms. This is particularly due to the fact that the EU Commission has published the biodiversity strategy within the EU Green Deal, thus increasing the pressure for environmental and social sustainability (VC 2020). This is a step into a sustainable direction, but still favoring large farms over ecologically sustainably operating ones, therefore hindering NBS applications in small scale agriculture. Moreover, based on the Water Reuse Regulation, the framework conditions hold uncertainties for institutional investors. As the scope of action is not clearly defined for each individual NBS project, it is more challenging to find investors. Furthermore, the Water Reuse Regulation only regulates the reuse of water for agricultural irrigation and no other reuse (e.g. street cleaning, industrial process water, etc.), i.e. in all other areas this problem is even more present. Evidence based knowledge on the performance and benefits of the NBS is an essential element for the establishment of EU-wide or even global NBS standards and policies, thus allowing for an enhanced implementation of the NBS (Somarakis et al. 2019). However, according to the proposal for minimum requirements for water reuse, the EU can only legislate as far as the contracts with its member states allow it, and with due consideration for the principles of necessity, subsidiarity and proportionality (EC 2018). Therefore, there must be better cooperation between the member states and the EU, as well as the insurance of multiple stakeholders, in order to implement and harmonize these regulations.

In the area of financing NBS applications, it has become apparent that overarching centralization stands in the way of strengthening local governments and administrations. This is primarily due to a lengthy bureaucratic process in which efforts to obtain funding are often treated inconsistently by its authorities. Furthermore, most EU funding opportunities are only focused on research projects, not on funding for private users. It requires a solid foundation of knowledge about the process and perseverance even in the acquisition of funding for research purposes. This is also reflected in the agricultural sector, where these obstacles make it easier for farmers to follow the conventional path familiar to them to obtain funding. Thus, the further spread of NBS is hindered from the outset. However, the fact that there are few subsidies in this area also offers the potential that a completely new funding pot could be created to support and thus expand the NBS applications for resource recovery from wastewater on household or municipal level. In addition, a low-threshold access to these funds is necessary to reduce bureaucratic barriers. The public sector takes a key role in creating inducements through politics and financial incentives. For example, a redesign of the tax system could help to create the right market conditions for the further adoption of NBS systems, e.g. Eco-taxation[14] (Somarakis et al. 2019).

Communication and transparency are two more newly found factors that have an impact on the dissemination of NBS. At the municipal or urban level, for example, there is actually no knowledge of whether the population or community prefers a centralized or decentralized water treatment system, because they are not asked. Furthermore, established water treatment plants are not obliged to make all their data on water quality etc. publicly available. More participative methods for engaging and educating society as well as clear policies on transparency for wastewater-treatment operators are necessary. It can be assumed that this is based on the European education system, from kindergarten to universities, where humanity is thought to rather look for the synthetic as opposed to the nature. Furthermore, ethics is not anchored in this educational system, which would bring with it a profound approach to nature and the environment that has been missing in recent decades. However, there is a tendency to change and private kindergartens as well as schools implement one or the other measure, which sharpens more holistic and sustainable thinking. At the university level, too, it can be observed that, at least in the area of product design and technology, a change is taking place regarding ecologically sustainable education (e.g. KF Uni Graz, BOKU Vienna, TU Graz, TU Vienna). Nevertheless, it is up to the EU, on the one hand, to give a clear line on where education should develop as an inherent part of the system and, on the other hand, to provide an understanding of why education is one of the most important pillars of sustainable and social development.

The regulatory and systemic obstacles found in this study allow NBS to be considered exclusive, expensive, and fraught with imperfections. In order to support the wider diffusion of NBS, side benefits such as the cooling of ambient air or improved air quality should be considered when setting, for example, water quality thresholds for recovered water. It would be even possible to strive for a conventionalization of NBS in wastewater treatment and resource recovery as a

[14] Eco-taxation = is a tax levied on activities that are considered harmful to the environment. Ecotaxes address the failure of free markets to take environmental impacts into account (e.g. OECD 2011). Markets are drivers for innovations, but the regulation of the markets, via eco-taxation can be essential to indirectly influencing the global markets. This is to stir innovation in the right direction and to force changes in behavior and consumption patterns of people. It is closely coupled with the political system (e.g. Radermacher 2016).

strategy. This means that in addition to the legal framework for the application of NBS, the EU could also make awareness raising mandatory for the member states. Awareness for scientifically based knowledge in sustainable wastewater treatment and, more precisely, the recovery of secondary nutrients as well as their reintroduction into the social metabolism within the framework of the CE goals (e.g. CE 2020). Beyond, clearly emphasizing the importance of circularity, reduction of water waste, and enhancing the awareness of the nature-human relationship in educational institutions should be a focus within the strategy for 2050.

In the micro scope of action, the following four potentials and barriers have become apparent: Lack of awareness, lack of financial incentives, availability of examples, and distrust.
A lack of awareness and understanding of the role of humans as part of the overall Earth system has been identified as a general but new factor hindering the wider dissemination of NBS. With simple means, such as the example of plastic packaging in supermarkets, distance to raw materials has been made explicit. Sewage and garbage are not seen as resources with positive characteristics to be recovered and reused, instead they are seen as something bad that should be eliminated. Therefore, many people are not aware that solutions from nature can do the same job as commercial conventional water and nutrient recovery systems. Since NBS is often not only about technologies based on natural processes, but explicitly uses elements from nature (Somarakis et al. 2020) it is necessary to have an awareness and understanding of nature. Otherwise undesired side effects, e.g. the falling off of leaves of clarifying plants or smell, cause aversions. Addressed by Kisser et al. (2020), besides a lack of awareness of natural processes, there is also a lack of knowledge concerning the financial input. When using NBS higher capital expenditures are required at the beginning, but ultimately this results in lower operating costs (Kisser et al. 2020). However, many people are discouraged by the costs that have to be incurred because they do not know what the actual yield will be if applied successfully in the long-term. There are possibilities for subsidies to support the Capex, but it takes too much work to get them. Often an external person with knowledge of grant applications must be paid to prepare the necessary documents and initiate the process. For the financial and time expenditure the financial support is not in relation, thus makes it unfeasible and often prevents the use of NBS in wastewater treatment.

Furthermore, there is hardly a lucrative market for water and nutrients that are recovered by NBS (Langergraber et al. 2020), especially small-scale treatment. The smaller units process less water, but the basic costs (planning, installation, etc.) are the same. Hence, for those who are within the water network, there is no economic benefit there. There is a lack of market economy and circular structures, which would make it easier for private users to transition to NBS. However, one of the goals of the new Circular Economy Action Plan is to create a market for recovered resources, as there the large potential for secondary resources is acknowledged (EC 2020).

These hindrances thus also cause the further spreading, which likewise feeds these obstacles. Due to a lack of examples and the low awareness of NBS for nutrient and water recovery from wastewater, access to experience is limited and the rate of replication is low. NBS systems still seem to be regarded as exclusive and are far from being conventionalized. This intensifies a lack of trust and easily creates a form of disapproval of NBS. Mistrust is also based on a lack of interdisciplinarity in application and maintenance, and the resulting malfunctioning systems on the market. Thus, negative side effects such as smell, water quality or insects are feared. This worsens the reputation of NBS and therefore hinders the development of a broad acceptance of this type of wastewater treatment systems. However, there is a great potential in generating best practice examples and to furthermore disseminate the relevant knowledge to the world. Strategically, this could be facilitated through bottom up initiatives by strengthening cooperation between NGOs, local authorities, and other stakeholders through a campaign on NBS for nutrient and water recovery. It turns out that the meso scope is the bridging and unifying scope of the macro and micro levels, and is therefore a powerful interface of bottom-up and top-down actions. For that reason, it is tackled as the last scope. *Top-down* proceeds step by step from the abstract, general, superior to the concrete, special, subordinate, *bottom-up* refers to the opposite direction (e.g. Fraser 2006). The interviews clearly indicate that the collective awareness and education of society about the nature-human relationship is directly related to the widespread dissemination of NBS. At the institutional level, however, it is also clear that the framework conditions and structures that could support a transformation towards a broader use of the NBS are far from exhausted, but act as obstacles. The meso scope of action holds the most powerful potential for this change. In fact, because of the pressure from the population (bottom-up), it is more effective at the municipal or national level and can be achieved within the framework of the regulations implemented by the EU (top-down).

Similarly, this level acts as the one that could exert pressure on the macro and apply measures to the micro. This is a major responsibility for municipalities and countries, which is why decentralization on the one hand, but also a supportive EU framework on the other, is necessary.

How do technological, social, and institutional barriers interact?

The barriers are of circular and interacting nature. As social input all behavioral actions, which build the economic and cultural systems, are considered. That includes technologies and regulative frameworks that are being implemented. However, policies and regulations have the potential to be revisited and changed based on new findings or malfunction. This leads on to the shaping of social output, which is seen here as everything that develops out of society and is underpinned by the given input. Thus, the cycle closes. Everything on the societal sphere impacts the natural sphere and likewise. With this framework in mind, especially the educational system has to be addressed. It has been found that a lack of education about and attention to the natural environment creates distance. This prevents from thinking circularly and seeing where the waste flows are moving to and what effects these movements have. Thus, making it difficult to prioritize something like NBS, or to establish regulations based on environmental impact, and further explains the rather unfavorable public financial support system for NBS.

What are first steps that could be taken to catalyze the transition to a circular economy for water and nutrients in the EU?

A major barrier found is the externalization of costs. An innovative institutional approach could be that the externalized and socialized secondary costs of unsustainable technologies, agricultural practices, mobility infrastructures, and the construction sector are internalized. Fiscal and environmental taxes could be adapted to that, i.e. changing taxation of labor and resources. Thus, taxing primary raw materials more, while secondary raw materials and working hours should be taxed less. Only in this way secondary resources can be subject to multiple taxation, even in our "expensive" system before they are returned. In the same way, environmental costs generated by the (primary) resource production should be reflected in the product price. Furthermore, a reorganization of the customs tariffs as a regulating tool would have to be carried out, and this throughout Europe. Right now, decentralized NBS water and nutrient recovery systems can enhance the transition towards the afore mentioned taxation change, by showcasing the recovery and reintroduction of nutrients and water.

What can different stakeholders do to facilitate the transition?

At the macro level, with the aforementioned change in the tax system, the EU can issue rules for the member states, which would contribute significantly to a faster transition. The path taken with adjusting the water reuse regulation and establishing the wastewater directive, is already a good step into this direction. However, perhaps the pressure on the member states to implement the recommendations has to be increased. Furthermore, the area of education and funding opportunities has great potential to promote a broader dissemination of NBS. Up to now, there has been a lack of focus on environmental education by the EU and the EU countries, which in the future should be increased with the help of public funds instead of private initiatives. In addition, there should be adequate subsidies for NBS installations, even at household, as well as small scale farm level; on the one hand, to enable people to make the effort to gain NBS knowledge for implementing it, on the other hand, to open the possibility for hiring a properly skilled person to execute it. Furthermore, transparency and participation should be increased at state, city, and district level (meso). First, people have to be informed about the current sewage system and asked whether this is in their interest. Second, established companies must be transparent with their data to allow NBS technologies to even participate in the market. This should be clearly regulated by the proper authorities. Increased participation, increases responsibility and thus also the awareness of the scope of action, hence motivates people to engage. The engagement factor occurs again at the micro level, where it is important to keep working on dissemination of NBS for nutrient and water recovery as well as circularity.

Conclusion

Due to the European ambition to implement circular concepts within the framework of the CE, as well as to promote sustainable innovative solutions, NBS have also moved into the center as a feasible solution. In Academia, NBS technologies in the field of water and nutrient recovery have been widely explored in recent years. Much attention has been paid to the barriers to implementation and dissemination of NBS solutions, since the prove to be an interesting solution to tackle the issue of closing water and nutrient cycles. On the one hand, this research confirms a large number of barriers that led to the hypothesis, but on the hand also locates new barriers. Among the confirmed ones, the most important are institutional barriers such as missing or stringent regulations (including standards), financing and organizational structures, as well as the access to proper education on NBS. Further, the lack of financial incentives is amongst the most defined barriers on the institutional level. Lack of awareness as well as availability of examples fuels distrust, which is categorized as social barriers and are newly found.

The barriers found are mostly not compartmentalized, but interact with each other and are systemic by nature. What is interesting is that by determining the barriers, potentials can be identified as well. Therefore, based on the findings of this thesis, it can be deduced that generally more attention should be paid to NBS systems. This concerns especially the general knowledge dissemination around NBS for water and nutrient recovery, the financial (support) means for these technologies as well as less bureaucratic hurdles in the field of implementation. The multitude of co-benefits of NBS, such as ambient air cooling, increase of air quality or aesthetic appeal, support the potentials for application and implementation. Furthermore, it can be stated that decentralized wastewater treatment plants tend to have positive effects on the human-nature relationship, as well as increasing the sense of responsibility towards one's own waste. This is especially interesting for those countries that are directly and permanently affected by water stress. Lastly, through increased awareness and institutional support, these changes in wastewater treatment can lead to a more sustainable long-term change of the linear input-output patterns. In this context, the EU's CE concepts can definitely support useful frameworks for a transition to a more socially and ecologically sustainable society.

At this point, I would like to remark that this research does not represent universal validity, but serves as another element in the study of NBS for water and nutrient recovery.

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Appendix

(A) Personal (for framing purposes)

- Would you please briefly introduce yourself and tell me how you are involved in GROW GREEN?
- How long are you already in your position for?
- What exactly is your field of expertise/work within the project?
- Could you tell me at which state the project is at right now?

(B) Motivational

- What are your main motivations for using Nature based solutions as a technology?

  → Could you elaborate on the short- and long-term objectives of it?

- What are the KPI's to evaluate/measure the process?

(C) Technical Background

- Could you explain shortly the NBS technology your project in Valencia, Benicalap, is using to treat the (waste)water?
- Which performance standards and codes must the technology(ies) comply with? **(water reuse regulations, hygiene, safety)** → Any relevant standards or codes for designing and constructing it?
- Which products are recovered and for which user groups?

(D) FinancialBackground

• Where do you see future (long-term & short-term) financial benefits? **(-> direct financial gains, direct revenue, public services, sustainability overall)**

→ How can the costs for NBS installations be covered? Please elaborate. **(private revenues, public fees/tariffs)**

→ How easy is it to gain financing for NBS compared to fully engineered systems?

- What are the procedures to obtain financing to support the design and installation of NBS systems?
- Which financial barriers/difficulties did you encounter for replication (so far)? How could the financing framework be improved?
- Which sources of public financing/or financing of public services (/financing) can NBS for wastewater treatment tap into?

(E) Structural/Social (macro)

- To what extent is the consideration/use of NBS influenced by relevant EU legislation?

    a. Water reuse directive
    b. Urban Wastewater Treatment Directive b. Water Framework Directive
    c. Floods Directive
    d. Habitats Directive
    e. Others?

- How easy is it to acquire the necessary land and planning/development permits, to install NBS systems? → Where do you see the difference to engineered systems in this context?
- Are treatment systems subject to an institutional licensing or permitting regime/instance/System? If so, could you elaborate on obtaining any permit(s) in order to operate?
- What are the legally defined water quality standards (f.i. wastewater)? If so, do NBS make it easier or more difficult to meet these standards?
- Did you come across any particular institutional barriers of implementing NBS technologies?
- Are there legally defined reporting requirements (f.i. water quality, emissions, technical performance) for your treatment systems? → Where does NBS make it easier or more difficult to comply to these requirements?
- Can you identify the Trade-Offs of using NBS in your particular case? **(Rebounds such as higher production -> energy use, social conflicts -> landregimes etc.)**

(F) Structural/Social (meso)

- Which social and institutional barriers exist that prevent the wider adoption of NBS?
- Which stakeholders have been involved in the development and progress of the NBS scheme? Please elaborate on their involvement.
- Of all the governance factors discussed so far, which do you feel are the most important for the future development of NBS in your country?
- Which of the factors concerning governance require the most improvement? → Are there any other important factors that we've missed out?

(G) Structural/Social(micro)

- Are the customers/ direct users of the recovered products **(local inhabitants connected to the treatment system, farmers etc**.) aware of the use of NBS? → If so, how did they become aware?
- How are the reactions generally?
- What benefits or concerns in connection to use of NBS have been raised? → Can you attribute benefits and concerns to stakeholder groups? → Are there any conflicts or trade-offs? → Have you experienced any conflicts or trade-offs in terms of stakeholder group's responsibilities? **(perception of the Co-Benefits)**
- Where do you see future (long-term) social and ecological benefits? Please elaborate.

  → To which stakeholders are they communicated, how and why?