D5.2 Assessment of NextGen value chains

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

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6	26/10/2021	Strane, Semilla IPStar, Biopolus, Aquaminerals, Cranfield University	Charles-Xavier Sockeel and Alexandra Jaunet (Strane) For CS3 and CS5: Olaf van der Kolk and Pelle Snoeij (Aquaminerals), For CS6, Erzsebet Poor-Pocsi (Biopolus), Marine Poncet (Cranfield University) For CS2 and 7, Clara Plata Rios (IPSTAR).

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Summary

NextGen aims to boost sustainability and bring new market dynamics throughout the water cycle at the 10 demo cases and beyond. WP5 focuses on exploitation activities to bring NextGen innovative solutions to the market by identifying new business models to promote the implementation of those solutions.

The objectives of the deliverable are:

1. Provide a holistic point of view of selected circular value chains of NextGen project.
2. Highlight the good practices and foster mutual learning among demo cases.
3. Identify success and failure factors of the value chain implementation thanks to partners experience.
4. Facilitate the replication activities with lessons learned in NextGen demo cases.
5. Propose recommendations for policymakers and circular project leaders to solve challenges and difficulties hindering circular value chain implementation and development.

This report presents 23 circular value chains from the 10 NextGen demo cases, according to duplications, progress of the implementation and data available. The scope of the deliverable is to explore value chains, stakeholders' ecosystems, drivers and barriers, and overall benefits..

AquaMinerals proposed a list of critical factors to implement value chains based on 92 circular projects in the water sector. Main success factors are the maturity of the process, the readiness of the market and the product, the involvement of a third party with circular experience, the financial engagement and the size of the most important partner. All factors are presented for demonstrators and facilitators in section 3 to assess the potential of the value chains to be successfully implemented.

Some value chains are closely related and are studied as a whole (La Trappe and Athens cases), while other value chains have been separately studied in detail (Braunschweig, Altenrhein, Filton Airfield, Westland). Other case studies have limited information which led to make qualitative description of their value chains (Costa Brava, Spernal, Timisoara). The social values related to circular projects have been studied in detail with Gotland and La Trappe case (based on the outputs of WP4).

Based on critical factors of value chain implementation, the potential of replication, main drivers and barriers identified in the demo case analyses are listed and discussed in section 7:

- Regulations have proven to be both potential drivers and barriers.
- The business case is a key factor in stakeholders' willingness to invest in circular solutions, but it is still full of uncertainties.
- The integration of local stakeholders is the key to raise awareness and identify motivated local partners.
- Overall, a favourable context supports the deployment of circular value chains
- The high investment costs are a difficulty that still needs to be addressed

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- The technology readiness level is still uncertain in some demo cases
- The amounts of resources managed matters to achieve circularity

Thanks to these lessons learned, this report proposes recommendations for policymakers (EU and national authorities) and stakeholders leading circular projects (demonstrators, technology providers and researchers). These recommendations consider the governance of water resource (e.g. measuring of the drinking water used in non-potable water application) or materials (e.g. mitigate fossil resource consumption on the territory), regulations that could foster circular value chain creation (e.g. homogenised legislations in Europe), the companies commitment (e.g. raise awareness about efforts related to value chains with circular resources which are more difficult than traditional resources), the need of subsidies (to support the transition), or the stakeholders involvement in projects (e.g. raise awareness and the importance of circular resources to face the lack of acceptance).

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Glossary

Acronym	Meaning
ADI	Intercommunity Development Association
AnMBR	Anaerobic Membrane Bioreactor
BDG	Business Development Group
CCB	Consorci Costa Brava
CE	Circular Economy
CH	Switzerland
CHP Plant	Combined Heat and Power
COD	Chemical Oxygen Demand
CoPs	Community of Practices
CS	Case Study
DE	Germany
EBPR	Enhanced Biological Phosphorus Removal
EoW	End-of-Waste
EU	European Union
EYDAP	Athens' Water Supply and Sewerage Company
FOG	Fat, Oil and Grease
GR	Greece
HACCP	Hazard Analysis and Critical Control Point
IEX	Ion Exchange
ISPA	Instrument for Structural Policies for Pre-Accession
LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
MBR	Membrane Bioreactor
MNR	Metabolic Network Reactor
MWTP	Municipal Water Treatment Plant
NA	Not Available
NF	Nanofiltration
NL	The Netherlands
OLR	Organic loading rate
PE	Population Equivalent
PLC	Product Life Cycle
PNRR	National Plan for recovery and resilience
PNSB	Purple Non-Sulphur Bacteria
RO	Reverse Osmosis
RO	Romania
ROI	Return of Investment
RWH	Rainwater Harvesting
SCDA	Station for Agriculture
SE	Sweden
SP	Spain
SSW	Surface Water System

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SW	Switzerland
TBD	To Be Defined
TLN	Transport & Logistics Netherlands
TRL	Technology Readiness Level
TSS	Total Suspended Solids
UF	Ultrafiltration
UK	United Kingdom
USAMV	University of Agronomic Sciences and Veterinary Medicine
UV	Ultraviolet
VC	Value Chain
VSM	Value Stream Model
WES	Water Saving Efficiency
WWTP	Wastewater Treatment Plant

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1. Introduction

NextGen promotes transformational circular economy solutions and systems around resource use in the water. WP5 focuses on exploitation activities to bring NextGen innovative solutions to the market. Business models in the framework of the NextGen project have been assessed in D5.1. This report brings complementary data on cases studies allowing a better understanding of solutions and their added value on the market. Value chains have been assessed and studied to collect good practices and propose recommendations. The deliverable includes all 10 demo cases, and the analysis is supported by all field data available at the time. As such, it will be a corner stone for WP5 until the end of the project to foster case studies replication and bring out potential spinoffs.

The study is also supported by previous deliverables from the NextGen project:

- as mentioned above, D5.1 “New business models and services related to CE” serves as the foundation for this deliverable,
- technical data have been aggregated from D1.1 “Assessment of baseline conditions for all case studies” and D1.2 “Operational demo cases”,
- and social framework was provided by D4.2 “Final report on societal acceptability”.

In the future, D5.2 is expected to contribute to D2.1 “Environmental Life Cycle Assessment and risk analysis of NextGen CS solutions” and D2.2 “Economic assessment and cost efficiency analysis of NextGen CS solutions” by giving an overview of the supply chains in NextGen projects.

Data collection was limited until September 2021 (M40), as it fits the objectives of the deliverable: giving an overview of all value chains existing within NextGen and providing pointers for further deployment and potential replication. All technical, economic, and environmental data will be further studied by WP2, and social aspects in WP4.

This deliverable aims to facilitate to the replication activities and to give a holistic point of view of circular systems based on NextGen case studies.

For case studies, it is an opportunity to get a clear picture of the status of their value chains and to highlight the good practices they should apply on a daily basis. It will foster their understanding of their own value chains, and mutual learning among case studies. It should be noted that, as case studies are still developing their solutions and processes, the value chains are uneven in terms of maturity.

Built on feedbacks and partners experience, the deliverable proposes recommendations for both policymakers as well as demonstrators, researchers and technology providers, to solve challenges and difficulties hindering circular value chain implementation and development.

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The deliverable is structured as follow:

- A Literature Review to better understand the specificities of sustainable value chains in the water sector.
- A section about critical factors to implement circular value chains based on AquaMinerals experience.
- A Methodological section explaining how data was collected.
- Case Studies Analysis: All 10 CS have been studied and the results are displayed in this section.
- A section on social value assessment based on WP4 outputs, focusing on Gotland and La Trappe, to identify incentives to go beyond economic value chain and consider the overall stakeholders ecosystem.
- The success factors for the value chain implementation of AquaMinerals applied to the cases studied and main lessons learned to deploy circular value chains.
- And finally, recommendations for policymakers and circular project stakeholders identified during the study.

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2. Value Chains – Literature Review

This section aims to introduce findings from previous research works about value chains. It will allow to better scope the deliverable and understand the specificities of sustainable value chains in the water sector. As such, it will be a founding work for the case studies value chains assessment that are the heart of this deliverable.

2.1. Definitions

2.1.1. Value Chains in Circular Economy

2.1.1.1. Circular Economy

To start the literature review, it is necessary to recall the principles of circular economy. As described already in previous deliverables within the NextGen project, especially in the work on "New Business Models and Services for the Water Sector" (Clara Plata Rios, 2020), circular economy principles rests on the assumption that to tackle consequences of resource scarcity, it is necessary to promote reuse and waste reduction. Contrary to the traditional linear economy where economic growth implies a destruction of resources and materials, a circular economy aims to optimise resources consumption by closing "resource loops" (Vanner et all., 2014) in all economic activities.

> *"A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Source: Kirchherr et al. in Werning et all., 2017)*

Figure 1 describes some of the numerous circular economy loops available from the raw material extraction to the end-of-chain waste landfilling and disposal.

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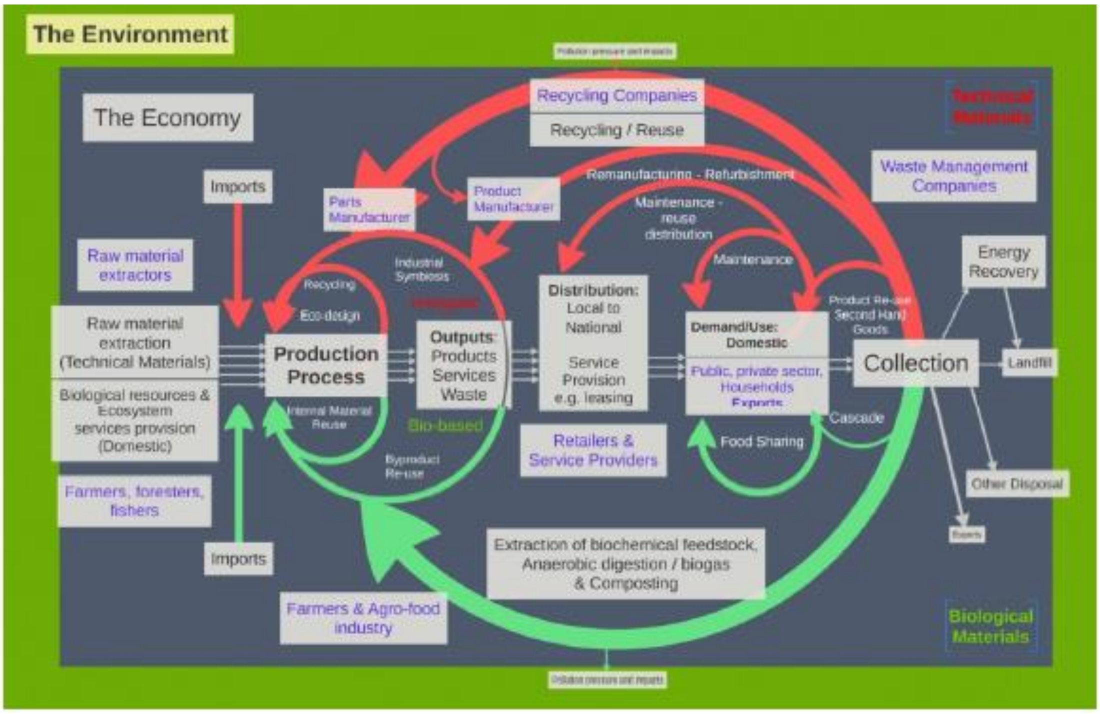

Figure 1 – Simplified illustration of circular economy (Source: Vanner 2014)

Several circular economy "loops" can be identified throughout the circular economy process: the **circular economy loops for technical nutrients** including reuse of goods, product refurbishment or component remanufacturing, cascading of components and materials, material recycling; the **circular economy loops for biological nutrients** with cascading of components and materials as well, extraction of biochemicals, anaerobic digestion and composting; and finally, the **energy recovery and landfilling loop** at the last stage of the circular economy chain. Potential benefits from the transition to a circular economy are presents throughout those loops in terms either of new value created and then creation of a new business model, or in terms of cost savings to avoid new resource spending or waste production.

The Ellen MacArthur Foundation[1] has identified four building blocks that will help fostering a more circular economy: promoting circular product design and production; developing new business models; developing reverse logistics and treatment methods to preserve materials; and promoting a favourable political, economic, and social framework. In this deliverable, all value chains analysis will be generated following those principles. From design and production, to consumption, and finally, to recycling and recovery, case studies value chains will be assessed with regard to this framework.

2.1.1.2. Circular Value Chains

Value Chains have been first introduced by Michael Porter in 1985 (Kaplinsky, Morris, 2000), it describes a chain of activities that a firm operating in a specific industry performs in order to deliver a valuable product or service for the market.

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[1] Ellen MacArthur Foundation, Towards the Circular Economy – Economic and business rationales for accelerate transition, (Sun, McKinsey & Co.), 2012

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"The value chain describes the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use." (Source: Kaplinsky, Morris, 2000)

Value chain analysis allows to better understand the activities conducted throughout the production process and identify potential gains of competitivity. The following figure describes a simple value chain following four steps: Design and product development, Production, Marketing, Consumption/Recycling.

The product/service is transformed after each of those four steps and carry the potential to create a new business model or save expenses. The simple value chain describes the links between four steps usually found in any production process, however, it does not consider the details of those steps. During the production phase for example, logistics, transformations, inputs, packaging etc. carry their own value chains and interactions.

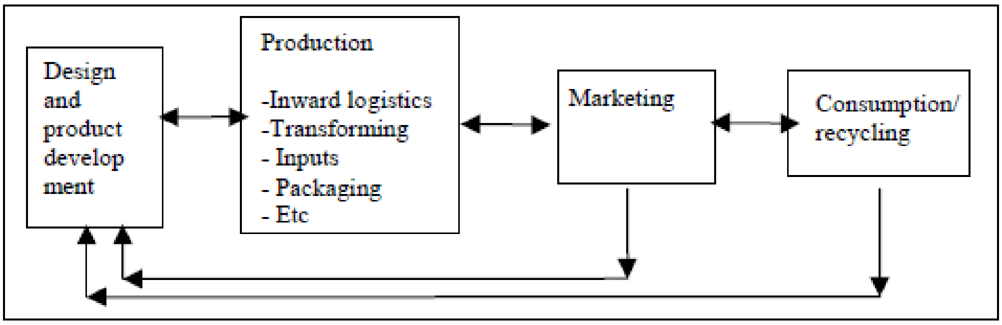

Figure 2 - A simple Value Chain (Source: Kaplinsky, Morris, 2000)

To have a comprehensive view of value chains in a circular economy, it is necessary to assess the different scales of circularity and consider all actors directly and indirectly involved in the chain. The extended Value chain is made with multiple value chains throughout the production process, of all kinds, economic, social, and environmental. Thinking circularity in terms of value chains means identify circularity loops as gains of competitivity.

It should be noted that value chain analysis is usually assimilated with the supply chain analysis under the premisses that the product/good/service from one step of the production process supplies the following one, and value is added at every one of those steps. As circular economy aims to transform products in such a way that there are workable relationships between ecological systems and economic growth (Genovese et all., 2014), the analysis of the supply chain identifies where in the production process, materials' flow could be minimized, or unintended negative consequences of production and consumption processes could be reduced. Two loops have been identified to achieve those aims: the **open-loop supply chains** involve materials recovered by parties other than the original producers who can reuse these materials or products; and the **closed-loop supply** chains deal with the practice of taking back products from customers and returning them to the original manufacturer for the recovery of added value by reusing the whole productor part of it. It highlights the necessity to consider a complex governance system where actors must actively search for solution to capture value from what was considered waste.

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> *"The supply chain considers the product from initial processing of raw materials to delivery to the customer. However, sustainability also must integrate issues and flows that extend beyond the core of supply chain management: product design, manufacturing by-products, by-products produced during product use, product life extension, product end-of-life, and recovery processes at end-of-life." (Source: Linton et all., 2007)*

Extending the supply chain to integrate circularity issues increases its level of complexity and can turn then into an increase of costs, at least in the short term (Linton et all., 2007). Potential strategic and operational issues might rise and act as barriers for stakeholders.

> *"Extending the supply chain to include issues such as remanufacturing, recycling and refurbishing adds an additional level of complexity to existing supply chain design in addition to a new set of potential strategic and operational issues, which in turn can increase costs, at least in the short term. Two basic problems give rise to these issues: (a) the uncertainty associated with the recovery process with regards to quality, quantity, and timing of returned products, containers, pallets and packaging and (b) the collection and transportation of these products, containers, pallets and packaging. Increased costs can reflect the transfer of external costs from society to supply chain partners."*

To integrate circularity within value chain management, it is then necessary to consider the global supply chain from the industrial-level perspective: increased complexity within the value chain is associated with increased levels of value-added activities (Gereffi et al. 2005 in Acquaye et al. 2017) and the coordination of all those activities is needed in a global perspective. The following figure describes the different level of value chains that can be relevant for value chain analysis: circularity usually involve inter-firm cooperation, as such, it seems relevant to assess value chains at a more comprehensive level which would be industry-level.

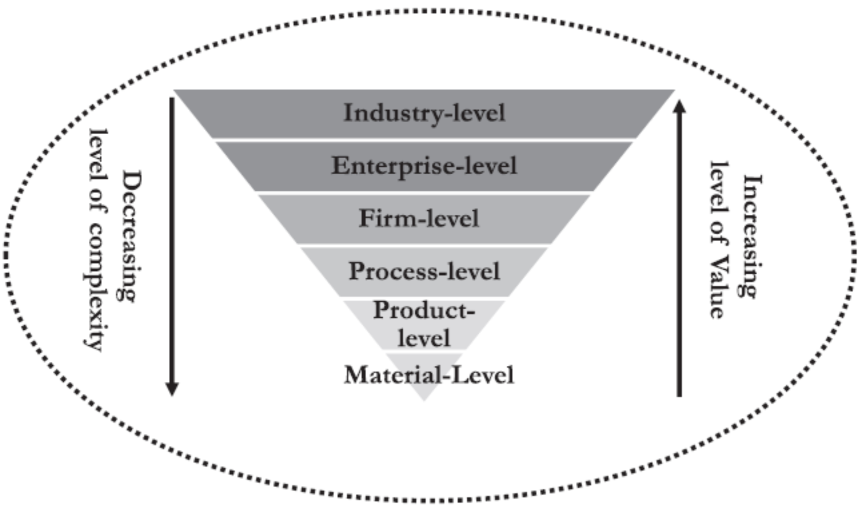

Figure 3: A hierarchal perspective of the value chain and complexity of supply chain (Source: Acquaye et all., 2017)

However, a firm level assessment is still needed to identify where in the production process could there be potential gains of value. Werning and Spinler (Werning et all., 2019) considers

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two different value chains at the firm level through the Value Stream Model (VSM): products and consumables.
The VSM is a tool based on system dynamics: changing conditions within the system are reflected by the interaction of different stocks and flows based on stock level. It is useful to map product flows and barriers to the transition towards circular business models.

2.1.1.1. Circular Business models

Value Chains analysis and Business models are intricately linked. Developing new business models is a necessity to promote circular economy, as an incentive for the water sector. Circular business models have been intensively discussed in previous deliverable 5.1 as "business models that are cycling, extending, intensifying, and/or dematerialising material and energy loops to reduce the resource inputs into and the waste and emission leakage out of an organisational system" (D5.1, Clara Plata Rios, 2020). Several tools with diverse scopes and complexity are already available but lack of a comprehensive point of view. Indeed, none of those tools can assess the different scales of circularity. However, it stays relevant to assess the level of technical circularity (nano and meso/macro) regarding water reached by case studies.

Value chains analysis complements business models analysis as it allows to identify where value is created in the production activities. Here value represents both the potential creation of new commercial value, hence the development of a new business model, and the potential avoided costs and expenses in the production process. As such, it allows to assess how can a company lower its costs while reusing materials and energy or benefits from findings new output for their waste.

> *"In practice, a CE can be promoted and supported by the creation of new and innovative business models (Bakker et al., 2014; Bocken et al., 2016b; Lewandowski, 2016; Stahel, 2010) which embed CE principles into their value propositions throughout the value chains (from now on called CE business models)." (Source: Manninen & all., 2017)*

NextGen Deliverable D5.1 offers a set of tools (business model canvas and indicator) adapted further development for case studies and explored existing options of circular business model dedicated to water reuse. As several tools are available, depending on different definitions of sustainability, it is necessary to complete this first study with value chains analysis. It will allow to deepen knowledge of case studies and better understand potential drivers and incentives that support the development of innovative solutions for water reuse. The tool developed and tested in La Trappe demo case has been effective to gather information on the circularity of a site at different levels and identify opportunities to improve it. Value chains analysis will bring more information forward and complete the previous study.

2.1.2. Value Chain in the water sector

2.1.2.1. Challenges for sustainability in the water sector

The water sector is a key industry to achieve sustainability at a global level. According to the 2020 The UN World Water Development Report:

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"Water and wastewater utilities are reportedly responsible for between 3 and 7% of GHG emissions (Trommsdorf, 2015), but these estimates do not include emissions associated with discharging untreated sewage. Indeed, untreated wastewater is an important source of GHGs. Given that, in developing countries, 80–90% of the wastewater is neither collected nor treated (Corcoran et al., 2010; WWAP, 2017), the emissions related to the water supply and sanitation sector – and its potential to contribute significantly to climate change mitigation – should not be neglected."

As such, significant progress needs to be made to lower the CO_2 consumption in the water sector. However as public institutions are usually involved at a deep level in this critical sector, it complexifies the value chain assessment. Public institutions are indeed usually interested in the service performance and quality rather than driven by profit and gain of competitivity. It results in a funding gap for sustainable investment as public stakeholders depends on tax revenue and not on profit from production sites. The water service is in many cases delegated to private operators; however, the funding gap still exists as public services aim to reduce the cost for citizens.

""Water sector" is a general term that incorporates all water related institutions, infrastructure and management strategies. Contrary to the term water sector, the term water industry is normally used to describe all institutions that are in charge of drinking water supply and wastewater treatment services. For the majority of states, the public domain, predominantly municipalities are legally responsible for the reliable delivery of clean drinking water and sewage disposal. Yet, any local authorities delegate the operational business to other public or private entities. […] Many countries still fail to foster sustainability in the water sector because of investments gaps and missing operation capability, both by local contract partners and in the public domain (e.g. Rodriguez et al. 2021, p.7). […] the water industry covers all companies that participate in the water market with regard to the creation of an overall sustainable water sector." (Source: Kalinowski-Gausepohl et all., 2016)

To close the investment gap, financial incentives for the private sector to become more sustainable are identified as a potential solution. Circular economy aims to transform waste in resources. Savings or profits from new value could play the role of incentives for the private water sector. To capturing value where it did not exist before requires considering every possible circular loop.

The water sector is a sensitive issue in terms of governance as well because water consumption is a vital need. As such, it is critical to consider the public receptivity as well to water products from circular economy (Smith & Shannon, 2020). All those elements will be assessed in detail by WP4 within the NextGen project. However, it seems important to consider them to identify potential barriers or drivers within value chains that could facilitate their implementation throughout the project.

"Public receptivity (or resistance) towards circular systems, and/or the products of those systems (such as recycled water, recovered nutrients, and other recovered materials) is seen as a key challenge to the overall feasibility of circular schemes." (source: Smith & Shannon, 2020)

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Identifying where within existing value chains sustainability could be improved is then necessary to ensure the transition with as little resistance as possible.

2.1.2.2. Components of the water sector studied in NextGen

The water sector identified three focus point to achieve transition to the circular economy and promote new circular value chains. The most replicable, scalable and/or appealing good practices from 10-years experiments are summarized in this section (Plata Rios, 2020).

- Water.

Water itself is an important resource that is increasingly scarce in Europe and at a global scale. Furthermore, water treatment costs (financial and environmental) are increasing as well and put pressure on private individuals, industries, public structure, and nature. Water treatment is usually a responsibility carried by (local) governments, even when delegated to a private operator.

- Energy.

Water is an important carrier of energy and can make an important contribution in the energy-transition, promoting synergies between industries. The value chain analysis is less applicable for this component contrary to energy balance assessment which should be performed in other deliverables for some case studies

- Materials and nutrients

Water treatment processes leads to residuals from chemicals and energy. Such wastes are reusable in sourcing or in disposal but can also be treated and reused within the treatment process itself, hopefully lowering the operational costs.

The water sector carries a lot of potential to achieve sustainability and solutions are already in motion to change the industry. To promote those solutions and ensure their viability, it is necessary to consider all the benefits attached to develop circular value chains. Such assessment will allow to analyse what could play the role of initiatives for sustainability.

2.1.2.3. Water sector value chain models

Various models have been developed and researched to map value chains in the water sector. This section aims to provide an overview of existing value chains models that could be of use in the analysis.

Mapping of the water service system at different stages

The water service system is composed of several following stages and steps from water resource withdrawal to discharge of treated wastewater into the natural environment. Water follows three main steps during this process: water supply, water use and water treatment (Mita, Deltares, Ivl, Dhi, 2012).

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Water supply aggregates all operations necessary from resource withdrawal to water distribution (industries, households, buildings etc.): water retention, methane extraction and reuse of calcite from softening plants could be interesting solutions during this stage. It should be noted that water supply can have different origins (surface water or groundwater) and industrials are often supplied with their own wells instead of water from public distribution system.

Water use stage is self-explanatory: value chains will depend on which stakeholders are using water and what are the facilities available, namely Non-Domestic water users and Domestic Water Users (Dimova et all., 2012).

Water treatment stage gather all solutions from collection of wastewaters to disposal: struvite, cellulose, biogas can be extracted and reused at this stage.

Considering a loop that could be set at each step, a simplified and linear water value chain is described in Figure 4 based on previous descriptions.

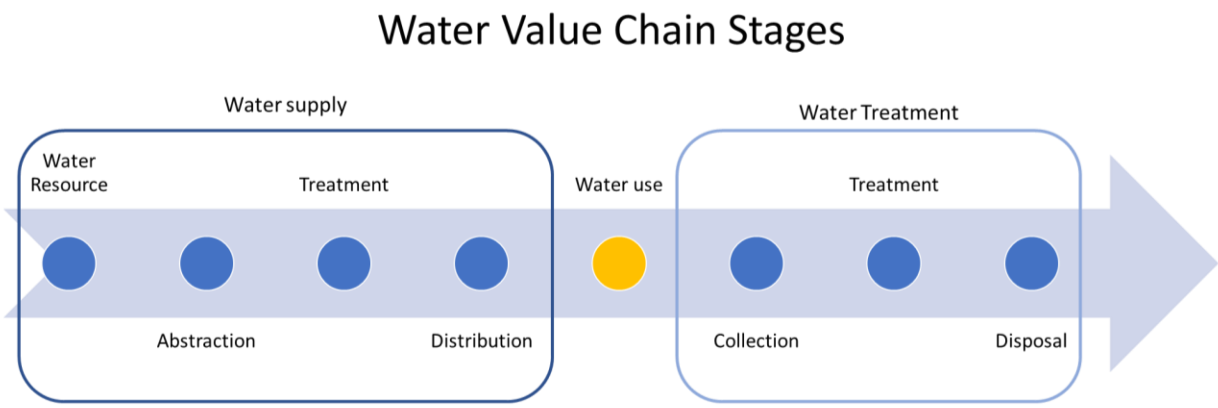

Figure 4: Water Value Chain Stages

Describing value chains depending on the water system stage allows to understand the interactions between among stakeholders and the overall reaction of the water system to adding more circularity.

Value Chain Mapping from actor's perspective

Historically in industry, two types of value chain can be identified (Gereffi in Kaplinsky, 2000) by type of actors:

- Buyer-driven chains characteristic of labour-intensive industries, where buyers play a critical governing role.
- Producer-driven chain, where producers take responsibility for assisting the efficiency of both their suppliers and their customers, playing the role of coordinator.

In the water sector, producers usually play the role of coordinator and manage both their suppliers and their customers.

> *"Systemic integration involves closer cooperation between links in the chain, and this often involves enhanced responsibilities for governors, as well as the growth of*

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greater levels of trust between different links in the chain." (Source: Kaplinsky, 2000)

As circular economy aims to transform globally value chains within industries, greater level of cooperation is needed to cooperate between different links in the chain and find sustainable solutions that profit producers, suppliers, and consumers at the same time.

Conclusion

At the time, circularity is not considered properly in value chains models for the water sector. However, those references will serve as basis to understand the elements necessary for value chain assessment.

Involving users and stakeholders of water management is necessary to ensure the transition toward circular value chains. It requires high level of engagement and motivation, as well as strong technical knowledge. Considering stakeholders' ecosystem is essential to better understand how and why circular solutions should be promoted. Local governments, industries, and civil society should be considered when assessing value chains to ensure the feasibility and sustainability of the water reuse system. It can bring forward new outlets and produce positive impacts.

2.1.3. Social values assessment

The principal challenges to achieving a circular economy are governances related to the social acceptance according to Smith and Fantinel (2017).

Studying social benefits of new circular value chains is then necessary to improve value chain assessment. It allows to identify stakeholders' motivations, and subsequently, potential **drivers and barriers** that could hinder or facilitate circular value chain implementation.

"This emphasis on social acceptability is important because it is frequently raised as a concern among stakeholders in the sector. Public receptivity (or resistance) towards circular systems, and/or the products of those systems (such as recycled water, recovered nutrients, and other recovered materials) is seen as a key challenge to the overall feasibility of circular schemes." (Smith H., Shannon C., 2019)

Social benefits cover (not exclusively):

- Improvement in life quality: improvement of the quality of the discharged water and the treatment system, positive impact on health
- Economic gain: tax cut, savings from waste recycling, development of tourism, lower water cost
- Employment opportunities: development of new skills and job creation around circular schemes.

The social capital concept is interesting to address as it allows to account for values generated or destroyed thanks to the creation of the new stakeholder ecosystem linked to circular value chains. Social capital designates all resources accumulated through the creation and operation of a stakeholders' network (Ogé, S., 2021): it accounts then relationship (trust, cooperation, reliability, honesty) and structural (interconnexions, density) variables. Evaluating social

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capital can provide information and motivations on the ecosystem. Identifying relevant indicators to evaluate **social benefits and values** created along value chains provides data on available resources. However, those social values are not easy to quantify.

One way to evaluate **social benefits and values** is to use the legitimacy lens (Harris-Lovett *et al.*, 2015; Binz *et al.*, 2016). Indeed, the legitimacy lens comes into play at the four value chain steps:

- design and product development (i.e., does the product answer a societal need?);
- production (i.e., will the production be safe?);
- consumption/recycling (i.e., will end users buy the product?).

Conceptually, legitimacy is defined as "a generalised perception or assumption that the actions of an entity (i.e., a circular economy initiatives) are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions" (Suchman, 1995, p. 574).
Legitimacy[2] has been conceptually described as three categories: moral, cognitive and pragmatic legitimacy (Suchman, 1995). Others define a fourth category, regulative legitimacy (Scott, 1995).

- The moral legitimacy refers to the active judgment that a circular solution fits social norms and values and enhances societal welfare (Scott, 1995; Suchman, 1995).
- The cognitive legitimacy refers to the passive assumption that a circular solution is comprehensible and taken-for-granted (Suchman, 1995).
- The pragmatic legitimacy relies on the benefits provided by a circular solution to its end users (Suchman, 1995; Harris-Lovett et al., 2015).
- The regulative legitimacy is the capacity to establish rules and assess a circular solution to them (Suchman, 1995; Binz et al., 2016).

To provide a picture of **social benefits and values**, we used the legitimacy lens to explore social perceptions towards two NextGen case studies (La Trappe and Gotland). We presented the results in section 6, including the **good practices** to adopt, the **benefits** provided by the case studies as well as the identified **drivers and barriers**.

[2] For an in-depth literature review on the legitimacy lens, please refer to D4.2 Part B.

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3. Critical factors to implement circular value chains

This section aims to present lessons learned from 2 matured value chains and success factors to implement value chains in circular economy for the water sector. These lessons learned are based on AquaMinerals experience in circular economy for the water sector.

AquaMinerals organisation and business model is presented in detail in the deliverable 5.1.

3.1. Value chains managed by AquaMinerals

In this chapter, examples are given of two value chains that AquaMinerals currently runs out of 92 circular projects. These are the value chains for iron(hydr)oxide and calcite. These two value chains are chosen because they are mature, represent significant volumes, are well-documented and give a good insight in how these residuals have taken a solid position in the 'real' economy.

3.1.1. Aquafer

Figure 5 shows an overview of the value chain of iron(hydr)oxide (trading name 'aquafer'). Aquafer is a residual from the drinking water production and is produced at 74 locations throughout the Netherlands and Belgium. Iron dissolves in groundwater in the reduced form of Fe(II), this is a natural process. Drinking water companies simply remove this Fe(II) by oxidizing this groundwater, the Fe(II) then converts to Fe(III) which is unsolvable and flocs out as iron(hydr)oxides. This forms a sludge that is stored in ponds or silos at the production sites.

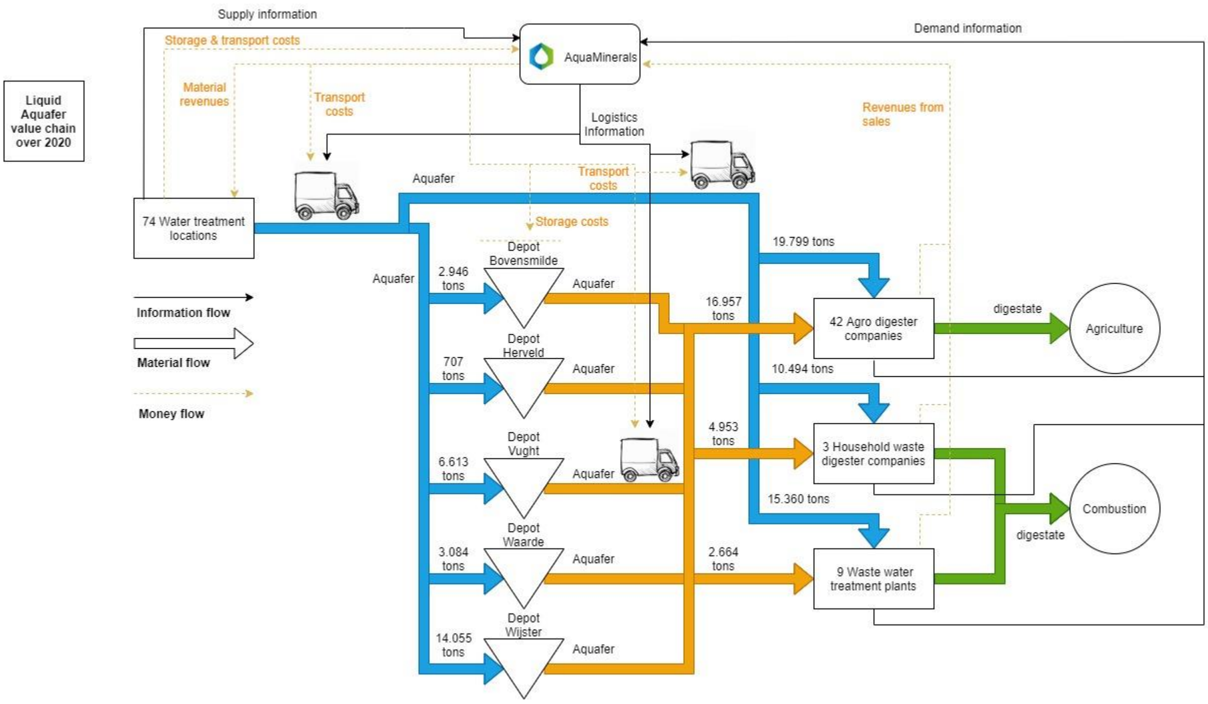

Figure 5 - Value Chain Aquafer

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This value chain shows two routes for the sludge from the drinking water companies: (1) directly to the end user (2) via a silo to the end user. There are 5 silos in the Netherlands, all exploited by external service providers and managed by AquaMinerals. The direct route is preferred because of the additional costs and environmental impact when transported via an external silo. Depots are used for (i) quality improvement for batches that do not meet the specifications of the customer and/or (ii) to balance differences in supply and demand.

3.1.1.1. History

To get an overview of the origination of this value chain, a brief overview of history will be given. Before AquaMinerals started the valorisation of aquafer, the aquafer was stored in flushing pounds. When these flushing pounds got full, new ones were excavated or the sludge from the full one was brought to a dumping ground.
AquaMinerals started valorizing the aquafer it first found a low-impact application as building material in for instance road constructions, sound barriers and 'un-deepen' old sand pits.

Nowadays the aquafer is mainly used for sulphur control in digesters. The iron(hydr)oxide is highly reactive and binds sulpher to FeS. This chemical binding is relatively strong and prevent the formation of the highly toxic and corrosive H_2S in the digester. The timing of the development of this market could not have been better: together with the raised ambition of the water sector to valorise its residuals, the digestion market boomed due to the transition to renewable energy sources.

In order to become a reliable supplier in this market, AquaMinerals connected its shareholders by agreeing on standardization of the quality. This means that the quality of all the production site is -within certain boundaries- more or less the same. This means that the water companies took measures to ensure they could meet the standards, for instance by installing silos instead of open ponds. For AquaMinerals this meant that they implemented a strict quality control scheme.

The water sector has become the market leader for S-control in digesters.

3.1.1.2. Description of stakeholders

This chapter gives an overview of the stakeholders involved in the aquafer value chain.

1. Water companies

Water companies in this value chain are all drinking water companies. In general, these companies have circular sustainable ambitions. This, combined with a financial motive, leads to motivated water companies that are highly involved in the development and maintaining this value chain. The financial motive consists of avoiding dumping costs and actually getting paid for the supply of aquafer.

2. Depots

In the depots, aquafer is temporarily stored. There are two major benefits for using the depots. Firstly, it makes it easier for AquaMinerals to link demand and supply. Secondly, the depots are able to increase the quality of the aquafer, by increasing the dry matter and

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decreasing the arsenic content. This removes the accountability for the quality from the water companies to the depots. A major disadvantage are the costs. Water companies pay for both the transport as the storage in the depot. When residuals are transported directly to the end user, water companies only pay once the transport costs. However, when residuals are transported through a depot, water companies pay transport costs to the depot, storage costs and the transport costs from the depot to an end user.

3. End users

End users in the Aquafer value chain can be divided into three groups: agricultural digesters, household waste digesters and wastewater treatment plants.
All these groups use the aquafer for the same purpose: the binding of sulfur in the biomass to prevent the formation of H_2S. The demand of aquafer has risen over the last couple of years because the government stimulates the demand of sustainable energy. Several subsidy schemes are available for the digesters, which leads to a higher production of biogas and subsequently the demand of aquafer. The digestate, which is the residual product of this agro digester process, is currently used in agriculture as fertilization. This is legally not possible with household waste digester and wastewater treatment plants. This digestate goes to incineration plants for further (safe) processing.

3.1.2. Calcite

Figure 6 shows an overview of the calcite value chain.

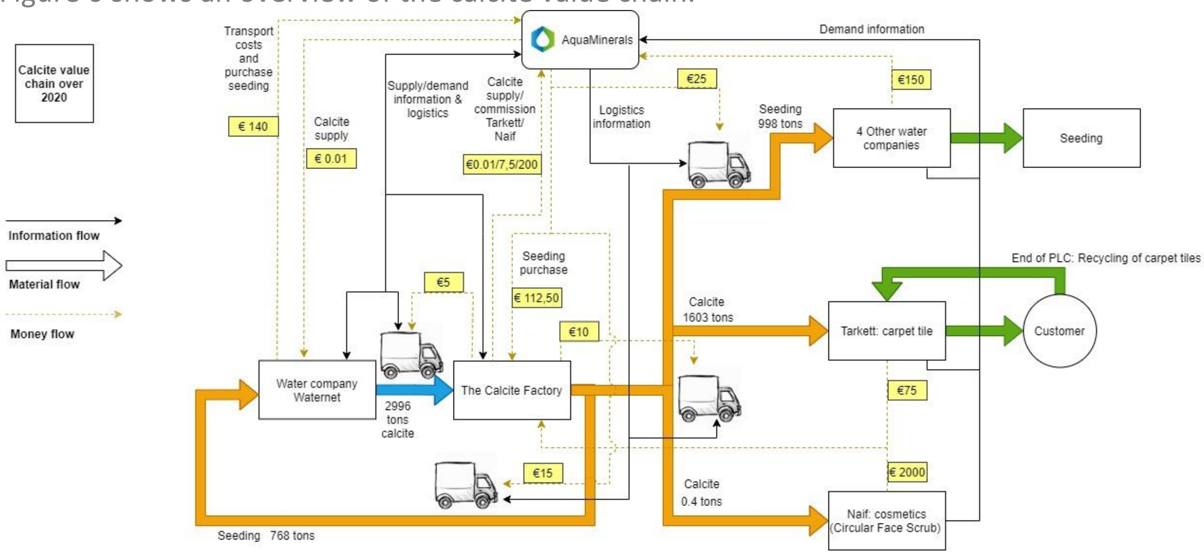

Figure 6: Calcite value chain

In this value chain, calcite that is extracted from the drinking water production process is transported to The Calcite Factory. In this factory, calcite is processed to calcite granules that can be used in various applications, such as seeding material in the original drinking water production process. This makes the whole value chain circular, as the calcite goes back into the production process. The other two applications are the usage in carpet tiles and the usage in a whole other industry: cosmetics, where it is used in a face scrub.

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3.1.2.1. History

Seeding material is needed for the softening of drinking water. This seeding material assures that calcite starts crystallizing on these small granules in the softening reactor. Before, garnet sand from Australia was used as seeding material in this process, which has a high carbon footprint due to the large transportation distances. The use of the sand also led to a two-component residual: are core of sand (the seeding material) with a layer of calcite. This 2-component residual is much harder to valorise than a 1 component residual (both core and shell made out of calcite).

Dutch drinking water companies established, together with AquaMinerals and the British Advanced Minerals, the Calcite Factory, where calcite granules can be transformed into seeding material for the same water companies. In this plant the calcite pellets are dried, sterilized, crushed, and sieved, all on specification of the customers. At this moment (medio 2021) this value chain is at the end of its pilot phase, that has started in 2017.

3.1.2.2. Description of stakeholders

This chapter gives an overview of the stakeholders involved in the calcite value chain.

1. Water companies

Currently, one water company is involved in the delivery of calcite granules to The Calcite Factory, and four others are involved in the purchase of seeding materials. Water companies are relatively high involved in the value chain. The interest is high for the water companies, which leads to motivated water companies and a high quality of calcite granules for The Calcite Factory.

2. AquaMinerals

In this value chain, AquaMinerals takes the roles of chain management and trader. AquaMinerals is the only actor that can take this role, as AquaMinerals is legally the only actor allowed to offer residuals to water companies, without a public tender needed. Furthermore, AquaMinerals can offer guarantees about supply and revenues, because of the governance of AquaMinerals.

3. The Calcite Factory

The Calcite factory plays an essential role in the supply chain, namely the processing of the calcite pellets into fit products for the end users. The Calcite factory is owned by the UK-based company Advanced Minerals. Advanced Minerals is a SME and operates a calcite pellet processing plant near Sheffield. Starting the plant in Amsterdam is part of a bigger concept that is the valorisation of calcite pellets through Europe. The technology developed in the '90 in the UK is (strongly) improved in Amsterdam and can be relatively easy copied at other locations. Advanced Minerals is a commercial company and sees a solid business model for the processing of calcite.

4. Carpet industry

In the carpet industry, the processed calcite is used in the 'backing' of the carpet tiles. This part of the value chain is completely circular as well because the carpet companies dismantle

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and reuse the components of used carpet tiles. The reason the carpet industry is involved, is because of circular and sustainable ambitions. Furthermore, the processed calcite has a higher value-in-use than de fossil calcite. The reason for this is that the degree of filling is higher and therefore the use of the very expensive bitumen lower.

5. Cosmetics industry

A relatively small application of the calcite is in the cosmetics industry. This company uses the calcite from The Calcite Factory in a face scrub. This company is involved, completely by sustainable beliefs and ambitions. It even claims to have a completely circular face scrub, which is partly true, as the face scrub disappears in the shower drain after usage.

3.2. Critical success factors

For the NextGen-project, AquaMinerals has analysed the success and failure factors of its 92 business development projects like presented in the previous section over the last 10 years. Knowing these critical factors will help increasing the success rate of new projects for case studies.

3.2.1. Background

One of the core businesses of AquaMinerals is the development of new value chains, which are executed with business development projects, each year the project list is discussed with its participants (water companies) and eventually approved. A business development project is a project in which the end goal is a fully developed value chain with active cash- and material streams. There are currently 23 active value chains.

The projects are well described, in goals, activities as well as results. Each project has a unique set of variables, like participants, grants, TRL-level etcetera. Analysing these data will give insight in critical success factors. AquaMinerals has a database over the last 25 years, but the quality of the generated data is best for the projects over the last 10 years.

The goal of this part of the research is to explore the different success- and failure factors of business development projects.

3.2.2. Methods

The research is divided into two segments. The first (1) segment consists of determining the success rate of the business development projects over the past ten years and exploring different variables in these projects. Calculating the success rate was done by determining which projects are relevant and what classifies as a successful project. A successful project is a business development project that results in a fully developed value chain with active cash and material flows. Thereafter the different project variables were determined. The next step was to determine each variable for all projects. The success rate got calculated by dividing the number of successful projects by the total number of projects.

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The second (2) segment consists of an analysis of the causes of project failure. This was done by analysing all 36 projects that were rated not successful. The first part of the analysis consisted of determining different reasons for project failure by interviewing stakeholders of the business development process. These interviews resulted in eleven unique causes. The failed projects got judged by the AquaMinerals employee accountable for the project. They divided ten points per project over all the causes. The cause that had the highest impact got the most points. The way the points were spread over the projects did not matter, as long as the total amount of points per project added up to ten. This data was then used to calculate the impact of each cause, which was done by adding up the points per cause and dividing the total number of points by the previous number. The total number of points was 360 (36x10).

3.2.3. Results and conclusion

3.2.3.1. Success factors

There were 92 business development projects in the period of 2012 to 2021. Of these 92 projects, 56 have been rated successful which equals to a success percentage of 61%. The Table 1 contains the options of each variable with the highest success percentage. The column on the left holds the eleven different variables on which each project was rated.

Two variables that require an explanation are the Ansoff segment and TRL-Level. The Ansoff segments are four market segments based on the type of market and product. Materials in the first segment are existing products that cater to existing markets (market penetration). The second segment is new products that are designed for an existing market (product development). The next segment is existing products for new markets (market development). The final segment is new products that cater for a new market (diversification). Materials are considered new if the material is modified somewhere in the value chain.

The second variable is the TRL. TRL stands for the Technology Readiness Level of a project. The level of a project depends on market and technology readiness. Normally, TRL-levels are ranked from 0 (idea) to 9 (full commercial application). For analytical reasons, the options here were reduced to three: Exploration, Pilot and Full scale. Exploration is the lowest on the scale and projects in this category require a lot of research and time. Pilot is the category in the middle level, in this category there are usually prototypes of the project available. Full scale is the highest on the scale and this is when the project is almost ready for widespread use.

The number of projects stands for the number that had that option for the variable in that row. If the number of projects for a certain option was below ten, they were deemed too low and were excluded from this table. When the number of projects is between 10 and 17 the cell is coloured orange, between 18 and 25 is coloured yellow and 25 or higher is coloured green.

The cells in the column success percentage represent the percentage of projects which validate the option among the projects that have the variable available ("number of projects"). These cells are coloured yellow if the success percentage is below 70 and green for 70 and up.

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Table 1- Success rate per variable

Variable	Option	Number of projects	Success percentage
What is the technologcal readiness factor with the highest succes rate?	Full scale	28	86%
What Ansoff market segment had the highest succes rate?	Market penetration	11	82%
Is more than 95% performed by a third party?	Yes	23	74%
How many employees had the most important stakeholder in the project?	Medium (50-250)	18	72%
What type of party was the primary investor?	Third Party	20	70%
Who initiated the project?	Market Party	23	70%
Is the project subsidized	No	78	63%
Was a participant involved?	Yes	27	67%
Was the enduser involvend in the project?	Yes	58	62%
What type of participant was involved in the project?	Drinking water company	69	64%
Was the project budgeted	No	28	61%

The success percentage of projects with the full scale TRL differentiates the most from the average success percentage with 86%. A potential cause of this is the fact that that projects with a lower TRL usually know more hurdles and take longer which leaves more room for errors and opportunities for discontinuation. Selecting projects based on a high TRL gives certainty on the success capabilities of the material. However, only selecting projects with a high TRL goes at the expense of innovation because projects with a high TRL are usually already developed technologies.

The variable Ansoff segment also differentiates a lot from the average success percentage with 82%. Sidenote for this number is that it is based on 11 projects which means the success percentage could increase/decrease significantly when new cases are added. The reason for these projects being successful is that market penetration projects usually require a predictable methodology because they cater an old market with an old product.

3.2.3.2. Failure factors

The figure below contains a diagram with the impact of each reason on the discontinuation of business development projects. Each bar stands for a reason for the discontinuation of a business development project. An explanation of each reason is given underneath the graph by the corresponding colour of each bar.

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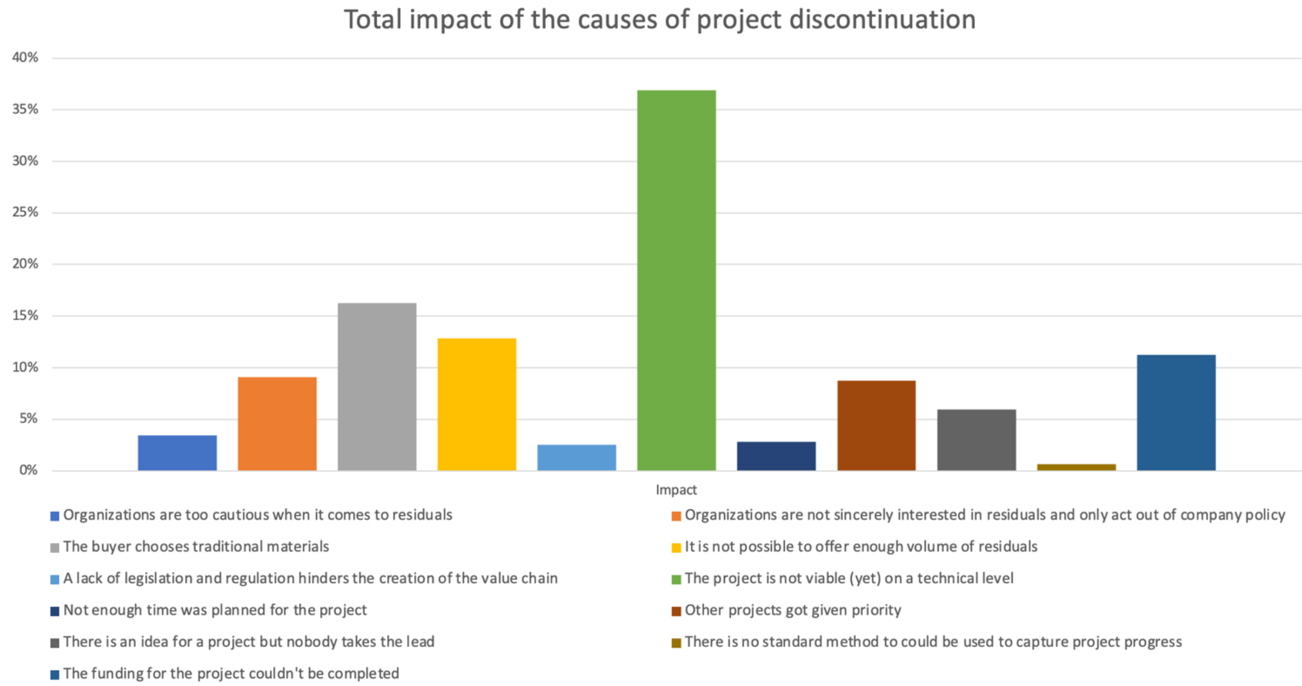

Figure 7: Reasons why projects stopped / failed

The most prevalent reason for a business development project to be discontinued is that the project is not technically viable yet. The second most prevalent reason is that buyers tend to go for traditional materials instead of residuals. Apparently, the project itself makes them realize that the use of residuals comes with more efforts and challenges. The third most prevalent reason is that it is not possible to offer the required volume of residuals. This is caused by the fact that some residuals only get released in small volumes in the water purification process.

3.2.4. Conclusion

The project database has proven to be a valuable asset to determine critical success factors. These factors can help future business development projects to become more successful. For instance, to prioritize projects and choosing the ones that statistically more successful than others. Also, business development proposals can be adjusted adding or eliminating factors that improve the success rate. Projects that contain the following criteria have an increased chance of success:

- The TRL level is full scale (the technology is ready for the market).
- Market penetration, so an existing product in an existing market.
- The execution of the project is done by a third party.
- The project is mainly financed by third parties.
- The most important partner has 50-250 employees.

And to a lesser extend:

- The project is not subsidized.
- The water company is involved.
- The project is initiated by a market party.
- The end-user is involved.

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In order to avoid a project to fail/stop, it is advised before starting of the project that:

- The technology is evaluated and considered to developed enough to start a business development project.
- The partners in the project are committed to bring in money, time and knowledge, and this is confirmed.
- There is enough supply of the residual to create a stable business case.
- The stakeholders realize that the use of residuals requires efforts and might mean some disadvantages compared fossil resources. This might avoid them choosing for the fossil alternative when confronted with setbacks in de business development process.

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4. Methodology

In the NextGen project, the goal of Value Chain analysis is to understand where value is created within the demo case, how stakeholders interact with each other to create this value, what are the drivers and barriers they face, and how NextGen solution address the challenges and needs of the market. This section describes the methodology used to make this deliverable. Data for Value Chain analysis was gathered from previous deliverable, especially D1.1 and D1.2, and confronted to case studies with interviews conducted throughout March and September 2021.

4.1. Scope of the study

4.1.1. Focus of case studies in NextGen

Using deliverable D1.2 "Operational Demo Cases" (2021), three types of case study can be identified throughout the NextGen project: Municipal WWTP, project and programs at a regional scale, and industrial WWTP.
Value chains assessment has already been carried out in some case studies outside of the NextGen project and can serve as reference for further analysis.

Table 2: Case studies within the NextGen project (Source: Strane, adapted from NextGen Deliverable 1.2)

Site	Focus of the case study	Relevant sectors	Circular Solutions for
1. Braunschweig (DE)	Municipal WWTP level	Water treatment, Agriculture, Energy	Materials, Energy
2. Costa Brava (SP)	Municipal WWTP level	Factory, Agriculture, Water treatment, Drinking water	Water, Materials
3. Westland (NL)	Regional scale project	Horticulture, Heavy Port Industry, Chemicals Industry, Drinking Water Companies	Water, Energy
4. Alternheim (CH)	Municipal WWTP level (regional scale project)	Water treatment, Horticulture, Energy	Materials
5. Spernal (UK)	Municipal WWTP level	Agriculture, Domestic sector, Energy Sector	Water, Materials, Energy
6. La Trappe (NL)	Industrial WWTP level	Beverage industry, Municipal sector, Space infustry	Water, Materials
7. Gotland (SE)	Regional management strategy	Tourist Industry, Municipal Sector, Water sector	Water
8. Athens (GR)	Municipal WWTP level	Water treatment, Horticulture, Energy	Water, Materials, Energy
9. Filton (UK)	Regional/city scale project	Urban Services, Land Developers, Commercial Sector	Water, Materials, Energy
10. Timisoara (RO)	Municipal WWTP level	Agriculture, Water treatment, Industry	Water, Materials, Energy

4.1.1.1. Municipal WWTP

Municipal wastewater treatment plant is usually operated either by private operators on behalf of (local) government or directly by (local) government. It represents more than half of case studies within the NextGen project.

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Product recovery from sludge have a strong potential for reuse and involve more or less stakeholders depending on the structure of the water system. A consolidated value chain configuration for product recovery from sludge has been developed by Smith and Fantinel in 2017 (see Figure 8).
Depending on the distribution of wastewater treatment, the value chain involves more services and suppliers to use recovered products. It suggests potential interlinkages between each stakeholders' value chains.

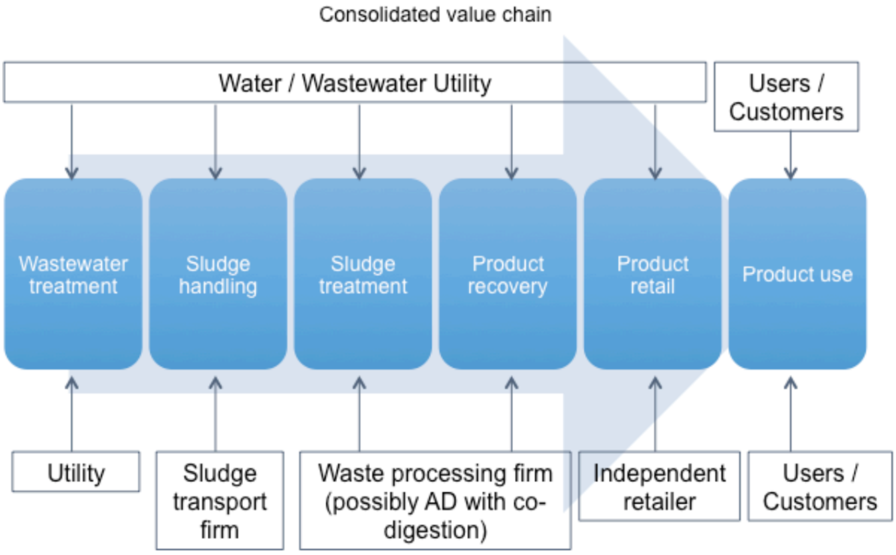

Figure 8: Potential value chains configurations for product recovery from sludge (Source: Smith & Fantinel, 2017)

More than half of the concerned cases reuse water or materials from WWTP for agriculture purposes.

Considering value chains within their context provides complementary information and leads to implement solutions at a more systemic level. It helps to consider all potential profits and savings and can serve then as an argument in favour of circularity.

4.1.1.2. Regional scale project for circularity in the water sector

The role of a supporting framework and an involved local government allows to raise awareness about circular economy in the water sector. Furthermore, it provides support for practices changes and a safety net that promotes innovation in the private sector.
Economic and financial incentives in France, and the waste and resources action programme (WRAP) in UK, have been identified as important levers to support transition to a circular economy (Vanner et all., 2014). In the water sector, especially in wastewater infrastructure, the EU policy framework provides concrete lever within the value chain to support reuse (Smith & Fantinel, 2017) described in the following figure.

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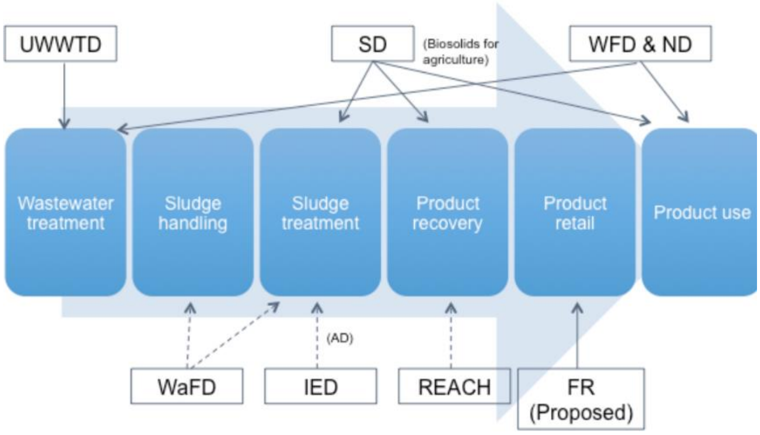

Figure 9 - Hypothetical value chain, showing the application of different policy frameworks (extracted from Smith & Fantinel, 2017)

The case of the Kalundborg industrial symbiosis (Matthews, Tan, 2011) site is interesting in the regional perspective. It considers the water system as a resource shared by all industrial and public sites and promotes reuse at a territorial scale (Figure 10).

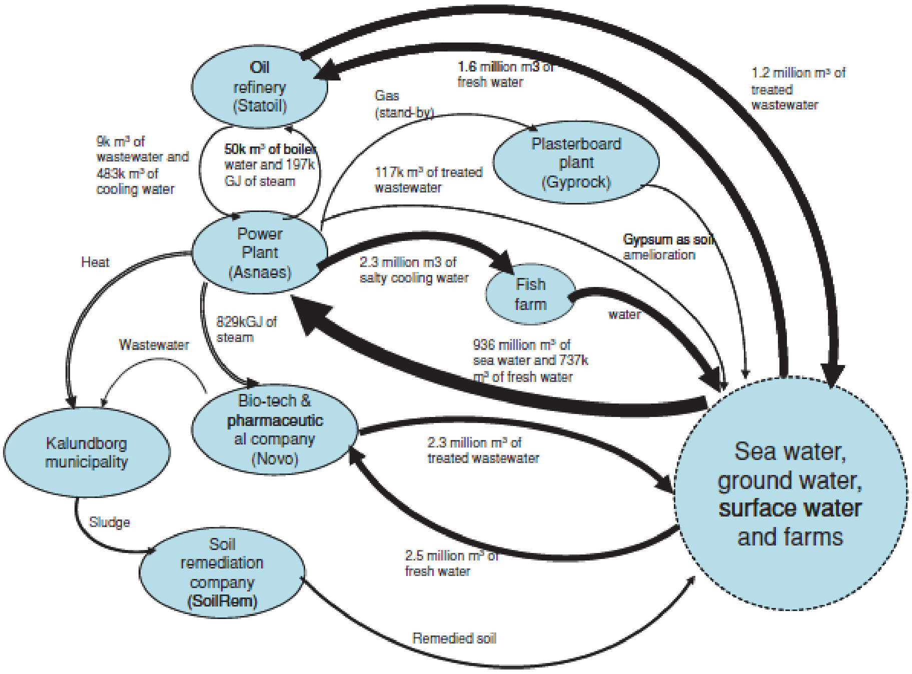

Figure 10: Selected industrial symbioses related to water in Kalundborg, Denmark (Source: Matthews, Tan, 2011)

The Kalundborg Symbiosis is a partnership between eleven public and private companies in Kalundborg[3], Denmark. It creates local growth and supports the green transition, and rests on a long history of local collaboration and partnership among industrial manufacturers and the municipality. The Kalundborg Industrial Symbiosis will be further studied in the H2020-project ULTIMATE.

Three case studies within NextGen project (Westland, Gotland and Filton) are regional/city scale project for circularity in the water sector. Those initiatives are supported by local

[3] http://www.symbiosis.dk/en/, accessed on the 26/02/2021.

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government and aim to provide a supporting framework within their territories for water reuse.
As Altenrhein case, some case studies in NextGen could also be considered as a large-scale project as WWTPs address many regional challenges because of the extent of projects with other municipalities and WWTPs. However, in NextGen, cases like Altenrhein case focuses on the WWTP scale for its development.

4.1.1.3. Industrial WWTP

La Trappe case study is peculiar in the sense that it focuses on wastewater treatment out of municipal water system, at the industrial level. Such eco-industrial initiatives, which close industrial loops by turning wastes in a point of the value chain into inputs at another point, are increasingly promoted to support circularity in industrial systems (Matthews, Tan, 2011). Industrial scale initiatives aim to promote industrial symbiosis, starting from low-level values shared between industries and upgrading progressively products exchanges.

Industrial wastewater characteristics usually make it difficult to reuse due to potential pollutions and risks prevention regulations. The Ecowater collaborative project funded by the European Commission from 2011 to 2014 developed a methodology to assess the industrial water supply chain (2012) at the meso-scale. Four industrial cases eco-efficiencies have been studied within this project giving elements on dairy, automotive, textile and thermal industries, and where they could improve.

4.1.2. Scope of the study

The study will focus on the streams between stakeholders and not on the processes. These parts are studied in the deliverables from WP1 (mainly D1.3, D1.4 and D1.5) and WP2 (mainly D2.1 and D2.2).

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4.2. Phase 1: Data collection

This section aims to present the tools available to select the methodology conducted to gather necessary data.

4.2.1. Value Chain Mapping

Value chain analysis is an iterative process based on the interactions between qualitative and quantitative data (Hellin, Meijer, 2006). As such it requires to list outputs of the solution, involved stakeholders, their relationships, and all economic activities at each stage of the value chain (Faße and all., 2009). This process will help mapping value for all value chains within NextGen demo cases.

Gereffi and all. (2011) identified 4 dimensions for Value Chain Analysis:

- Input-Output Structure: identify the main activities/segments in the value chain and the dynamic and structure of companies under each segment of the value chain.
- Geographic Scope: the different geographical scales (local, national, regional and global) give information on potential logistic costs (economic, environmental, social).
- Governance: it allows to understand how a chain is controlled and coordinated, and what actors have more power than others
- Institutional Context: considering the institutional framework at different scales (local, national, regional and global) helps assessing the impact of policies on the value chain and improving stakeholders mapping.

A better understanding of local economic, social, and institutional dynamics contributes to identify drivers and barriers of the value proposition and business case.

According to Kaplinsky and Morris (2000), mapping Value Chains requires data on:

- gross output values
- net output values (that is, gross output, minus input costs)
- the physical flow of commodities along the chain
- the flow of services, consultants and skills along the chain
- employment (not studied in this deliverable), where relevant distinguishing between permanent (on payroll) and temporary (off payroll) staff, gender, ethnicity
- destination of sales - for example to wholesalers and retailers; concentration of sales amongst major buyers; number of buyers
- imports and exports, and to which region

The data collection phase for the deliverable will consider all above parameters to analyse the value chains according to the availability of the data.

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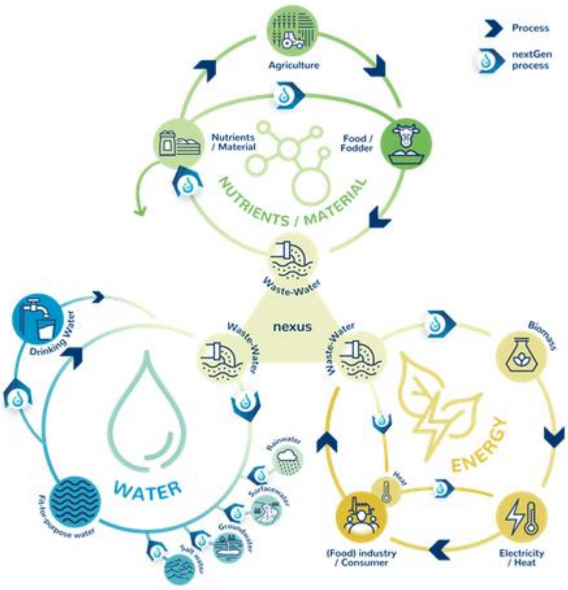
4.2.2. Value chains in NextGen identification

The objective of the NextGen project is to better understand the circular loops created in the water system. Three types of value chain are analysed: materials, energy and water.



All expected value chains in NextGen were identified from data collected in D1.1 and D1.2, and confirmed by demonstrators. It served as a first basis to value chain analysis.

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Table 3: Value chains studied in NextGen

Case studies	Value chain	Type	Process or source / Application
1. Braunschweig (DE)	Struvite	Materials	Struvite_precipitation/Fertiliser
	Ammonium sulfate (liquor)	Materials	Ammonia_stripping/Fertiliser
	Biogas (methane)	Energy	Digester/WWTP_city
2. Costa Brava (SP)	Non-potable water	Water	Tertiary_treatment/Irrigation
	Regenerated membranes	Equipment	Reverse_Osmosis/Desalination
3. Westland (NL)	Sludge	Materials	Drying/Cement
	Aluminium sludge	Materials	Dewatering/Building
	Heat	Energy	Aquifer/City
	Non-potable water	Water	WWTP/Aquifer
4. Alternheim (CH)	PK-fertilizer recovery	Materials	Pyrolisis/City_plant_fertiliser
	GAC	Materials	Pyrolisis/GAC_consumer
	Ammonium sulfate	Materials	Ammonia_stripping/Fertiliser
5. Spernal (UK)	Sludge	Materials	Dewatering/Agriculture
	Biogas (methane)	Energy	CHP/Electricity_network
	Calcium phosphate	Materials	IEX/Fertiliser
	Ammonium sulfate (solid)	Materials	IEX/Fertiliser
6. La Trappe (NL)	BioMass: purple non-sulfur bacteria (PnSB)	Materials	BioMakery/Fertiliser
	Water	Water	BioMakery/River_ornamentalplant
	Sludge	Materials	BioMakery/WWTP
	Consumables	Materials	BioMakery/WWTP
	Electricity (solar panel)	Energy	Solar_panels/WWTP
7. Gotland (SE)	Water	Water	Water management on the island
	Non-potable water (rainwater)	Water	Rain/Aquifer_storage
	Electricity (solar panel)	Energy	Solar_panels/plant
8. Athens (GR)	Non-potable water	Water	Sewer_miner/Tree_nursery
	Thermal Energy	Energy	Sewer_miner/Tree_nursery
	Compost	Materials	Sewer_miner/Tree_nursery
9. Filton (UK)	Non-potable water (rainwater)	Water	Rain_Roofs/Irrigation_toilets_tbd
	Thermal energy	Energy	Used_water/Drinking_water
	Nutrients	Materials	Wastewater/Agriculture
10. Timisoara (RO)	GAC & Biochar	Materials	Pyrolisis/Agriculture
	Gas and oil	Energy	Pyrolisis/WWTP
	Non-potable water	Water	WWTP/Irrigation

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4.2.3. Data collection process

To conduct the analysis on NextGen Case Study, a questionnaire based on data from deliverable D1.1 and D1.2 was created and confronted with partners from each demo-case.

After an interview to better understand the stage of development the case study, partners were invited to fill the questionnaire and a VSM with the data they had.

Data gathered from case-studies were about:

- stakeholders' ecosystem (locations, interests, influences, relations, etc.)
- material, water or energy streams (physical properties, quantity, origin and destinations, etc.)
- economic aspect (market value, treatment costs, savings, etc.)
- environmental aspect (carbon footprint, raw material reduction, etc.)
- drivers and barriers to implement the value chains (PESTLE framework)

All value chains and case studies are not at the same level of advancement (due to technical development, implementation progress or Covid-19 situation) which implies different level of information.

High: the demonstrator was able to provide quantitative and qualitative data and/or to suggest viable assumptions for the value chain analysis. However, LCA and LCC still have to be carried out during the project to complete the analysis.
Moderate: the level of information was enough to propose a qualitative analysis. Many assumptions had to be done to make a proper analysis
Low: the demonstrator was not able to provide information about the future value chains or the current value chain. Only a description of potential value chains has been carried out for these case studies
Not Available (NA): No data was available yet for the value chain analysis in the scope of the deliverable.

According to the data availability, some value chain analyses limited or were not possible especially for CS without available data. The level of data collected for each case study is presented in section 4.4.

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4.3. Phase 2: Case studies analysis

4.3.1. Type of analysis

Different types of analysis have been performed in this deliverable due to the resource studied in the value chain, if it is possible to differentiate one single stream of the organisation or it is necessary to all streams as a whole, and the information available.

In the case of “high” level of information or thanks to many assumptions, it was possible to differentiate the analysis of one **single value chain** of the case study (CS1, CS3, CS4 and CS9). For the case study 1 and 4, enough information about **energy** has been shared to include it in the analysis.

For value chains less documented, value chain analyses have been merged to consider value chains as a whole (**multi value chain analyses**). Only a **qualitative analysis** was performed for those (CS6, CS8).

For value chain more complex or with almost no data available at this stage of the project, a **qualitative description** of all streams in the case study has been presented (CS2, CS5, CS10).

In the case of Gotland (CS7), no data was available for the value chain analysis. However, the social values and stakeholders’ ecosystem are studied section 6 with the case of La Trappe.

As seen in section 2.1.2.2, contrary to the energy balance analysis, the value chain analysis is not the most suitable tool to analyse the energy synergies between stakeholders. This component will be studied in detail in the WP2.

4.3.2. Stakeholders’ analysis

Based on the interviews with CS, an overview of all stakeholders involved or needed in the value chain is studied. It will allow to identify stakeholders needed to implement and replicate value chain and potential drivers and barriers.

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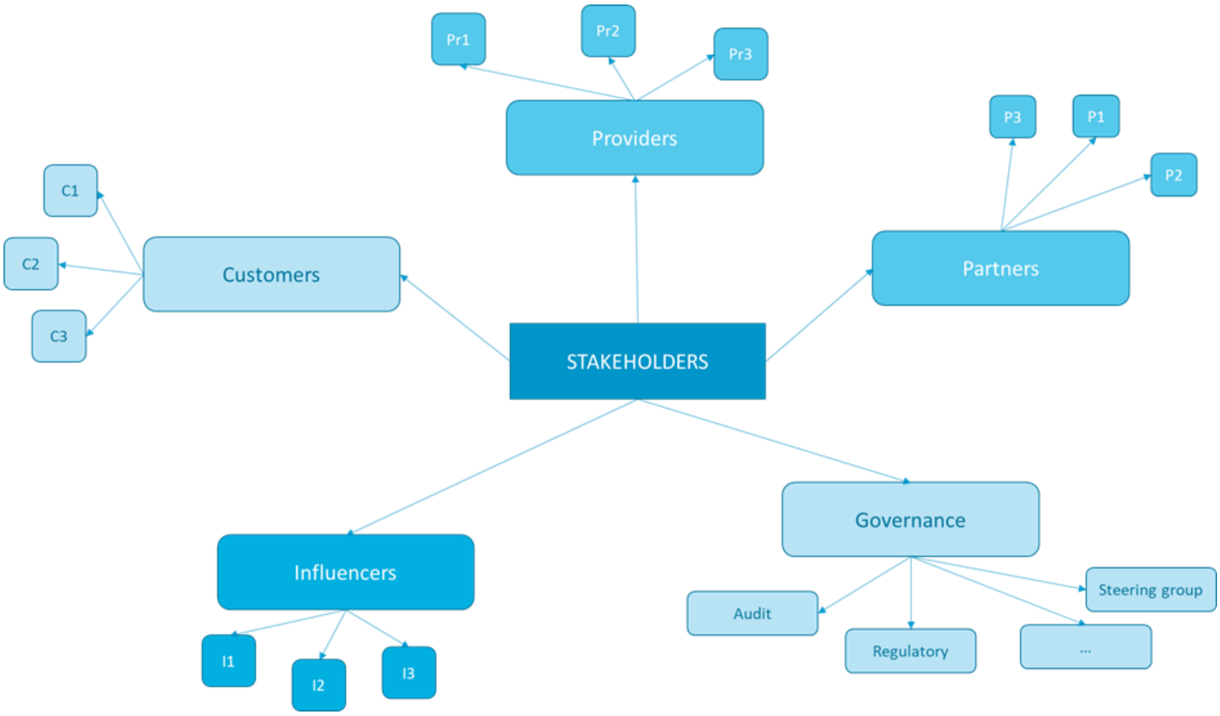

Figure 11 - Stakeholder's matrix (Source: Strane adapted from Azkarate and all., 2016)

For value chains with a concrete knowledge about the stakeholders' ecosystem, the influence and the interest of each actor is mentioned in the analysis to estimate the weight of their involvement in the value chain implementation. This assessment is illustrated in the Figure 12.

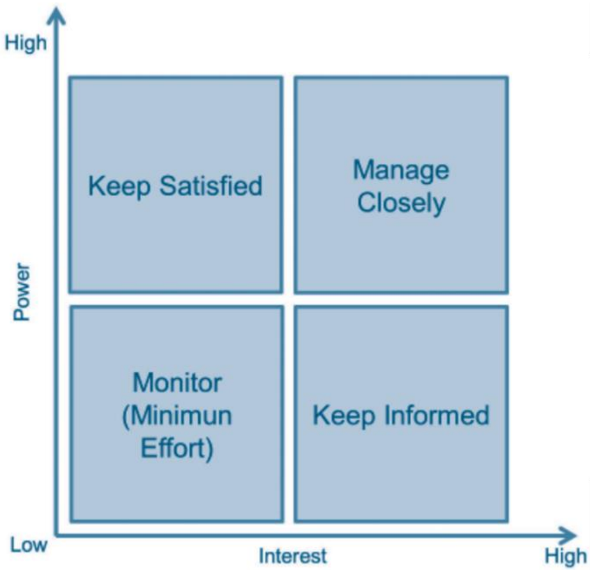

Figure 12: Stakeholders' power and interest grid

An actor with a high interest and/or a high influence can be considered as "main actors" to implement the value chain. Others will be considered as "intermediary" and "external" actors.

Except for La Trappe and Gotland stakeholders' ecosystems which are comprehensively studied in D4.1 and D4.2, no interviews with third parties and other stakeholders involved in the value chain has been carried out for the study.

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La Trappe and Gotland cases are studied in detail to assess stakeholders' relationships and the potential benefits that motivate actors to contribute to circular value chain creation in Section 6.

4.3.3. Value proposition assessment

In these sections, the economic and environmental aspects will be studied in order to estimate the potential benefits or barriers related to the value chain implementation. Main conclusions of these study will be summarised in the business model canvas of the value chain presented below.

These sections intrinsically depend on the data available and provided by the demonstrators. If the analyses are not quantitative, a qualitative description will be carried out to highlight main economic and environmental benefits.

For detailed Life Cycle Cost Analysis (LCCA) and Life Cycle Analysis (LCA) of circular solutions, this work will be performed in deliverable 2.1 and 2.2 in the Work Package 2.

4.3.4. Drivers and Barriers identification

According to the PESTLE[4] framework, main drivers and barriers to implement the value chains of case studies have been asked to demonstrators in order to foster the replication with policy recommendations summarised in the Recommendations section.

4.3.5. Business Model Canvas

The work done in this deliverable complements the work done in D5.1 on business models. Value chain analysis focuses on meso and macro level as the objective is to study the streams between stakeholders, where value is created and how it benefits to the ecosystem.

This deliverable proposes to present all main components necessary to replicate the value chain through a business model canvas centralised on a resource or a value chain. This framework created by Stéphane Ogé (2021) is presented in Figure 13.

[4] Political, Economic, Sociological, Technological, Legal and Environmental

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Ecosystem of stakeholders	Key activities	Key resources	
Main actors: Ex: WWTP and the product consumer	Ex: Storage Treatment Transport	Ex: Sieving process Granulation process Trucks	Creation and value distribution
Intermediary actors: Ex: haulier	**Stakeholders relationship** Ex: Classic business relationship Collaboration and co-benefits distribution		
External actor: Ex: nature, local authorities			

Economic Value	Environmental Value	Territorial Value	
Ex: savings, sales, disposal costs avoided	Ex: Water consumption reduction	Ex: Potential new synergies implemented between local organisations	Value proposition

Cost structure	Impact of the organisations (micro & meso)	Public funding	
Ex: - XXK€ investment (CAPEX) - XK€/y operational expenditure (OPEX)	Ex: - Carbon footprint producer - Carbon footprint transport	Ex: Subsidies from local authorities to implement the synergy	Value capture
Revenue stream	**Global impact (macro level)**	**Public non-financial Costs and benefits**	
Ex: - Xk€/y avoided cost, - Yk€/y or t new business	Ex: Environmental impacts of the value chain if it is replicated through Europe	Ex: advantages for circular materials, regulations	

Figure 13: Business model for synergies (adapted from Ogé, 2021)

The model allows to have a clear understanding of all value created along the value chain. It highlights potential motivations from stakeholders to get involved in circular value chain, and potential drivers and barriers for each type of value identified during the study to upscaling value chain.

4.4. Overview of the value chains studied

The value chains expected to be found in the analysis of NextGen case studies are described in the following table. Depending on the data available, some have been studied deeper than others: those are highlighted in blue in the table and described in detail in each case study section. Six level of analysis have been conducted depending on the data available.

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Table 4: Summary of value chains studied in the deliverable

CS	Value chain	Type	Data available	Type of study	From/Application
CS1	Struvite	Materials	High	Single value chain analysis (with energy)	Struvite_precipitation/Fertiliser
CS1	Ammonium sulfate (liquor)	Materials	High	Single value chain analysis (with energy)	Ammonia_stripping/Fertiliser
CS1	Biogas (methane)	Energy	NA	Not analysed	Digester/Plant_city
CS2	Non-potable water	Water	Low	Single value chain description (Qualitative)	Tertiary_treatment/Irrigation
CS2	Regenerated membranes	Equipment	Low	Single value chain description (Qualitative)	Reverse_Osmosis/Desalination
CS3	Sludge	Materials	High	Single value chain analysis	Drying/Cement
CS3	Aluminium sludge	Materials	High	Single value chain analysis	Dewatering/Building
CS3	Heat	Energy	NA	Not analysed	Aquifer/City
CS3	Non-potable water	Water	NA	Not analysed	WWTP/Aquifer
CS4	PK-fertilizer recovery	Materials	High	Single value chain analysis (with energy)	Pyrolisis/City_plant_fertiliser
CS4	GAC	Materials	NA	Not analysed	Pyrolisis/GAC_consumer
CS4	Ammonium sulfate	Materials	NA	Not analysed	Ammonia_stripping/Fertiliser
CS5	Sludge	Materials	Low	Multi value chain description (Qualitative)	Dewatering/Agriculture
CS5	Biogas (methane)	Energy	Low	Multi value chain description (Qualitative)	CHP/Electricity_network
CS5	Calcium phosphate	Materials	Low	Multi value chain description (Qualitative)	IEX/Fertiliser
CS5	Ammonium sulfate (solid)	Materials	Low	Multi value chain description (Qualitative)	IEX/Fertiliser
CS6	BioMass: purple non-sulfur bacteria (PnSB)	Materials	Low	Multi value chain analysis (Qualitative)	BioMakery/Fertiliser
CS6	Water	Water	Low	Multi value chain analysis (Qualitative)	BioMakery/River_ornamentalplant
CS6	Sludge	Materials	Low	Multi value chain analysis (Qualitative)	BioMakery/Plant
CS6	Consumables	Materials	Low	Multi value chain analysis (Qualitative)	BioMakery/Plant
CS6	Electricity (solar panel)	Energy	Low	Multi value chain analysis (Qualitative)	Solar_panels/plant
CS7	Water	Water	NA	Not analysed	Water management on the island
CS7	Non-potable water (rainwater)	Water	NA	Not analysed	Rain/Aquifer_storage
CS7	Electricity (solar panel)	Energy	NA	Not analysed	Solar_panels/plant
CS8	Non-potable water	Water	Medium	Multi value chain analysis (Qualitative)	Sewer_miner/Tree_nursery
CS8	Thermal Energy	Energy	Medium	Multi value chain analysis (Qualitative)	Sewer_miner/Tree_nursery
CS8	Compost	Materials	Medium	Multi value chain analysis (Qualitative)	Sewer_miner/Tree_nursery
CS9	Non-potable water (rainwater)	Water	Medium	Single value chain analysis	Rain_Roofs/Irrigation_toilets_tbd
CS9	Thermal energy	Energy	NA	Not analysed	Used water/Drinking_water
CS9	Nutrients	Materials	NA	Not analysed	Wastewater/Agriculture
CS10	GAC & Biochar	Materials	Very low	Multi value chain description (Qualitative)	Pyrolisis/Agriculture
CS10	Gas and oil	Energy	Very low	Multi value chain description (Qualitative)	Pyrolisis/Plant
CS10	Non-potable water	Water	Very low	Multi value chain description (Qualitative)	WWTP/Irrigation

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According to the framework of NextGen, value chains can be gathered in 3 groups:

Materials (incl. equipment) Value Chain

14 Value chains related to materials (including membranes regeneration) have been studied in detail in this deliverable. Four types of outputs are expected in those value chains:

- fertiliser production from nutrients recovered in the process (struvite, ammonia, phosphate, ammonium sulfate etc.)
- construction materials from dewatered or dried sludge
- agriculture (water, compost, GAC)
- on-site use

Water Value Chain

5 Value chains related to water have been studied in detail in this deliverable. Most outputs are expected to supply irrigation water: agriculture, tree nursery, river ornamental plant.

Energy Value Chain

4 Value Chains related to energy have been studied in the deliverable. Energy is expected to be reused on site, sent to the electricity network, or to be used in a tree nursery.

In addition, a detailed Social Value assessment has been done for La Trappe (CS6) and Gotland (CS7).

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5. Case Studies Analysis

5.1. CS1 – Braunschweig (DE)

5.1.1. Description of the CS

The current WWTP in Braunschweig comprises a conventional activated sludge treatment system and a digestion stage. The wastewater treatment plant treats the wastewater of 350.000 PE with 22,3 Mm^3/y.

5.1.1.1. Challenges and/or opportunities

Until 2016, in summer, the digestate was directly reused in agriculture, while in winter, the digestate was dewatered and stored or incinerated.

Due to the new legislation in Germany, periods for fertilization with digested sewage sludge are restricted and the nitrogen load of the fields is limited since 2017. Only 70% of the digestate can be applied on the fields. Thus, the other 30% of the digestate are dewatered and incinerated, which is a loss and has an important environmental impact.

5.1.1.2. Circular solutions

The WWTP decided to build a nutrient recovery unit for nitrogen and phosphorus in order to achieve the required effluent quality.

The new technologies should create 3 new value chains, which are: (1) the struvite value chain (2) the ammonium sulfate value chain, and (3) an optimisation of the energy value chain.

5.1.1.3. Status of the demo case

The new technology for nutrient recovery and sludge treatment, and TPH, are still in implementation phase and the technical units have not operate continuously for more than 3 months at a time especially due to Covid-19 situation. To analyse and evaluate the effect of the TPH on the sludge handling, more time is still required to verify the optimistic hypothesis of a 25 % increase of the biogas production and a significant better dewatering process.

5.1.2. Limitations of the study and scope of the study

Scope:

The energy balance and the LCA of the processes will be studied in detail in the WP2 deliverable 2.1. The value chain analysis of this section will focus on transport and incineration avoided thanks to the new value chains.
The scope of the value chain analysis is limited at the supplier of chemicals upstream and the fertiliser producer downstream.

Limited data:

Some data have not been collected because of delays due to Covid-19 situations:

- No data has been measured about the maintenance costs. Some assumptions will be elaborated based on the literature.

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- No data has been shared about the new chemical suppliers' locations.
- As the full-scale plant is not implemented, the data does not allow to assess the double benefits issues. The incineration emissions avoided by value chains could have been calculated twice in the document.

5.1.3. State of the art of streams before NextGen solution

5.1.3.1. Pre-existing sludge value chain

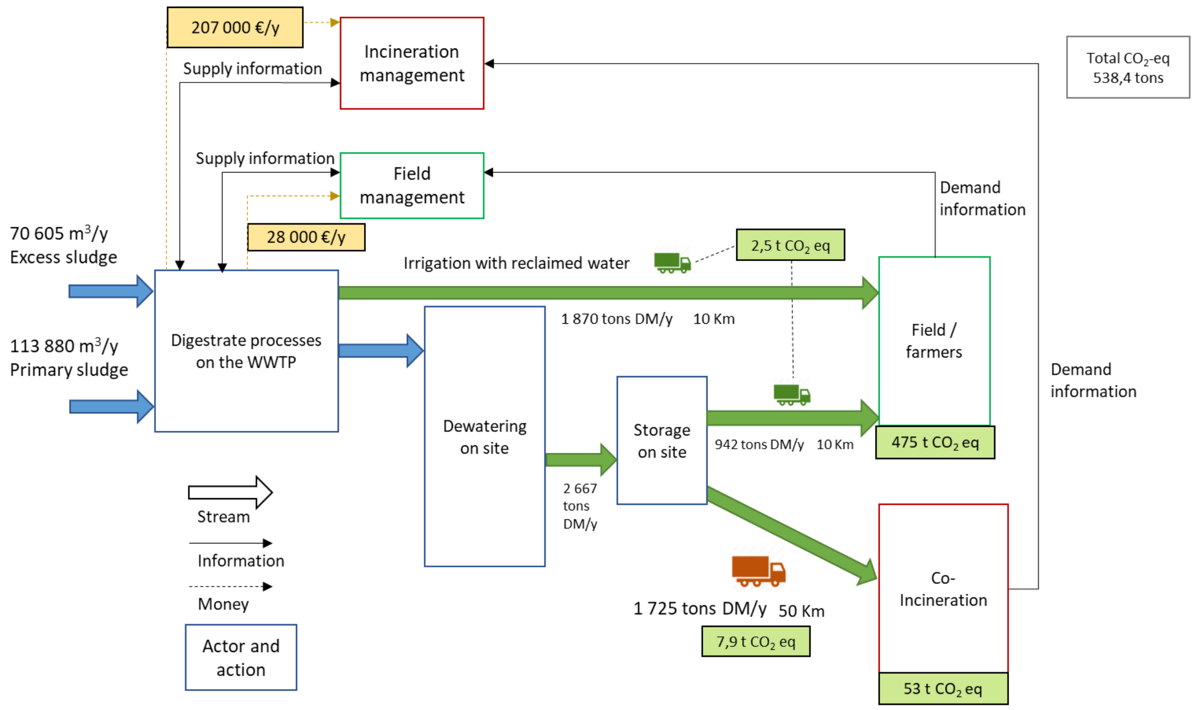

Figure 14: Braunschweig case before technologies implementation

Streams' description:

The WWTP treats on average 20.7 million m³ wastewater per year. This corresponds to 350,000 population equivalents (PE), even though the WWTP was designed originally for 275,000 PE. The COD-, N-, and P-loads of the WWTP are on average 16,000 t COD/year, 1,500 t N/year and 230 t P/year, respectively.

Currently, the primary and excess sludge as well as fat, oil and grease (FOG) resulting from the fat separator are digested in three one-stage digesters (please refer to the Deliverable 1.1). On average, they produce 470 Nm³ biogas/h with a methane content of around 61%. Thus, the corresponding methane yield is 0.26 Nm³ CH4/(kg VS).

Around 2 812 tons of dewatered sludge are reused in agriculture (62% of the total production) and 1 725 tons are incinerated.

Stakeholders' ecosystem:

In this value chain, the following stakeholders can be identified. For each stakeholder, its power or interest in the value chain is described.

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1. WWTP: the WWTP is owned by AVB and operated by 'SEBS' (a subsidiary company from Veolia).
2. The incinerator is located at 50 km from the WWTP and burns around 1 725 tons of dewatered sludge per year, which is a cost for the WWTP (120 €/ton).
3. Farmers and their fields are closed to the WWTP (around 10 km). These stakeholders used to reuse the dewatered sludge (1 870 tons per year) as a fertilizer on their fields. The WWTP pays farmers 10 €/ton for disposing of the solid sludge.

Economic aspect:

With a cost of 10€/t for sending sludge to farmers and 120€/t for managing the rest of sludge not reused in agriculture, the WWTP spent more than **235 000 euros** for disposing of solid sludge each year.

Environmental impact:

- Transport

Data for transport emission calculations	
CO_2 emissions factor for skip[5]	0,0916 kg CO_2 / t.km
Volumes of sludge for field	2 812 tons DM/y
Distance from WWTP to farmers	10 km
Volumes of sludge for incinerator	1 725 tons DM/y
Distance from WWTP to incinerator	50 km

Based on these assumptions and the data provided by the case study, the transport of the pre-existing value chain emits around **10,4 tons of CO_2 eq. per year**.

- Incineration and the farming scenarios

Within the LCA performed in WP2, it has been calculated for the baseline situation about **475 t CO_2-Eq** for agricultural sludge valorisation due to N_2O released (nitrification/denitrification on fields) and **53 t CO_2-Eq** for the co-incinerator.
These calculations only concern the direct emission. However, sludge creates energy in the incinerator which should be considered in a holistic balance

The pre-existing sludge management emits about **538,4 tons of CO_2** each year.

[5] https://www.ademe.fr/sites/default/files/assets/documents/86275_7715-guide-information-co2-transporteurs.pdf

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5.1.4. Struvite value chain

5.1.4.1. Struvite recovery description

Due to the very high nutrient loads of the WWTP, the operator decided, instead of extending the nitrification and denitrification stages as well as the P-removal unit, to build a nutrient recovery unit for nitrogen and phosphorus in order to achieve the required effluent quality.

Struvite ($MgNH_4PO_4.6H_2O$) precipitation occurs naturally during sludge treatment in WWTP running an enhanced biological phosphorus removal (EBPR) and has been traditionally a leading maintenance problem for wastewater facilities via the excess growth of struvite crystals in pipes, thereby resulting in encrustation, scaling, and subsequent high maintenance costs for removal. However, the precipitation of struvite can be controlled in a dedicated process via the addition of a magnesium source in the right conditions.

The WWTP expects to recover 200 tons of struvite per year to sell it which could create a new value chain with regional actors.

5.1.4.2. Market value assumptions for the value chain analysis

Struvite value chain assumptions	
NaOH price	289,17 €/t
$MgCl_2$ price	85,68 €/t
Struvite market price ex works[6]	100 €/t

The current marketed value of the struvite is between 0€ and 100€ per ton, but many cases show an increasing trend for the struvite. The material is under-estimated if it is compared with the market value of its macro nutrients (from 250 to 415 €/t). The market value of 100 €/t has been assumed for the analysis.

[6]https://www.susfert.eu/wp-content/uploads/2021/01/2020-SUSFERT_A-systematic-comparison-of-commercially-produced-struvite.-Quantities-qualities-and-soil-maize-phosphorus-availability.pdf

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5.1.4.3. Scheme of the struvite value chain

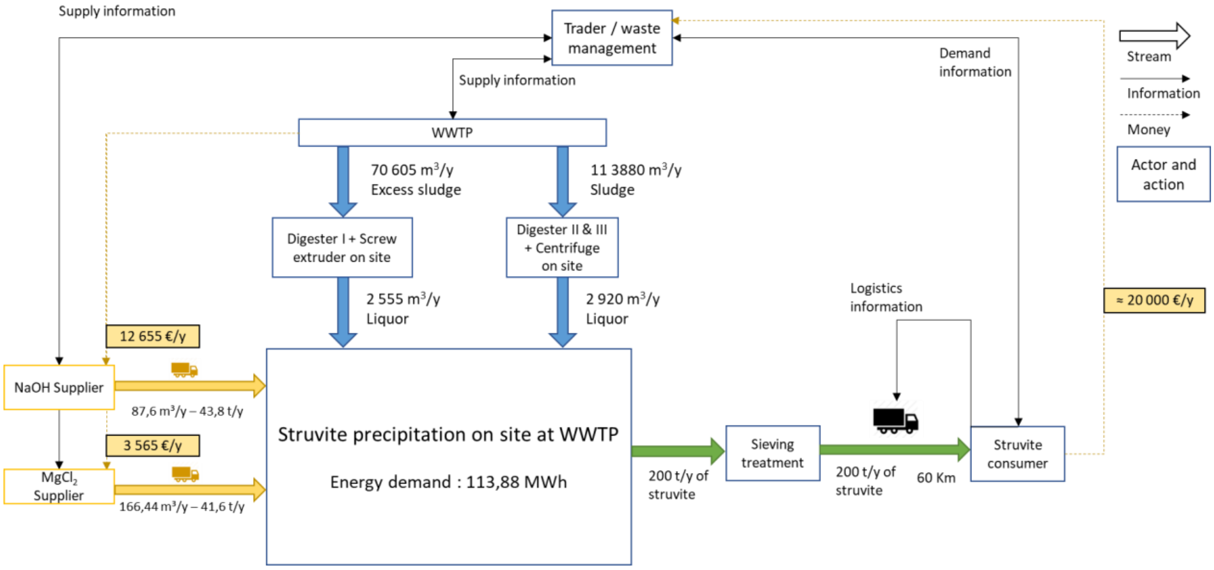

Figure 15: Struvite value chain scheme of Braunschweig case

5.1.4.4. Stakeholders' involvement

Main actors:

1. Struvite producer: Braunschweig WWTP

The WWTP has a high interest for collecting the struvite. In municipal wastewater plants, crystallisation of struvite is an often-observed reaction. This is nuisance for operators, this uncontrolled crystallisation leads to blockage of pipes and thus interruptions of the treatment process. Deblocking is expensive, as well as prevention measures.

2. Struvite consumers: Soepenberg GmbH

Soepenberg is regional fertiliser company that treats waste materials and sells fertilisers to farmers and gardeners. The company has a high interest to develop this value chain as it is part of its business model. This actor is a facilitator quite necessary to deploy this value chain and make it technically viable. In this case, the transport is managed by the Soepenberg.

Intermediate and external actors:

1. Process supply: chemical components suppliers:

These suppliers (NaOH, $MgCl_2$) are moderately interested by the value chain as the quantities of the chemicals used in Braunschweig (and other replication cases) are negligible compared to the chemical production of these actors. However, these actors could have an influence on the economic viability of the value chain according to their offer. No data about their locations have been shared for now.

2. Transport:

In this case, transports are managed by the receiver and the supplier, but it can also be replaced by another organisation. This actor can have an influence on the value chain viability.

3. Farmers:

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This actor is the end user of the struvite resource before coming back to the wastewater. This actor is quite external of the system but could have a real interest for the struvite-based fertilizers.

4. Energy producer:

The resource recovery could globally affect incinerators if good practices are widely applicated. At this stage, only the struvite value chain does not imply a significant reduction of sludge incineration.

5. Phosphate rock supplier:

This actor provide phosphate extracted from rocks. This resource is probably imported as Europe countries are the main importers of phosphate in the world with 1,3 Mt used per year. This actor has a significant influence on the phosphate market and could affect the market value of the struvite.

6. Public actors:

These actors could foster and facilitate the struvite production with new regulations as it is the case in Braunschweig with the reduction of sludge reuse on fields.

5.1.4.5. Value proposition and benefits of the struvite value chain

Economic aspect:

In terms of global market related to the phosphate, Russia and Morocco are the main exporters of phosphate fertilisers. The market price of phosphate is suffering from many factors (strong increase of demand from emerging countries, higher energy prices, increase export taxes from China, etc)[7], and past price peaks have affected the market value of the struvite.

In Braunschweig case, the struvite is planned to be sold at 100 €/t by WWTP. With this assumption the potential sales revenue of the struvite reaches around 20 000€ per year, without considering savings related to maintenance costs avoided, aeration cost for nitrogen removal avoided, carbon source cost for phosphorus removal avoided, and polymer use in the dewatering process[8].

In a previous economic study on Braunschweig, it has been estimated that the full cost to produce struvite is around 710€/t for a PO_4-P load of 350 mg/L[9], by considering chemicals (≈69,8% of the cost), maintenance (4,9%), staffs (3%), energy (2%), investment with 10 years of depreciation period and an interest rate of 6% (20,6%).

Based on data collected and the previous economic study, the precipitation of 200 tons of struvite should have the following costs:

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[7] Lécuyer, B. The World Phosphates Market: What Risk for the European Union? Food and Agriculture Organization of the United Nations: Rome, Italy, 2014; pp. 1–6

[8] Bird, Amanda R., "Evaluation of the Feasibility of Struvite Precipitation from Domestic Wastewater as an Alternative PhosphorusFertilizer Resource" (2015). Master's Projects and Capstones. 141. https://repository.usfca.edu/capstone/141

[9] International Conference on Nutrient Recovery from Wastewater Streams (Vancouver, 2009)

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- The struvite precipitation process requires chemicals (NaOH and MgCl2) which are estimated at 16 230 € per year.
- The process should consume 114 MWh per year (≈34 653 €10).
- The WWTP has invested around 4 722 943 € to implement processes of struvite precipitation. With 6% of interest rate and financed over 20 years, this investment should cost 411 768 € per year.
- The maintenance cost of the process is estimated at 3% of the total investment costs (≈141 688 €).
- The labor costs for the production have been estimated at 4 260 € per year.

These calculations lead to a struvite production cost of **2 028 € per ton** without considering public fundings and energy consumption.

The chemicals represent 2,7 % of the production cost instead of 69,8% as expected in the previous economic study. The difference of the production cost since the economic study in 2009 is mainly due to the increase of 787% of the total investment. In 2021, the investment depreciation and interest rate represent 68% of this production cost.

Based on these results, the struvite value chain is not economically viable without considering the following elements:

- Maintenance savings: The key economic driver of the struvite recovery is the maintenance cost reduction11. No sufficient data basis has been collected yet on this aspect for Braunschweig case study. However, preventing measures, deblocking or replacing pipes are extremely expensive for the WWTP and can interrupt the treatment process at any moment. It has been shown that the resulting annual costs of this maintenance can range between 27 000€ and 138 000€ for WWTP such as Braunschweig case12. This maintenance cost could make the value chain viable.
- CHPs electricity production: The energy consumed by the precipitation should be mainly compensated by the electricity produced by CHPs in the WWTP. CHP technology facilitates the implementation of this value chain, but a double counting benefits study should be carried out in detail.
- Investment cost: This type of investment can be subsidised thanks to governance incentives.

Environmental aspect:

Compared with the pre-existing value chain of sludge, the environmental impact of the value chain will be noticed on the following aspect.

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[10] Electricity price in Germany= 304,3€/MWh https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

[11] An Assessment of the Drivers and Barriers for the Deployment of Urban Phosphorus Recovery Technologies: A Case Study of The Netherlands

[12] Struvite Control - A Common and Nuisance (2002)

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- Transport

Struvite recovery implies transports for struvite delivery (located at 60 km) from the WWTP and chemicals supply (due to lack of data, assumed at 100 km from WWTP). This new travels emit around 1,88 tons of CO_2 eq. per year.

- LCA (comparison with P-mineral)

According to Kersti Linderholm[13], life cycle assessments have shown that struvite-based fertilizer has a lower environmental impact than phosphate rock. The main reason of this conclusion is related to the difference of distance travelled by the P-fertilizer and the P emissions to water during the mining process. However, the comparison between P-mineral and struvite from precipitation still has to be demonstrated.

5.1.4.6. Barriers and drivers to implement the struvite value chain

Drivers

The following drivers are based on feedbacks collected from the case study:

- Regulation about the reuse of sludges:

Due to the new legislation in Germany, since 2017 only 70% of the digestate can be applied on the fields. Periods for fertilization with digested sewage sludge are now restricted and the nitrogen load of the fields are limited. Thus, the other 30% of the digestate are dewatered and incinerated.

- Certifications around the product:

Certification of struvite and REACH classification support the product safety and facilitates the creation of the value chain with end-users.

The Table 5 gathers drivers found in a Netherlands case study[14].

Table 5: Drivers identified for struvite value chain development based on PESTLE aspects

PESTLE aspects	Drivers
Political aspects	Sustainability goals from government contribute to sustainable developments and implementations of struvite recovery. External stimuli, like the green deals stimulate sustainability goal.
	Positive effect of Nutrient platform. The nutrient platform has helped in accelerating developments at the political and legislative level.
	Political interest in phosphate sustainability has grown a lot at the European level. Incorporation in the EU critical materials list is seen as vital in this respect

[13] Life cycle assessment of phosphorus alternatives for Swedish agriculture
[14] An Assessment of the Drivers and Barriers for the Deployment of Urban Phosphorus Recovery Technologies: A Case Study of The Netherlands

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Economic aspects	Reduction maintenance costs
	Implementation opportunities for struvite in niche markets
	The “green” marketing aspect of struvite is attractive
Social aspects	Popularity of circularity and circular economy
	The value of struvite as a green marketing tool for the water board
	Public opinion: A positive public opinion regarding to struvite due to the green label

Barriers

The following barriers are based on feedbacks collected from the case study:

- Supply with mineable phosphorus:

The traditional supply of phosphate is really competitive with struvite recovered in WWTP. The quantities recovered are too small in comparison with mines and the EU demand. EU could supply its own demand for P fertilisers for 150 years only by using its own resources in Finland without considering imports.

- Little amount of production:

Besides the marketing of the recovered fertilisers is still under construction as the WWTP produces until now only little amounts of struvite solution due to discontinuous operation of the recovery plant.

- Low market value of the struvite:

Market price for struvite is too low to cover the production costs.

- Inadequate properties:

Struvite has proven its feasibility as fertiliser. However, the low water solubility and physical criteria (powder) of struvite appear to be inappropriate for farmers. Struvite is not a stand-alone product and requires additional treatment to be used on fields.

The Table 6 gathers barriers from the assessment in a Netherlands case study[15].

Table 6: Barriers identified for struvite value chain development based on PESTLE aspects

PESTLE aspects	Barriers
Political aspect	The long process of implementation of passed legislation, especially for the revision of the fertilizer regulation and the end-of-waste (EoW) status
Economic aspects	Transport issues
	Conservative market

[15] An Assessment of the Drivers and Barriers for the Deployment of Urban Phosphorus Recovery Technologies: A Case Study of The Netherlands

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	Low price of phosphate rock/fertilizers
	Vested interests and complexity stakeholders
	Uncertainties in return on investment
Social aspects	Popularity of circularity and circular economy
	Different mind-sets concerning recycled resource per country
	A negative public opinion due to the uncertainties of health issues/safety
	Low awareness among farmers about struvite
Technological aspects	Product safety is unclear
	Negative chemical characteristics struvite
Legal aspects	Trade barriers of waste between countries hinders the trade in P recovered materials (end-of-waste (EoW) status)
	One thing that is lacking at the political level is the implementation of passed legislation, especially revision of the fertilizer regulation and so the EoW status

5.1.4.7. *Business case of the struvite resource*

The business canvas of the value chain presented in the Figure 52 summarises values assessed and highlights advantages and disadvantages for deploying the value chain.

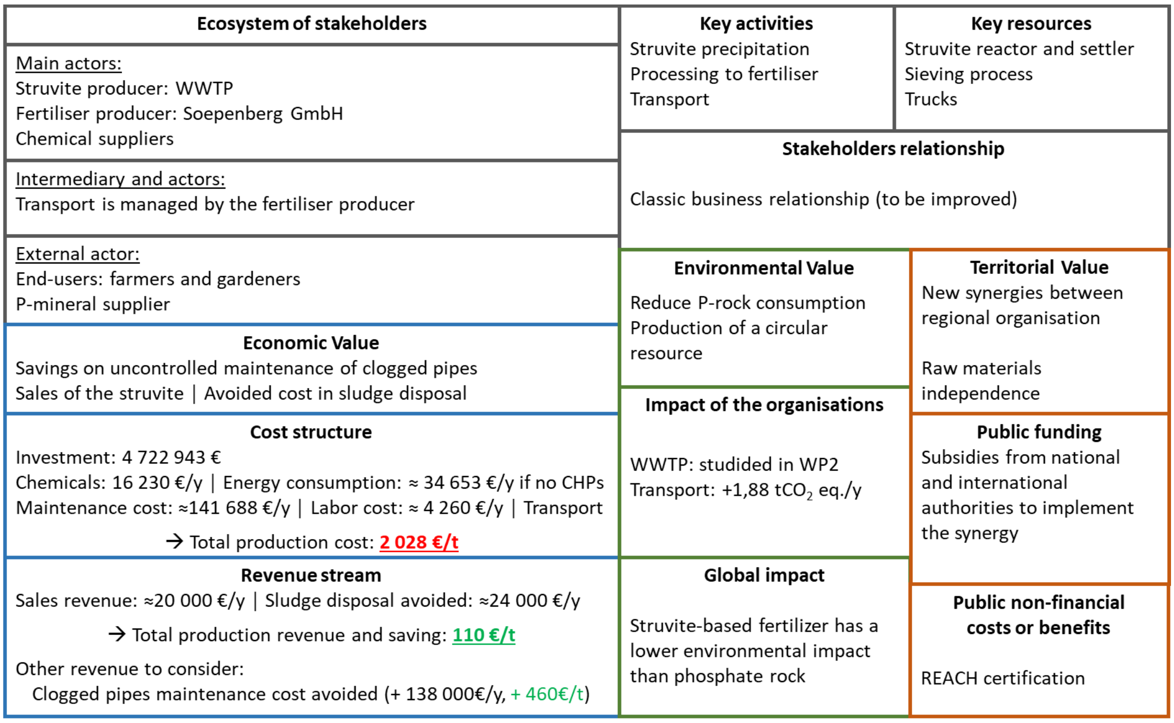

Figure 16: Business canvas centralised on the struvite resource

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5.1.5. Ammonium sulfate value chain

Ammonium sulfate can be recovered by an adsorbing unit (acidic trap) immediately after the gas stripping phase implemented in the WWTP.
This recovery reduces the load of ammonium in liquors that comes from centrifuge. These liquors used to go back to the wastewater treatment as seen in the Braunschweig scheme in Figure 14. The WWTP is overloaded with nitrogen and side stream removal of N helps to cope with the legal limits for effluent N of the WWTP.

5.1.5.1. Market value assumptions for the value chain analysis

Table 7: Ammonium sulfate value chain assumptions

Ammonium sulfate value chain assumptions	
H_2SO_4 price	143,35 €/t
Ammonium sulfate market price ex works	8 €/t DAS (38% solution)

Even if some scientific article suggests a market value that could reach 90€-120€[16], the ammonium sulfate solution supplier who will markets the solution from Braunschweig confirmed a market price at 0-10 €/ton depending on the season.

The market value will be confirmed when the recovery plant will work continuously during the project.

5.1.5.2. Scheme of the ammonium sulfate value chain

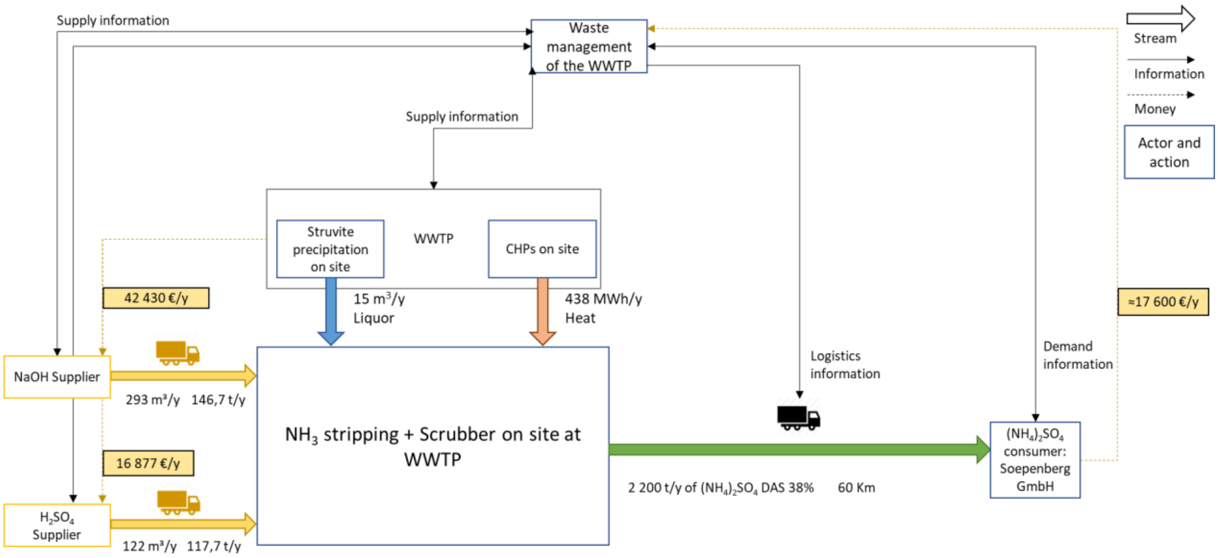

Figure 17: Scheme of the ammonium sulfate of Braunschweig case

[16] Environmental and Economic Sustainability of Swine Wastewater Treatments Using Ammonia Stripping and Anaerobic Digestion: A Short Review

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5.1.5.3. Stakeholders' involvement

Main actors:

1. Ammonium sulfate producer: Braunschweig WWTP

The WWTP has a high interest in recovering the ammonium sulfate as resource can be sold as by-product, and because of restrictions related to the nitrogen load in WWTP.

The ammonium sulfate value chain implies the same actors than the struvite value chain with the same interest and influence. Please refer to the previous section.

5.1.5.4. Value proposition and benefits of the ammonium sulfate value chain

Economic aspect:

In Braunschweig case, the struvite is planned to be sold at 8 €/t by the WWTP. With this assumption the potential sales revenue of the liquid ammonium sulfate could reach around 17 600€ per year.

Based on data collected, the ammonia stripping unit that should produce 2 200 tons of ammonium sulfate per year should have the following costs:

- The ammonium sulfate requires chemicals (NaOH and H_2SO_4) which are estimated at 59 307 € per year.
- The process should consume 87,6 MWh of electricity per year (≈26 656 €[17]), and 438 MWh of heat per year (≈14 826 €[18]). However, the heat will be provided by the CHPs. The heat consumption is not considered in the production cost.
- The WWTP has invested around 5 157 159 € to produce ammonium sulfate. With 6% of interest rate and financed over 20 years, this investment should cost around 449 6524 € per year.
- The maintenance cost of the process is estimated at 3% of the total investment costs (≈153 714 €).

These calculations lead to a potential ammonium sulfate production cost of 313 € per ton without considering public fundings, or **302 € per ton** if the electricity consumption is provided by internal production. The electricity provided by CHPs support the value chain viability, but it remains non-viable economically.

The investment depreciation represents 65% of the production cost. Extending the depreciation period or the interest rate should reduce the production cost. Considering public fundings or increasing the market value of the ammonium sulfate could also improve the value chain economy.

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[17] Electricity price in Germany= 304,3€/MWh
https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

[18] MWh average price produced by natural gas combustion with boilers in Europe = 33,85€/MWh

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Environmental aspect*:*
Compared with the pre-existing value chain of sludge, the environmental impact of the value chain will be noticed on the following aspect.

- Transport

As struvite precipitation, ammonium sulfate recovery implies transports for chemicals supply and to deliver the by-product. With chemical suppliers location estimated at 100 km of the WWTP, the new travels to deliver the ammonium sulfate and for chemical supply should emit around **10,9 tons of CO_2 eq. per year**.

- N_2O released from sludge on fields

The emissions of CO_2 eq. related to N_2O released from sludge on fields can be avoided thanks to the ammonia stripping. This could be studied to assess the global impact of the value chain.

The environmental impact related to the energy consumption of the ammonia recovery process will be studied in detail in the WP2 (D2.1).

5.1.5.5. Barriers and drivers to implement ammonium sulfate value chain

Drivers
The following drivers are based on feedbacks collected from the case study:

- Nitrogen load reduction:

The main driver for WWTP is the reduction of the return load with ammonium. The WWTP is overloaded with nitrogen and side stream removal of N helps to cope with the legal limits for effluent N of the WWTP.

- Potential low CO_2 emissions of the recovery process:

The ammonium sulfate in solution from caprolactam production could subtitute ammonium fertilisers resulting from Haber-Bosch process. In this case, the unit of Braunschweig could have a lower carbon footprint to produce ammonium.

- Circular economy on regional level:

The case study mentioned that the potential viability of this value chain could be an example of circular economy at the regional level, which can be a driver for its implementation.

- Pure by-product:

As the ammonium sulfate is made with spontaneous chemical reaction, high quality and/or purity of these products should be ensured for reaching the market standards[19].

[19] Environmental and Economic Sustainability of Swine Wastewater Treatments Using Ammonia Stripping and Anaerobic Digestion: A Short Review

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- Regulation about the reuse of sludges:

Due to the new legislation in Germany, since 2017 only 70% of the digestate can be applied on the fields. Periods for fertilization with digested sewage sludge are now restricted and the nitrogen load of the fields are limited. Thus, the other 30% of the digestate are dewatered and incinerated.

Barriers

The following barriers are based on feedbacks collected from the case study:

- High investment costs for WWTP:

WWTP has invested around 5 157 159 € to implement the ammonia stripping unit, which is a high investment for a WWTP that can hinder the value chain deployment.

- Storage issue:

Fertiliser demand is mainly in springtime. The seasonal demand complicates the storage as it implies large tanks for ammonium sulfate solution. It is an additional investment for WWTP, and it also requires space that all WWTPs do not have.

5.1.5.6. New business cases

The business canvas of the value chain presented in the Figure 18 summarises values assessed and highlights advantages and disadvantages for deploying the value chain.

Ecosystem of stakeholders

Main actors:
Ammonium sulphate producer: WWTP
Fertiliser producer: Soepenberg GmbH

Intermediary and actors:
Transport is managed by the fertiliser producer, Chemical suppliers

External actor:
End-users: farmers and gardeners

Key activities
Ammonia stripping
Processing to fertiliser
Transport and storage

Key resources
Ammonia stripping unit
Trucks
Large tanks

Stakeholders relationship
Classic business relationship (to be improved)

Economic Value
Sales of the ammonium sulphate

Environmental Value
Production of a circular resource
Potential emissions of N_2O avoided

Territorial Value
New synergies between regional organisation
An example for the region

Cost structure
Investment: 5 157 159 € | Chemicals: 59 307 €/y
(Electricity consumption: ≈ 26 656 €/y, if not provided by CHPs)
Maintenance cost: ≈154 714 €/y | Labor cost (TBD)| Transport
→ Total production cost: 302 €/t

Impact of the organisations
WWTP: Studied in WP2
Transport: +10,9 t CO_2 eq./y
Fields: N_2O emission from sludge avoided (WP2)

Public funding
Subsidies from national and international authorities to implement the synergy

Revenue stream
Sales revenue: ≈17 600 €/y
→ Total production revenue and saving: 8 €/t

Global impact
If the process is replicated, it potentially reduce nutrients discharge and emissions (studied in WP2)

Public non-financial cost and benefits
Nitrogen load restrictions
REACH certification

Figure 18: Business canvas centralised on the ammonium sulfate resource

Recovering ammonium sulfate from wastewater is not economically sustainable due to the low ammonia concentration.

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The intention for the Braunschweig WWTP is to have a robust process to reduce Phosphate and especially Nitrogen in the effluent to stick with the limits of new water directives. Fertiliser production is not the primary intention.

5.1.6. Policy recommendations to foster Braunschweig case replication

The previous value chain analysis highlighted several policy recommendations to foster the replication of the struvite value chain:

- P-mineral and raw material supplier:

The phosphate rock is still cheaper than the phosphate in the struvite. Unfortunately, it directly affects the market value of the recovered resource which makes the value chain uncertain or not viable. More governance or regulations related to the importation of the phosphate from mines, and promotion of the recovered materials should foster circular value chain viability.

- Fertilizer regulations:

As seen in Braunschweig case, two of the main drivers for implementing struvite precipitation process was the legislations that restrict periods of the sewage sludge used as a fertilizer and the P return load in WWTP.
This regulation has been implemented for reducing nitrates in groundwater and environmental reasons. However, the implementation of P recovery products in the fertilizer regulation should directly foster struvite value chain creation.

- Struvite end-of-waste status:

The end-of-waste label is currently governed under national legislation which hinders the reuse of secondary phosphorus-containing products and generate trade barriers between countries. Struvite cannot legally be transported across national boundaries unless both countries approve it without a proper registration. The EoW status should be more homogeneous across EU countries.

- Subsidies:

With the significant investment cost for the solution, the return on investment is still uncertain for WWTP. Public funds are necessary to continue to deploy good practices before regulations and technological development makes the value chain more viable.

- Raise awareness about nutrient potential:

The low interest from society for the P-recovery is due to the invisible role that the phosphate has in the environment and the unattractiveness of sewage treatment[20]. The majority of food consumers are not aware of issues regarding phosphorus, at least in view of it being an

[20] Schipper, W. Phosphorus: Too Big to Fail. Eur. J. Inorg. Chem. 2014, 10, 1567–1571. [CrossRef]

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essential finite resource nor its environmental effects[21]. However, acceptance among the farming community and important market players will be decisive for the value chain exploitation. This current public perception can hinder the deployment of the value chain. It is necessary to raise awareness about the phosphate use.

[21] Withers, P.J.; van Dijk, K.C.; Neset, T.S.S.; Nesme, T.; Oenema, O.; Rubæk, G.H.; Schoumans, O.F.; Smit, B.; Pellerin, S. Stewardship to tackle global phosphorus inefficiency: The case of Europe. Ambio 2015, 44, 193–206

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5.2. CS 2 – Costa Brava Region (SP)

5.2.1. Description of the CS

5.2.1.1. *Challenges*

Costa Brava is a touristic region located on the Mediterranean, in the northeast corner of Spain. Costa Brava is characterized by high water seasonal demand and frequent water scarcity episodes, also causing saltwater intrusion. It is one of the first areas in the uptake of water reuse of Europe, with 18 EDAR and 15 full-scale tertiary treatment that provide 2,5 hm^3/year (2020) for agricultural irrigation, environmental uses, non-potable urban uses and, recently, indirect potable reuse.

5.2.1.2. *Circular solution*

The Operator Consorci Costa Brava (CCB) aimed to implement more flexible uses of reclaimed water. To do so, a pilot system has been implemented at Tossa de Mar WWTP to the existing tertiary treatment to provide water for sensitive uses (private garden irrigation and/or indirect potable reuse). The tertiary treatment at the start of NextGen was as presented in the following figure:

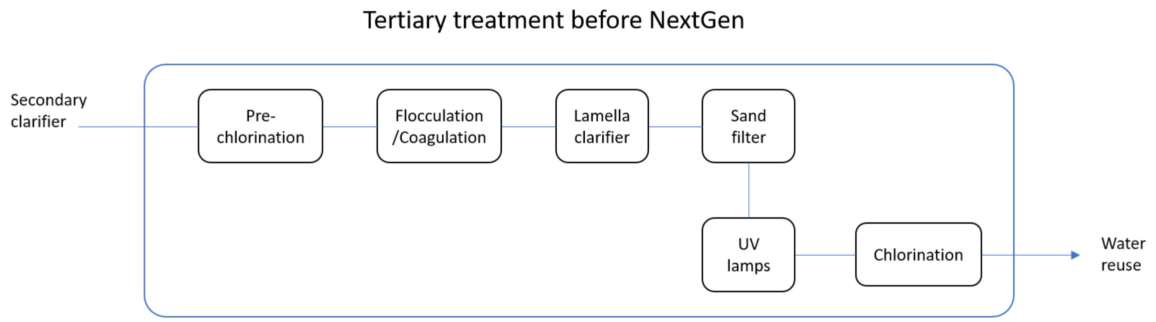

Figure 19: Tertiary treatment before NextGen

The pilot plant integrated by ultrafiltration (UF) and nanofiltration (NF) modules, this last one fitted with RO regenerated membranes was installed in December 2019. It has been located within a sea container of 20 feet (6.05m) and is fed with water from the sand filter of the tertiary treatment. The new scheme is presented in the following figure.

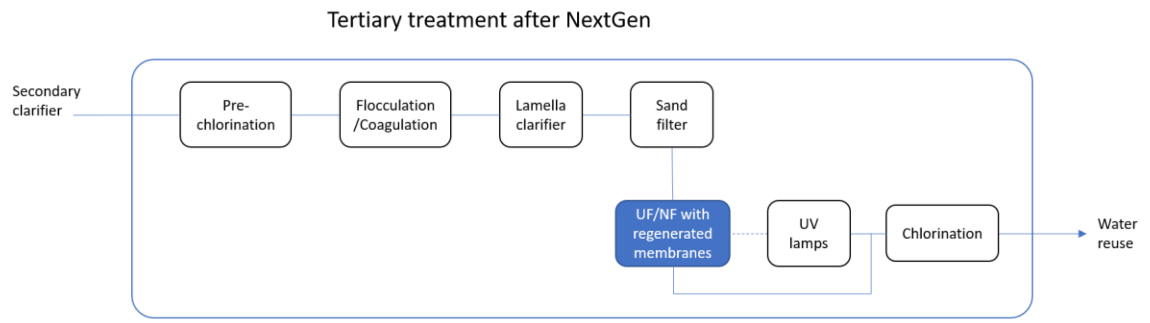

Figure 20: Tertiary treatment after NextGen

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The pilot plant consists of a 50 µm mesh filter to remove the coarse particulate matter coupled to a UF and NF stage. UF system operates with commercial membranes while NF stage is based on regenerated RO membranes.

The pilot plant has a maximum production flowrate of 2.2 m^3/h, but nowadays is operating at 1.4 m^3/h. The water produced is disinfected by the online addition of sodium hypochlorite and it is stored in a 10 m^3 tank. This tank is placed in an easily accessible area, from where the water tank truck can pick it up and distribute it to the end-user sites.

The main objectives of the implementation are:

- Regenerate end-of-life reverse osmosis (RO) membranes to obtain different molecular cut-offs to be used in the multipurpose fit-for-use reclamation system.
- Product fit-for-use water quality for sensitive uses to extend the use of reclaimed water in the area: irrigation of private gardens and, theoretically, indirect potable reuse through aquifer recharge.
- Integrated urban/regional water cycle optimisation including all the relevant actors.
- By this way, the time-life of RO membranes will be increased, and the generated quantity of this waste diminished.

5.2.1.3. Status of the democase

Currently, the membrane system is implemented at pilot scale and the membranes are being regenerated at Eurecat's facilities. The regenerated water distribution started in July 2021, and is being used to irrigation by some neighbours from Tossa del Mar.

5.2.2. State of the art of streams before NextGen solution

5.2.2.1. Pre existing value chains of Costa Brava case

In Costa Brava's democase, since the WWTP is public instead of a private company, the main value chain was water. Before NextGen, and as mentioned before, the WWTP was treating the incoming municipal wastewater to produce water that was partly being used to irrigate public gardens. When not used, water is partly discharged to a river (see figure below).

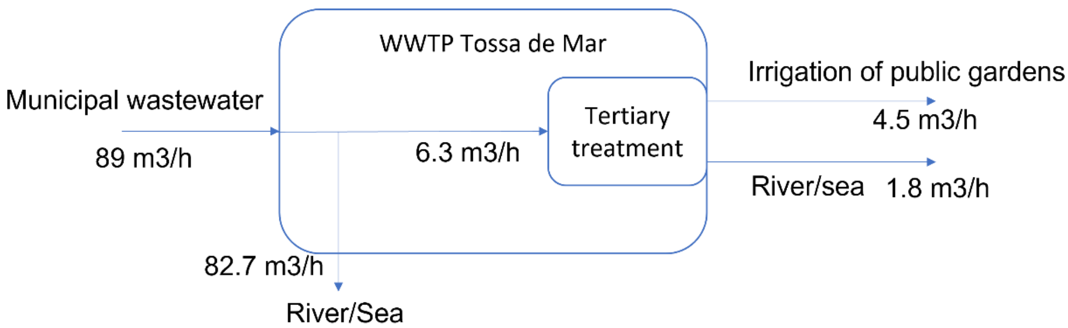

Figure 21 - Pre-existing value chain of Costa Brava case

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5.2.2.2. Identification and selection of new value chains

Thanks to the NextGen project, a new value chain has been added to the existing one regarding water due to the reclamation using membranes. Besides, the water value chain has been expanded. Both are described below.

5.2.3. Value chain 1: Water

5.2.3.1. Assumptions for the value chain analysis

After the installation of the pilot plant, the new membrane system improves the quality of the water. Regulation (Spanish RD 1620/2007) allows this higher quality water to be used to irrigate private gardens of close cities. Currently, 1 m^3/h of water is being treated by the new system but there is no estimation yet about the final demand of treated water for irrigation.

5.2.3.2. Scheme of the value chain

The new value chain of water is described in the following figure.

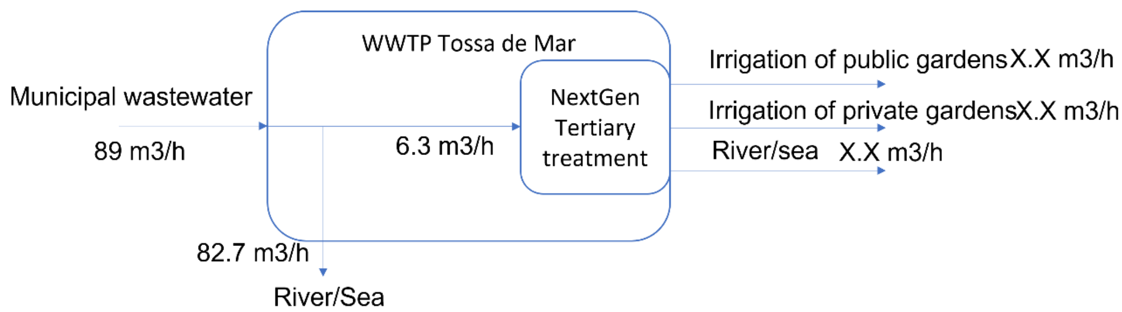

Figure 22: New value chain of water for Costa Brava

As mentioned before, the volumes that appear in the figure are those of the pilot. There are no estimation about the final setup once it is scaled up, it will depend on the cost of the produced water.

5.2.3.3. Stakeholders' involvement

The stakeholders identified in this value chain are:

1. Tossa de Mar city council.

The origin of the wastewater treated by the WWTP is Tossa de Mar. After the treatment with the regenerated membrane, the water is transported by a municipal truck to be used for irrigation by some neighbours. City Council is interested in this kind of actions because it may decrease the stress on potable water that some cities in the region suffers on holidays due to tourism. City Council may affect the final pricing of the water through subsidies to reduce it, promoting its use by citizens.

2. End users

Although nowadays few of them are taking part on the pilot. The water treated by the membrane system will be used in the future by neighbours from Tossa de Mar and close cities

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for irrigation. Nevertheless, this will be highly influenced by the final price of the treated water.

5.2.3.4. Value proposition and benefits of the value chain

In economic terms, there are still no estimations about the benefit. Calculations must be made about the cost of the treated water since price will have to be high enough to cover production and transport costs and low enough to be attractive for the potential users.

In environmental terms, the main benefit is to offer high quality treated water for irrigation so a decrease of potable water will be used for that end in an area where water scarcity is an issue. Besides, some support to aquifer recharge reducing the nature pressure over water use could be studied as well.

5.2.3.5. New business cases

Ecosystem of stakeholders	Key activities	Key resources
Main actors: WWTP and owners of private gardens Intermediary actors: Transport company External actor: Authorities that sets the water requirements for irrigation and the cost of water	Water Treatment **Stakeholders relationship** Classic business relationship Estimation of a price covering costs and accepted by clients	Tertiary treatment

Economic Value	Environmental Value	Social Value
Benefits from the regenerated water selling	Support to aquifer recharge reducing the nature pressure over water use	Job creation Rise awareness on water use

Cost structure	Impact of the organisations	Public funding	Public non-financial benefits
- Transport of regenerated water	- Carbon footprint producer - Carbon footprint transport - Carbon footprint receiver	Subsidies from local authorities to reduce the cost of the water	Circular opportunities created for the water sector.
Revenue stream - Sold water	**Global impact** Reduction on the used potable water.		

Figure 23 - Business canvas centralised on the water resource

The business case will come from the benefits of selling the treated water to be used to irrigation, but as mentioned above there is still no estimations about the costs of the full-scale plant and thus of the price of the water. This price will be affected by many factors: water demand, potable water price, transport costs, regeneration costs…

5.2.3.6. Barriers and drivers to implement the value chain

The main driver is the water scarcity of this area, combined with the high demand of water in some seasons due to tourism.

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The main barrier is the uncertainty about the business case since the cost of the produced water is not being estimated yet and there is no information about the price that potential clients would be willing to pay.

5.2.3.7. *Limitations of the study*

The main limitations of the study are related to the lack of available information. Nevertheless, estimations made are reasonable.

5.2.3.8. *Conclusion on the replication of the value chain and business potential*

The value chain and the business potential are easily replicable, but it is important to first find out if there is business case related to the selling of treated water. The price of water changes substantially from one country to another, and it's important to find out if the costs of regeneration and transport can be covered by the price of the regenerated water. Local or national authorities may help creating this kind of businesses in places where water scarcity is an issue through subsidies to decrease the price of the regenerated water.

5.2.4. Value chain 2: Regenerated membranes

5.2.4.1. *Assumptions for the value chain analysis*

The new membrane system has opened the opportunity to establish a new value chain based on the regeneration of membranes. Commercial membranes have a cost that can go from 100€ to 1000€ (For example, Dow Filmtec NF90-400 costs 907€[22]), while the regeneration of a membrane has an estimated cost of 18.4€. Furthermore, the water treated with regenerated membranes has a lower quality than the one treated by commercial membranes, but there are still many used for this kind of water that makes it an opportunity for a business case.

Before the NextGen project, membranes were disposed to landfill or incinerated. Currently membranes are being regenerated in Eurecat's laboratories. Once the system is operating full scale, the idea is to create a spin-off company devoted to the regeneration and selling of those regenerated membranes.

5.2.4.2. *Scheme of the value chain*

The new value chain of water is described in the following figure.

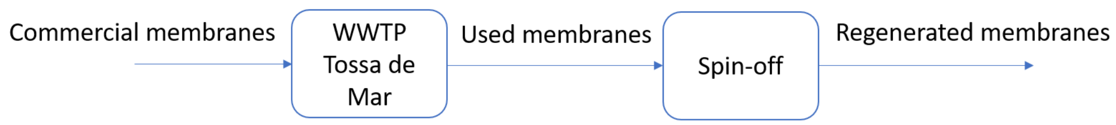

Figure 24 - New value chain for membranes in CS2

Some estimations will have to be made about the generation of used membranes, since each membrane last 5 years as average to check if make sense to create the spin-off company based on them.

[22] https://www.bigbrandwater.com/nf90-400.html

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5.2.4.3. Stakeholders' involvement

Currently membranes are being bought to providers such as Dupont, Big Brand Water Filter Inc. Once the decision about creating the spin-off company is made, the value chain will be expanded.

Used membranes can come from different WWTP treating different kinds of waste streams. Membranes used for different applications may give different water qualities after regeneration. An analysis of different sectors will be made in order to identify the most appropriate sector to obtain membranes to be regenerated and to use the regenerated membranes. This analysis will be used to identify the right stakeholders in each case.

5.2.4.4. Value proposition and benefits of the value chain

In economic terms, the regeneration of membranes is a very cheap process (in comparison to a commercial membrane), so costs can be reduced that way. A deeper analysis will have to be made once the decision of creating the spin-off company is made.
In environmental terms, regenerating the membranes reduces the disposal of waste in landfill or its incineration. Membranes can be reused for lower stringent applications such as water reclamation.

5.2.4.5. New business cases

The use of regenerated membranes could reduce considerably the costs of acquisition of membranes since the regeneration process is quite cheap. Nevertheless, there are some barriers as well:

- It's necessary to find sources of used membranes to be regenerated. If there are not a high density of such us providers close to the spin-off, the transport cost may increase the cost of the regenerated membranes.
- Similarly, it's necessary to explore a market for the regenerated membranes. Regulations would help in this case if companies were obliged to use treated water for irrigation or similar applications.
- Depending on the source of the used membranes, the quality of the treated water by the regenerated membranes may be different, which is a key point due to the regulations and restrictions to the use of treated water.

The following business canvas have been developed for this business case:

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Ecosystem of stakeholders	Key activities	Key resources
Main actors: WWTP providing used membranes Intermediary actors: Transport company External actor: Authorities that sets the water requirements for different uses	Storage Treatment Transport	Membrane regeneration systems
	Stakeholders relationship Classic business relationship Collaborations to get used membranes	

Economic Value	Environmental Value	Social Value
Savings from the use of cheaper membranes	Enlargement of the lifetime of membranes	Job creation

Cost structure	Impact of the organisations	Public non-financial benefits	Public funding
- Investment to create the spin off (CAPEX) - Operational and transport expenditures (OPEX)	- Carbon footprint producer - Carbon footprint transport - Carbon footprint receiver	Advantages for circular materials	Subsidies from local authorities to implement regenerated water systems
Revenue stream - Selling of the regenerated membranes	**Global impact** Promotion of the use of regenerated water		

Figure 25 - Business canvas centralised on the regenerated membranes in a selling scenario

Another business possibility comes from delivering a service regarding the treatment of water instead of selling the regenerated membranes. The service could be based on the use of regenerated membranes to build low quality water treatment units to be rent to specific uses. The business model would include a pre-analysis of the wastewater stream to be treated by the regenerated membrane and its possible fluctuations. Based on this analysis, a water treatment system could be designed including the right regenerated membrane and monitoring systems to assure the right quality of the water. The system could be rented, and the service could include maintenance and the reposition of the membranes when the quality of the water goes down the quality requirements. Systems could be retired and used somewhere else.

The canvas in this case would be the following:

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Ecosystem of stakeholders

Main actors:
WWTPs providing used membranes

Intermediary actors:
Transport company

External actor:
Authorities that sets the water requirements for different uses

Key activities

Transport
Analysis
Designing
Monitoring
Maintenance

Key resources

Membrane regeneration systems
Monitoring systems

Stakeholders relationship

Renting systems
Collaborations to get used membranes

Economic Value	Environmental Value	Social Value
Renting the systems	Enlargement of the lifetime of membranes and treatment systems	Job creation

Cost structure	Impact of the organisations	Public non-financial benefits	Public funding
- Investment to create the spin off (CAPEX) - Operational, maintenance and transport expenditures	- Carbon footprint producer - Carbon footprint transport - Carbon footprint receiver	Advantages for circular materials	Subsidies from local authorities to implement regenerated water systems
Revenue stream - Renting of the water treatement systems	**Global impact** Promotion of the use of regenerated water		

Figure 26 - Business canvas centralised on the water treatment service in a renting scenario

5.2.4.6. Barriers and drivers to implement the value chain

Drivers

In both cases, the main driver is the cost saving thanks to the use of regenerated membranes instead of new ones.

Barriers

There are some barriers related to the use of regenerated membranes that have been mentioned already:

- Membranes have a long life, what may make difficult to find membranes to be regenerated. Transport costs of used membranes may increase the cost of regenerating the membranes.
- The quality of the water treated by regenerated membranes may be different depending on the previous use of the membrane, what means that the treated water needs to be analysed to assure that its quality is adequate.

Regulations about the use of treated water change from one country to another, the analysis of the adequation of the regenerated water for different uses will have to be done case by case.

5.2.4.7. Limitations of the study

The main limitations of the study are related to the lack of available information. Nevertheless, estimations made are reasonable.

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5.2.4.8. Conclusion on the replication of the value chain and business potential

The value chain and the business potential can be replicated but is important to first analyse the national restrictions to the use of treated water and its quality levels. Apparently, there is a business potential due to the reduced costs of the regeneration of membranes, but some issues should be solved to assure the quality of the water. Although in this case the proposed used of the regenerated water is irrigation, other uses may be explored considering regulations and necessities that may make more attractive the business case.

The first business case about treating and selling the regenerated membranes can be attractive in areas where there is a high density of such as systems being used if the regulations allow the use of such as treated water. The second business case about the renting system can have a wider field of use, again restricted by regulations.

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5.3. CS 3 – Westland Region

5.3.1. Description of the CS

Westland is a region in the west of the Netherlands, where several pilots in the water sector are running and being studied. For this value chain analysis, two of the most representative value chains are described. These are the value chain of sewage sludge (also referred to as sludge) and aluminium sludge.

5.3.1.1. Challenges and/or opportunities

This case study contains several testing grounds in the Westland region. The Westland region is a highly densely populated region in the Netherlands, where also lots of water flows exist (river mouth of the rhine branches and lots of local flows). Combined with the presence of not only water treatment plants and wastewater treatment plants, but also lots of greenhouses, great opportunities arise for generating water and related residual flows. Another opportunity is the presence of AquaMinerals in the Netherlands, which has a lot of experience in the business development of new value chains.

Challenges that occur are those same greenhouses, that consume lots of energy and water, and a sustainable method for extracting the residuals from wastewater treatment plants.
In the case of the two value chains that will be described for the Westland case, both value chains have their challenges, especially for the initiator trying to develop a pilot (or idea, project) further to full scale. In general, the search for potential partners is difficult, because new production techniques need to be developed. This requires an investment; partners are not always willing to take that risk due to the various uncertainties. It is not only the investor that is needed to step in but also the full-scale operator of this new technology is often hard to find.

5.3.1.2. Circular solution

The chosen new value chains are the value chain of (1) municipal wastewater sludge and (2) aluminium sludge originating from drinking water production. The basic materials are the same as in the situation before NextGen, but both the sludge and the aluminium sludge will be processed and find a new application in the new value chains. This new application is more economic valuable, and moreover more sustainable.

(i) Municipal wastewater sludge value chain

The circular solution is the usage of sludge in the cement industry where both the caloric value as chemical composition (the present Al, Ca and Mg) is used. Therefore, sludge needs to be dried. This is an extra part of the value chain, after dewatering on-site at the water company, which also happens in the before situation.

(ii) Aluminium sludge value chain

A third party called Netics has developed a method for making shaped building blocks out of soft sediments, such as aluminium sludge. This technique has been proven in other markets. For example, blocks made out of local soft sediments are used in a sound-resisting wall. To

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use this method with aluminium sludge, a dewatering of the sludge to 23% before is required before processing.

These two value chains will be discussed separately in the chapter below.

5.3.1.3. *Status of the demo case*

Both chosen value chains are currently showing good potential. However, both value chains are still being developed and therefore not (completely) operational.

5.3.1.4. *Limitations of the study*

In both value chains, assumptions were made on the future situation. Both value chains are not completely operational at this moment. These assumptions naturally affected this study, as actual data is always more reliable than assumed data. However, the expertise in AquaMinerals does not doubt these assumptions, but the study could be more accurate with actual data.
The prices of alternative energy sources are highly volatile at this moment. They not only follow the spot markets of the fossil fuels, but due to policy measures that have an influence on CO_2-pricing (ETS, taxes) the biogeny sources added another prices mechanism. It is therefore difficult to predict what the prices will be of the dried sludge in the future. At this moment (medium 2021), the expectations are that they will be developed positively for the water authorities since demand will rise.

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5.3.2. Pre-existing municipal wastewater sludge value chain

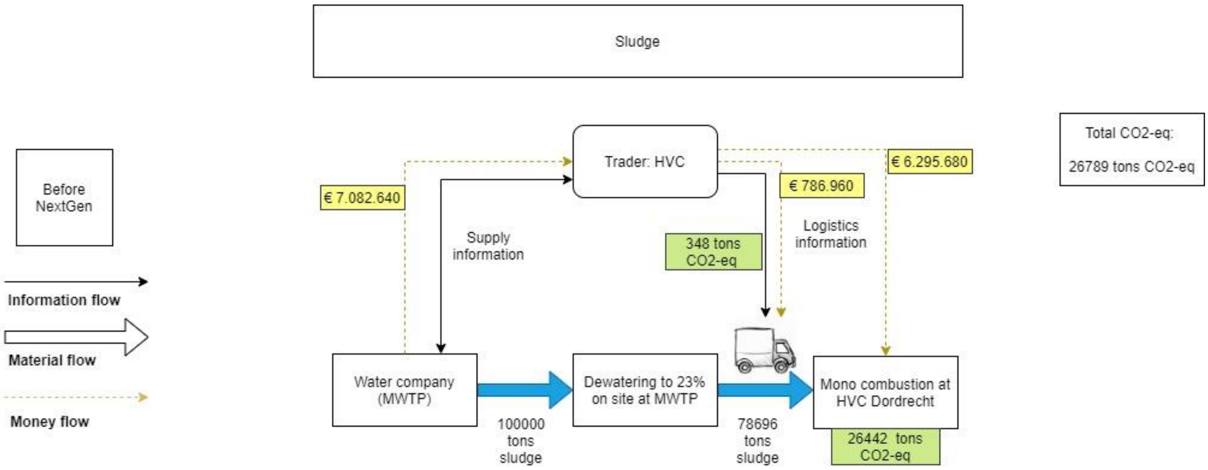

Figure 27: Sludge before NextGen

Streams' description:

In this before situation, the residual sludge generated by the water treatment plant (called water authority of Delfland) is transported to a combustion plant (called HVC), after being dewatered on-site at the MWTP.

In 2019, a total of 100,000 tons of sludge (equal to a 78 696 tons of dewatered sludge) was processed through this value chain. The water company pay HVC for the disposal of this sludge. HVC organizes the transport to its combustion installation, and the combustion itself. All data in this value chain scheme is actual data, as this value chain has been running for several years now.

Stakeholders' ecosystem:

In this value chain, the following stakeholders can be identified. For each stakeholder, its power or interest in the value chain is described.

1. Combustion plant: HVC

HVC is a company that has a core business in the combustion of household waste. HVC is currently in the transition of moving to a more circular business model, where waste is recycled to more sustainable applications. However, municipal wastewater sludge in the current situation is completely incinerated.

HVC is a big processor of waste. In most situations, this waste is being incinerated at HVC locations. HVC has a big interest in this value chain because the economic value is high for HVC. HVC's influence is also high, because (1) the water companies are in most cases shareholders in HVC and have therefore given each other long-term commitment and (2) the competition is limited and (3) the processing capacity is almost equal to the supply of sludge.

2. Water company: Hoogheemraadschap van Delfland

Water companies have a high interest in getting the sludge disposed. When this sludge would not be disposed, it should be stored somewhere on-site at the water company. However, water companies do not have any storage area available for sludge and even if this were the case, the storage would become full. Furthermore, the sludge is smelly. Quick processing is

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necessary to avoid complaints from local stakeholders. Therefore, water companies want to have the sludge disposed quickly and for the lowest price possible, compliant with regulations and with the best environmental impact possible. The power of water companies in the value chain is medium, as they also are a shareholder in HVC. When the water authorities want to change to another disposal route, they need to do that in close cooperation with HVC.

3. Transport company

Transport companies have a medium-sized interest in the value chain. For these companies, there is economic value in the value chain, but it does not matter what kind of material is being transported. The only aspect that makes the transportation of this kind of sludge different from other materials is that the haulier needs to take measures to control the odour. This is a relatively common measure, namely the closure of the containers with lids.
Therefore, transport companies are relatively exchangeable, which means that other transport companies should also be able to participate in the value chain. The power of transport companies is, for the same reason, relatively low.

Economic aspect:
With a disposal cost of 90 €/t, the water company pays 7 082 640 € to HVC for disposing of the dewatered sludge each year.

Environmental aspect:
The results are based on AquaMinerals data, which is involved in similar value chains in the Netherlands. The value chain scheme presents actual data, as the value chain is now mature.

Source of carbon emission	Value (unit)
Transport	4,42 kg CO2-eq/ton
Incineration	336 kg CO2-eq/ton
Total per ton	340.42 kg CO2/ton

The pre-existing value chain has, calculated with 78696 tons of sludge a CO_2-eq emission of 26,789 tons.

5.3.3. New value chain of municipal wastewater sludge

5.3.3.1. Assumptions for the value chain analysis

In this demo case, the solution is not fully integrated. In the sludge value chain, the suggested solutions are not yet implemented. The baseline situation is still the current situation. However, the solution in the sludge value chain is ready to be used at a full scale. Some operational challenges need to be faced before the value chain can start running.
Both the financial values and the CO_2 emissions are based on good assumptions, based on actual data in similar value chains.
The sludge value chain has a good potential to start. However, current contracts and interests are holding the new value chain back from being operational.

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5.3.3.2. Scheme of the new sludge value chain

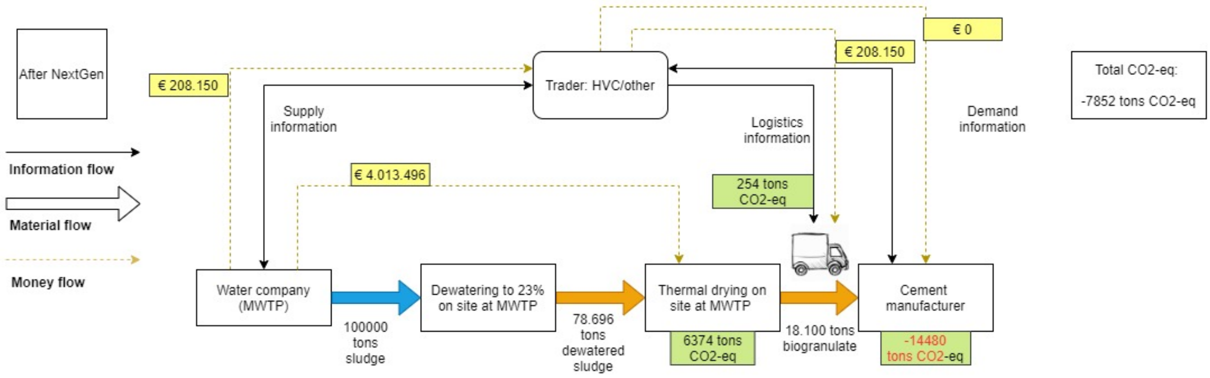

Figure 28: New value chain Sludge

In this value chain, sludge will still be dewatered on-site at the water company (MWTP). To create good quality sludge, an extra process step is needed. The sludge needs to be thermal dried. In this value chain, the choice was made to do this on-site at the water company. However, it is still possible to think of a scenario in which the thermal drying will take place at another third location. This latter adds transportation efforts but gains on either scale (when more manufacturers use this drying plant) or the use of residual energy.

5.3.3.3. Stakeholders' involvement

Main actors:

1. Water Company

The power of the water company has not changed much when compared to the before situation. The water company still has got sludge that needs to be transported. However, the water company also has circular ambitions. Therefore, the water company will support the transition in the value chain. Besides that, this value chain will provide an enormous financial benefit, that makes the interest of the water company high.

2. Cement manufacturer

This company is a cement manufacturer, that mostly produces cement from linear sources. In this value chain, the cement processor will not pay for the delivery of the sludge but will also not require an acceptance fee. Especially when compared to the before situation, which makes a difference in the total costs of the value chain. The interest of this company is medium, but its influence is high. If the cement actor decides not to accept the dried sludge anymore, the concept of this value chain expires.

Intermediary actors:

1. Trader

The trader fulfils the role of chain management, in which all information and money flow go through this company. The power and interest of this company are medium, as no big profit will be made from this value chain.

2. Transport company

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Transport companies are companies that have a medium-sized interest in the value chain. For these companies, there is some economic value in the value chain, but it does not matter what kind of material is being transported. In this case, the sludge is dried. Odour problems are much lower compared to the case where the sludge contains >75% water. Therefore, transport companies are exchangeable, which means that other transport companies should also be able to participate in the value chain. The power of transport companies is, for the same reason, relatively low.

3. Dryer

The municipal wastewater sludge is in this chain dried; thus an extra step is needed to go from dewatered sludge (23% dry matter) to dry sludge (> 95% dry matter). This position in the value chain is vacant but essential. This task can be executed by the water company itself, onsite, but also by another existing stakeholder in the value chain and that is the current incinerator. When either one of the two steps in, it will give them substantially more influence in the chain. There is also another option and that is a third, commercial, company stepping in and sell the drying (either on- or offsite) as a service.

Changes on the ecosystem and other stakeholders

Due to this new value chain, the business model of HVC will change. HVC will receive less sludge and will make less profit on the incineration of sludge. Therefore, HVC needs to look for another business model or find an alternative source of sludge. HVC is taking steps in establishing a sludge-dryer on their premises (where residuals warmth is available), giving them a good alternative business model. The same theory goes for the linear suppliers of cement (supply of Al, Mg and Ca). On the other side, the social impact is positive, as there is less carbon emission and high recycling of the resources.

5.3.3.4. Value proposition and benefits of the value chain

Economic aspect:

- Drying process:

Water companies need to invest in a thermal drying installation. Including operational cost, drying one ton of sludge cost 51 € to the MWTP, which corresponds to 4 013 496 € per year.

- Disposal savings:

The annual costs for the sludge disposal paid by the MWTP will decrease from approximately 7 M€ to around 200 k€. Considering the overall drying process cost, the MWTP could save 2,5-3 M€ annually thanks to the new process.

- Transport cost:

HVC pays for the transport of the 18 100 tons of biogranulates around 208 150 €.

The disinvestment of the current incineration plant has not been included in the calculation. The technical and financial life cycle is not at its end and will be carried out in the WP2.

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Changing to this alternative value chain will lead to reasonable large costs for HVC and as a shareholder, these costs might (partly) be brought back to the water authority involved.

Environmental aspect:

- Carbon emission reduced

The total carbon emission will be reduced in the sludge value chain. According to a dewatered sludge disposal of 80 000 tons a year, which is the current amount of sludge, there is a carbon emission of 26 789 tons CO_2-eq a year in the situation before NextGen. In the situation after, there is a total of -7 852 tons CO_2-eq. This difference can be explained by the fact that in the post NextGen situation, linear resources are avoided, and water is no longer incinerated but removed in an energy-efficient way. The carbon emission of the linear resource is subtracted from the carbon emission in the production process of the cement processor. The data on the new situation is assumed data, as this value chain is not completely operational. This data has been requested from experts at AquaMinerals, as they are also operational in the same area and have expertise on different value chains.

- Volume of raw materials consumption reduced

Raw materials that are used in the situation before NextGen and not in the situation after NextGen can be seen as a reduction.

In the new situation, about four times less sludge will be incinerated, because of the new drying installation. In cement processing, every ton of sludge will replace about a ton of treated wood in the oven. Moreover, every ton of sludge that is processed into cement, will replace chemicals that a sludge processor used to buy, such as calcium, magnesium and aluminium.

In total, an amount equal to 18 100 tons of treated wood is avoided in the new situation, which has a positive impact on the CO_2 emission.

- Amount of renewable energy produced

In the situation before NextGen, 75% more water was incinerated, which harmed the renewable energy produced. For that reason, the new situation will produce more renewable energy in the production process of the cement manufacturer, as the process will be more efficient.

- Barriers and drivers to implement the municipal sludge value chain

Drivers

Drivers are the financial benefit and the reduction of the carbon emission in the value chain. Besides that, wastewater treatment plants are aware of their role in a circular economy and a sustainable future. Therefore, they are willing to invest in the value chain. Moreover, in the future, new regulations may arise, in which sludge may no longer be incinerated. This could be a long-time driver for water companies.

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Barriers

The main barrier is the long-term contracts that HVC currently has with the water companies based on the high investment in the current incineration plants. This will obstruct this value chain from starting.

5.3.3.5. Business case of the new sludge value chain

The Figure 29 summarises the business model of the sludge value chain in Westland case.

Ecosystem of stakeholders	Key activities	Key resources
Main actors: Dried sludge producer: WWTP Incinerator: Cement actor	Dewatering | Drying | Transport | Cement activities	Thermal drying process Trucks Tanks for sludges storage
Intermediary and external actors: Transport company Trader | Other actors to be defined	**Stakeholders relationship** Classic business relationship	

Economic Value	Environmental Value	Territorial Value
Savings: Incineration cost avoided	Production of a viable resource Reduction of raw material consumption in cement industry	New synergies between regional organisation In Westland, the WWTP has to stop a long term contract with the previous actor which used to incinerate the sludge
Cost structure Investment + process cost: 4 013 496 € Annual transport: 208 150€ → Total production cost: **233 €/t**	**Impact of the organisations** WWTP: Studied in WP2 Transport: -94 t CO_2 eq./y Cement: No changes	**Public funding** No data
Revenue stream Avoided incineration ≈ 6 295 680 €/y → Total savings by drying sludges: **348 €/t**	**Global impact** Drying sludge is more energy efficient and avoids the incineration of water →Total emission of the value chain **≈ -7 852t CO_2 eq./y**	**Public non-financial cost and benefits** Future restriction about the incineration of the sludge

Figure 29: Business canvas centralised on the sludge resource in Westland case

The value chain appears to be economically viable and coming restrictions could foster its replication in other WWTPs.

The business potential in the sludge value chain is mostly the cost and carbon footprint reduction for water companies. The carbon footprint reduction has also internal virtual pricing at water companies of 60-100 €/t.

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5.3.4. Pre-existing value chain aluminium sludge

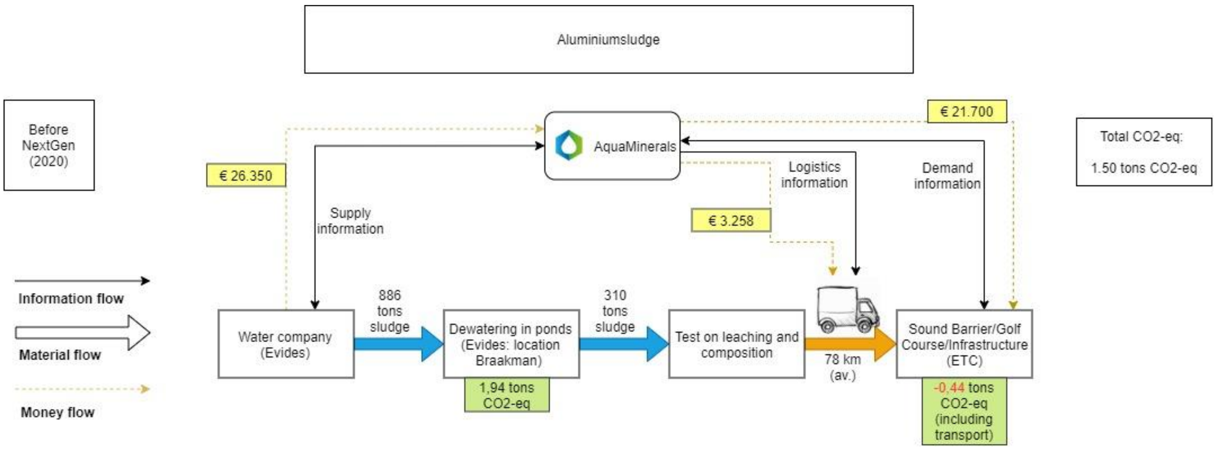

Figure 30: Aluminium sludge before NextGen

Streams' description:

In this pre-existing situation, the aluminium sludge that is eliminated from the water treatment process of Evides, is processed for usage in infrastructural works, such as sound barriers, golf courses and other massive infrastructural usages. Therefore, the aluminium sludge needs to be dewatered on site at Evides. AquaMinerals is a partner in this value chain and arranges the information and financial flows.

Stakeholders' ecosystem:

1. Water company (Evides)

The water company, in this value chain Evides, has a high interest in the value chain, as the sludge needs to be disposed of the water treatment plant. Evides is the actor in the value chain that pays for this disposal. The power of Evides is medium, as Evides is the supplier in the value chain, but not accountable for the usage in the value chain, which is the role of AquaMinerals.

2. Transport company

Transport companies are companies that have a medium-sized interest in the value chain. For these companies, there is some economic value in the value chain, but it does not matter what kind of material is being transported. Therefore, transport companies are exchangeable, which means that other transport companies should also be able to participate in the value chain. The power of transport companies is, for the same reason, relatively low.

3. Customer (Infrastructure)

The customer in this value chain is the infrastructural sector. AquaMinerals (eventually Evides) pays an acceptance fee to these companies for the delivery of the dewatered aluminium sludge. Their interest is medium, as they do get a sustainable material flow, but the aluminium sludge is also easily exchangeable. Their power is relatively low, as there is not much influence on the entire value chain.

4. AquaMinerals

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In this value chain, AquaMinerals has the role of chain management, which means that all information- and money flows are going through AquaMinerals. AquaMinerals has, in that role, high power on the chain. The interest is medium. Important for AquaMinerals is to fulfil the role of chain management to stay involved in this value chain, but there is no high economic value in this value chain.

Economic aspect:
Each year, the water company pays around 26 350 € to AquaMinerals to reuse aluminium sludge in different sectors.

Environmental aspect:

- Dewatering process:

Data is based on AquaMinerals expertise involved in the case study. A previous LCA study showed that the dewatering process emits 2,19 kg CO_2-eq per ton of sludge dewatered. With a total of 886 tons of sludge dewatered per year, around 1,94 tons CO_2-eq is emitted by the process.

- Raw materials consumption avoided

Assumptions	Value	Units	Source
Dry matter that replaces a primary source	10	%	AquaMinerals
Dry matter in aluminium sludge	20	%	AquaMinerals
Sand production carbon footprint	0,0043	kg CO_2-eq/kg	NMB sand

Dried aluminium sludge (DM = 20%) can replace sand in sound barrier sector, which is a linear raw material. Therefore, the carbon footprint of sand production can be avoided. This dry matter can replace a 10% of the primary source used to produce the sound barrier. For each ton of aluminium sludge reused, 20 kg of sand is not used in the sound barrier sector which corresponds to **0,0859 kg CO_2-eq.**

The reuse of aluminium sludge should avoid the use of around 620 kg of sand per year which corresponds to **2,66 kg CO_2-eq per year**.

- Raw materials transport avoided

Assumptions	Value	Units	Source
Average transport distance	78	km	AquaMinerals
Average transport carbon footprint	0,0846	kg CO_2-eq/tkm	TLN (Transport & Logistics Netherlands)

For each ton of aluminium sludge reused, 20 kg of sand is not used in the sound barrier and not transported which corresponds to **0,132 kg of CO_2-eq avoided.**

In the Westland case, **40,91 kg of CO_2-eq** related to raw materials transport per year.

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- Transport of aluminium sludge:

With the previous assumptions, the transport of the aluminium sludge should emit around **2,05 tons of CO_2-eq per year.**

The pre-existing value chain of the aluminium sludge management should emit around **1,5 tons of CO_2 eq** per year.

5.3.5. New value chain of aluminium sludge

5.3.5.1. Assumptions for the value chain analysis

In the case of aluminium sludge, technology is still being developed by a third party, called Netics, and is on its way. Netics is already able to show hopeful first results, but implementation will not be possible before the end of 2021. An important note on this value chain, is that the *avoided* impact will be compared. To clarify, in the before situation already has a negative carbon footprint, the after situation has got an even more negative carbon footprint.

5.3.5.2. Scheme of the Aluminium sludge value chain

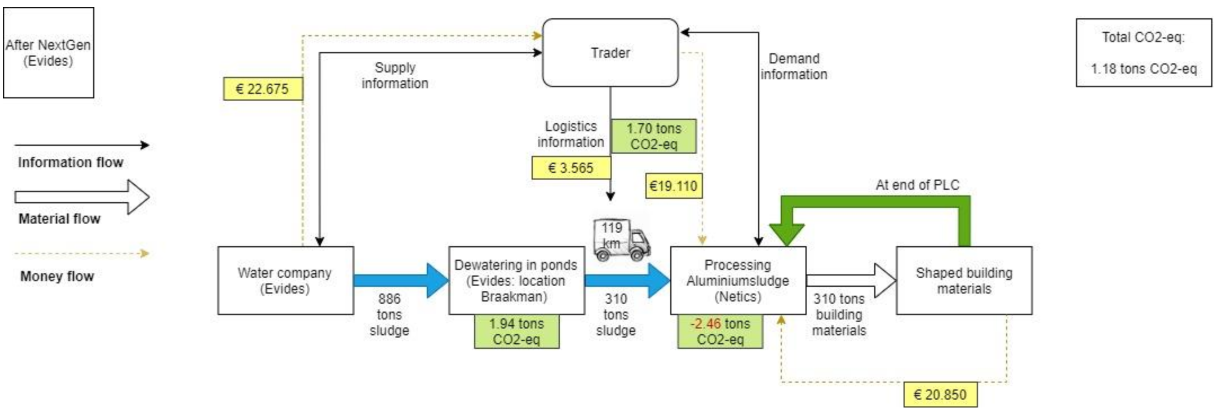

Figure 31: Aluminium sludge after NextGen

In this value chain scheme, sludge will still be dewatered on-site at the water company. From here, sludge will be transported to a third party, called Netics. Netics processes the aluminium sludge to shaped building materials. These materials are designed to be reused at the end of their product life cycle (PLC).

5.3.5.3. Stakeholders' involvement

Main actors

1. Water company (Evides):

The water company, in this value chain Evides, has a high interest in the value chain, as the sludge needs to be disposed from the water treatment plant. Evides is the actor in the value chain that pays for this disposal. The power of Evides is medium, as Evides is the supplier in

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the value chain, but not accountable for the usage in the value chain, which is the role of the trader.

2. Netics:

Netics is a company that has expertise in stabilizing and reusing sludges into shaped building materials (such as bricks). The interest in this value chain is high, as Netics want to prove it can make shaped building materials out of aluminium sludge. Furthermore, if this value chain is up and running, this technology can be exported to other countries. Coagulation with aluminium salts is very common as well as the use of shaped building materials, giving Netics a potentially large market and therefore create a financial benefit for Netics. The power is also relatively high, as Netics is currently the only company that is willing to invest in this technique and has the knowledge to do so.

Intermediary actors

1. Trader

In this value chain, a new trader could have the role of chain management, which means that all information and money flows are going through this trader. The trader has a moderate influence on the chain implementation, but it facilitates the relation between stakeholders. Its interest is medium. The trader needs to fulfil the role of chain management to stay involved in this value chain, but there is not a big economic value for this value chain.

2. Transport company

Transport companies are companies that have a medium-sized interest in the value chain. For these companies, there is some economic value in the value chain, but it does not matter what kind of material is being transported. Therefore, transport companies are exchangeable, which means that other transport companies should also be able to participate in the value chain. The power of transport companies is, for the same reason, relatively low.

5.3.5.4. Value proposition and benefits of the value chain

Economic aspect:

For the water companies, an economic benefit is in this new value chain. Based on the historic amount of aluminium sludge, which is 886 tons a year, the new annual costs for water companies should be 22 675 €. This gives an economic benefit of 3 675€ a year in comparison with the previous annual cost.

This seems to be a minor benefit as it comes to a stream of fewer than 1 000 tons of sludge per year. It must be noted that this is also small compared to the use of aluminium coagulant in other water production sites elsewhere in Europe, meaning that the business case will be much interesting at places with larger volumes. These figures are based on actual data from the current value chains and reliable data from AquaMinerals of the new situation.

The investment should be made by Netics. These costs are unknown by the project but were incorporated in the annual costs given by Netics and presented above.

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Environmental aspect*:*

- Reduce raw materials extraction

Out of 1 ton of aluminium sludge, 84 bricks of shaped building materials can be produced. This means that in the total value chain, given the amount of 310 tons dewatered sludge, 26 040 bricks can be produced based on circular resource

- Carbon emission reduced

In the pre-existing situation, the total carbon emission is 1,50 tons CO_2-eq for the management of 886 tons of sludge a year. The new value chain should emit around 1,18 tons CO_2-eq.
This gives a reduction of 0,34 tons CO_2-eq a year. There is a carbon reduction, because when using aluminium sludge in shaped building materials, linear resources (such as resources for street vowels, for example clay and fine sand) are avoided. These applications have a larger impact than the production of sound barriers as used in the pre-existing situation.

5.3.5.5. Barriers and drivers to implement the aluminium value chain

Drivers

Drivers are the ambition to participate in a complete circular value chain and the interest for the business potential.

Barriers

Barriers are the technology that is still in research by Netics, which is the reason that this value chain is still not running. The first industrial try of the process should happen by the end of 2021.

Aluminium sludge had the challenge that this residual has a certain kind of scarcity. Aluminium sludge has a potential for further use, but it has not a big volume, certainly not in the West-land region. This makes it hard to find a customer for the aluminium sludge because customers are looking for business potential and thus scale, in which higher volumes can be processed.

5.3.5.6. Business case of the new sludge value chain

The Figure 29 summarises the business model of the aluminium sludge value chain in Westland case.

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Ecosystem of stakeholders

Main actors:
Aluminium sludge producer: WWTP
Netics facilitates and process the aluminium sludge

Intermediary and external actors:
Trader
Transport company
Other actors to be defined

Key activities
Dewatering | Processing to shaped building materials |Transport

Key resources
Trucks
Process of Netics

Stakeholders relationship

Classic business relationship with a trader that still has to be defined (WWTP? Netics?)

Economic Value
A revenue stream improved for the WWTP thanks to a new application
New business activity in circular economy (Netics)

Environmental Value

Production of a circular resource
Reduction of raw materials consumption

Territorial Value
New synergies between regional organisation
Raw materials independence
Buildings with circular resources

Cost structure

Investment by Netics (no data)
Processing cost paid by WWTP: 19 110 €/y
Transport: 3 565 €

Impact of the organisations
WWTP: studied in WP2
Dewatering: +1,94 tCO_2 eq./y
Transport: +1,70 tCO_2 eq./y
Process + reuse: -2,46 tCO_2 eq./y

Public funding

No data

Revenue stream

Sales revenue for Netics ≈**20 850 €/y**
Increase of benefits for the WWTP ≈**3 675 € / y**

Global impact
With a global impact estimated at 1,18 tCO_2 eq./y → 0,32 tCO_2 eq./y avoided

Production of 26 040 bricks based on aluminium sludge

Public non-financial costs or benefits
Circular ambitions shown by water sector.

Figure 32: Business canvas centralised on the aluminium sludge resource in Westland case

The new application increases revenues for the WWTP and reduces the environmental impact of the sludge management.

5.3.6. Conclusion on the replication of the value chain and business potential

In combination with the big opportunities that exist in the living area of Westland, this makes that both value chains do show good potential to replication elsewhere. The reason why is relatively straightforward:

- The resources are quite common in the water sector: aluminium sludge and municipal wastewater sludge.
- The key technology making these chains possible is relatively simply: drying and binding.
- The market is large and to be found everywhere: energy production and the use of shaped building materials like bricks.

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5.4. CS4 – Altenrhein (CH)

5.4.1. Description of the CS

The WWTP of Altenrhein treats the sewage amount of 100.000 PE and an additional 200250,000 PE comes partly from 17 WWTPs in the federal states of St. Gallen and Appenzell, and partly from (food) waste. Within the smudge from 300,000 PE, approximately 25% is digested and only passes through the dryer. The sludge gets dried to a TR of 90%.

5.4.1.1. Challenges and/or opportunities

WWTP treats and manages used water, sludge from WWTP, solid sludge, digested sludge and dewatered sludge from many actors at the regional scale, which is an opportunity to collect nutrients from water and to close the loop.

5.4.1.2. Circular solution studied

The WWTP decided to perform a feasibility study for a PYROPHOS plant to produce fertilisers and energy.

Altenrhein case plans to develop 3 value chains which include: PK fertiliser, ammonium sulfate and GAC.
The deliverable focuses on one new value chain of the case, which is the PK-fertiliser value chain.

5.4.1.3. Status of the demo case

The pilot trials for the PK-fertiliser recovery are finished and well documented. The data collection for the ammonia stripping and GAC absorption processes is still ongoing.

Due to a lack of information about the full-scale plant, the GAC will not be studied in this deliverable. The ammonium sulfate value chain is introduced in the case of Braunschweig in section which is compared to Altenrhein ammonium sulfate value chain.

5.4.2. Limitations of the study and scope of the study

Scope:
The energy balance and the LCA of the processes will be studied in detail in the WP2 deliverable 2.1. The value chain analysis of this section will focus on transport and incineration avoided thanks to the new value chains.
The scope of the value chain analysis is limited at the chemical suppliers upstream and the fertiliser producer downstream.

Assumptions:
The

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Table *8* presented assumptions that have been made by the case study to analyse the value chain.

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Table 8: Common assumptions for Altenrhein case

Assumptions for Altenrhein case		
Gate Fees		
Fresh sludge	11,96	€/m³
Digested Sludge (not dewatered)	14,72	€/m³
Digested Sludge (dewatered)	73,6	€/t
Food Waste	73,6	€/t
Transport of Dried Sludge	73,6	€/t (to cement works)
Disposal Cost		
Ash to landfill (all inclusive)	368	€/t
KOH	598	€/t
Energy		
Electric Power	0,115	€/kWh
Heat Sale to District Heating	0,0506	€/kWh (average industrial/domestic)

5.4.3. State of the art of streams before NextGen solution

5.4.3.1. Pre-existing sludge value chain

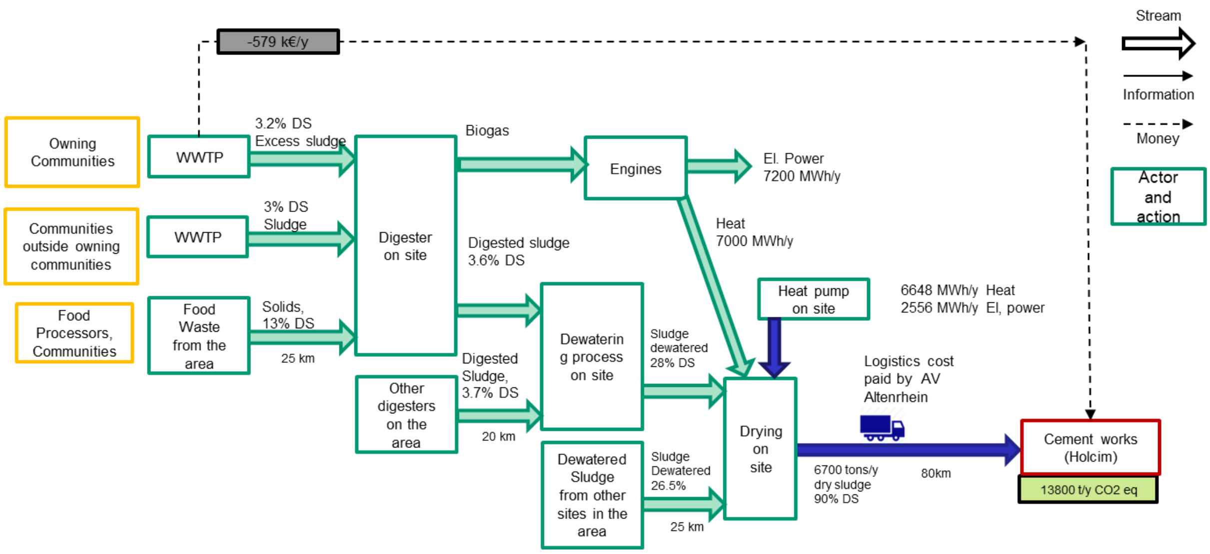

Figure 33: Altenrhein case before technologies implementation

Streams' description:

As detailed in D1.1, the WWTP of Altenrhein treats on average 24,000 m³/d of wastewater corresponding to 100,000 PE. The average nitrogen and phosphorus concentrations in the influent to the WWTP are 34 mg/L and 6 mg/L, respectively.

In addition to its own excess sludge (2 500 t DM/y), the WWTP receives sewage sludge and co-substrates from third parties, which are added to the digesters. The digestate is then combined with digested sludge from third parties to be dewatered and dried (total 6700 t DM/y). Referring to the influent to the WWTP and to the inputs from third parties, altogether, the nutrient loads entering the WWTP are 650 t/year of total nitrogen and 250 t/year of phosphorus. The composition of the co-substrates is highly variable over time. No data for

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their phosphorus (P) and nitrogen (N) content exist and thus, the amount of nutrients in the digester is not quantified.

The heat for sludge drying is generated by burning biogas from the digester thermal power coupling, and by heat recovery from wastewater using heat pumps. The dried sludge is coincinerated in the cement industry.

Before NextGen, the nutrients which are contained in the sludge are not recovered and/or reused.

Stakeholders' ecosystem:

In this sludge value chain, the stakeholders' ecosystem is wide, and includes many communities and sites that centralise their waste management in the Altenrhein WWTP. This ecosystem involves:

1. Altenrhein WWTP (the owning communities):

In the analysis, this actor includes several processes in the scheme ("WWTP", "Digester on site", "Dewatering process on site", Drying process on site"). This actor is split in several boxes in the Figure 50 as all input streams do not enter in the same process on site. The analysis is centralised on this actor and interact with all other actors at the regional scale.

2. Communities outside owning communities:

These communities own other WWTPs. However, they send sludge to Altenrhein digester and pay for this disposal.

3. Food waste producers:

Including food processors and other communities, these actors are located at around 25 km from Altenrhein site and pay for the disposal of their food waste in the digester at Altenrhein site.

4. Other digesters in the area:

These actors are located at around 20 km from the Altenrhein site and pay for dewatering and disposing of their digested sludge.

5. Other sites that produce dewatered sludge:

These stakeholders are located at around 20 km and pay Altenrhein site to dispose of their dewatered sludge.

6. Cement works: Lafarge-Holcim:

The final actor of the sludge value chain in this analysis is Lafarge-Holcim that incinerates dried sludge. This actor is located at 80 km.

7. Hauler:

The transport is important in this value chain.

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Economic aspect:
The case study estimates the disposal cost at **579 600 €** each year before NextGen project.

Environmental impact:
The following environmental impact can be calculated based on data collected:

- Transport

Environmental impact of the transport only considers the dried sludge incinerated as the implementation of new processes do not aim to affect input streams of the Altenrhein site.

Data for transport emission calculations	
CO_2 emissions factor for skip	0,08460 kg CO_2 / t.km
Volumes of sludge to be transported	7 400 tons DM/y
Distance from WWTP to LM site	80 km

Based on these assumptions and the data provided by the case study, the transport of the pre-existing value chain emits around **50,1 tons of CO_2 eq. per year**.

- Incineration

Currently, around 7 400 tons of sludge are incinerated each year. The case study has estimated that **13 800 tons of CO_2 eq. are emitted per year**.

The pre-existing sludge management emits about **13 847 tons of CO_2 each year**.

5.4.4. PK-fertiliser value chain

5.4.4.1. PK-fertiliser recovery description

Altenrhein case plans to pre-pyrolyse and gasify sewage sludge which will produce PK-fertiliser with an additional potassium source, and energy to reuse on site and sell to district heating network.

5.4.4.2. Assumptions for the value chain analysis

At the time of the PYROPHOS plant implementation, the sludge treatment would be changed. The following assumptions have been taken:

1. Slight increase in AVA sludge production (10%) due to increase in inhabitants and due to lower rainwater input (some separation in progress)
2. Increase of co substrate by 25% compared to business as usual
3. Significant increase of delivered dewatered sludge (from sites outside previous' perimeter) due to new legislation
4. Replacement of one of the existing dryers with a different type (running at higher temperature, new heat pump system with better efficiency)

New data used in the value chain analysis are presented in the *Table 9*.

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Table 9: PK-fertiliser value chain data

PK-Fertiliser value chain data	
Total dried sludge towards Pyrophos plant	10 000 t/y
Total energy sold to district heating[23]	12,56 GWh/y

These assumptions will help to compare the new value chain with pre-existing sludge value chain that should have been optimised without the PYROPHOS implementation.

5.4.4.3. Scheme of the PK-fertiliser value chain

Assumptions set above leads to a new scheme presented in the Figure 51.

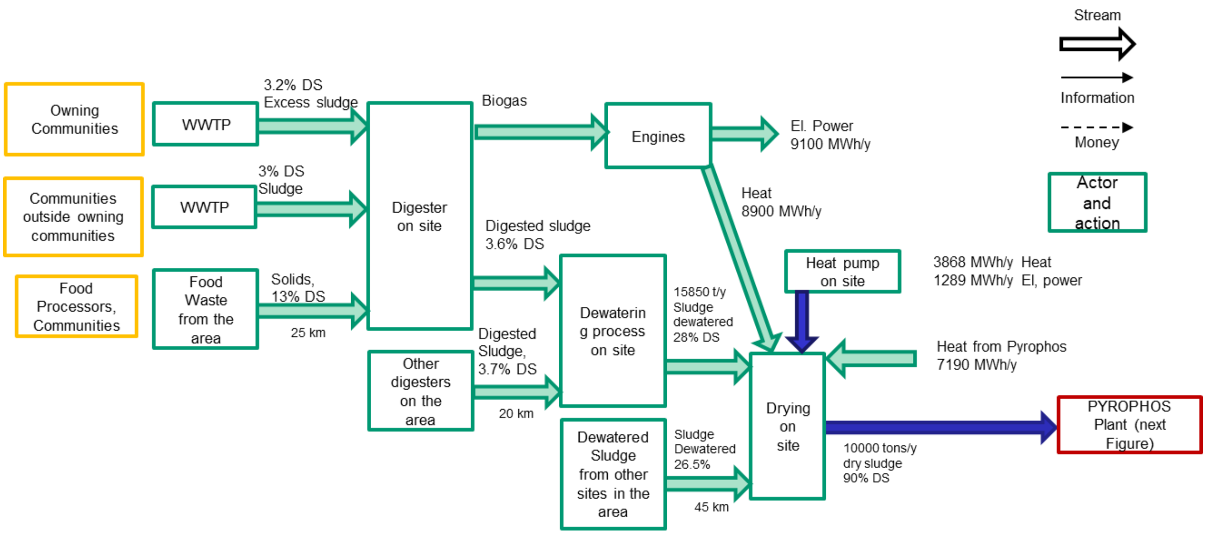

Figure 34: Pre-existing sludge value chain optimised upstream of the PYROPHOS plant

Figure 35 presents PYROPHOS plant streams studied for the PK-fertiliser value chain.

[23] District Heating already started in one of 2 possible areas and operational since December 2020 based on surplus installed power from heat pumps

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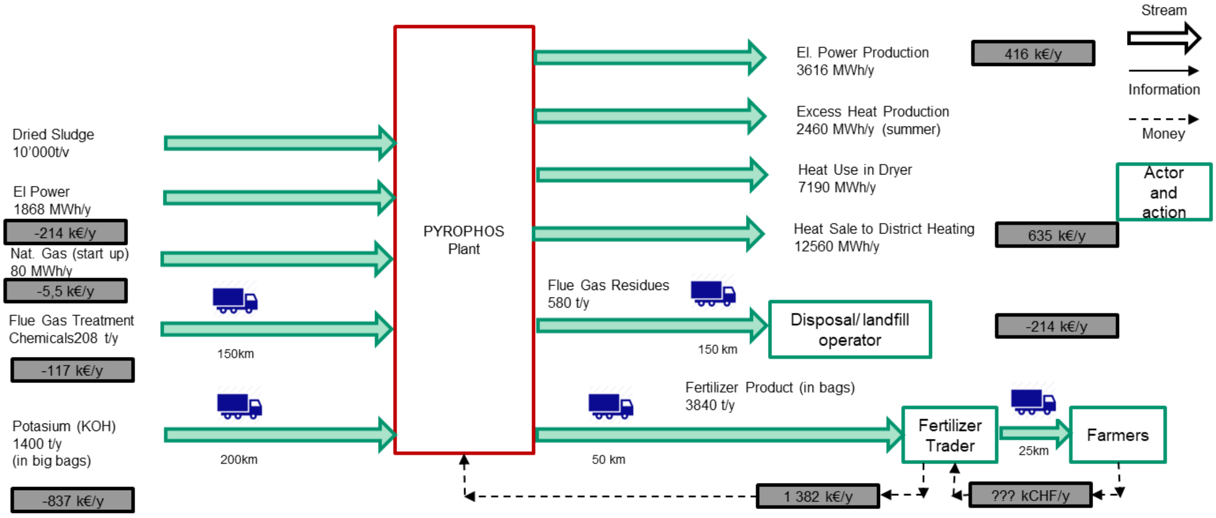

Figure 35: PK-fertiliser value chain at the PYROPHOS plant

5.4.4.4. Stakeholders' involvement

Main actors:

In addition to the actors presented in the pre-existing value chain, the following actors should have a specific interest and should be involved in the operation of the value chain:

1. PK-Fertiliser producer: Altenrhein WWTP

Altenrhein WWTP is one of the key actors to implement the value chain as this actor is investing in new processes and will manage the production of PK-fertiliser. WWTP expects to save disposing cost and potentially has a return of investment, in addition to have a positive impact and generate a circular resource.

2. Communities and food waste producers:

Altenrhein WWTP centralises a huge amount of sludge that comes from other communities. These communities are interested by the solution that could support the increase of sludge to treat and can have a potential influence on the process selected.

3. Fertiliser trader:

This actor will facilitate and make feasible the PK-fertiliser reuse thanks to its processes and its business network. Fertiliser company requires good raw material. They accept to recycle the materials in the condition it fulfils requirements.

Intermediate and external actors:

1. Chemical supply: Brenntag

The KOH supplier can be interested by the value chain creation. The deployment of this value chain is an opportunity to increase their market. However, these actors could reduce the economic and environmental viability of the value chain according to their offer and location.

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The competition between suppliers diminishes the influence of the supplier on the value chain creation.

2. Hauler:

In this case, transports are not managed by the WWTP. The hauler does not affect the value chain implementation as it can be replaced by another organisation. However, the transport still can have an influence on the economic viability of the value chain.

3. Farmers:

These actors are the end user of the circular resource in this value chain analysis. As the fertiliser above, this actor requires good raw material. They accept to recycle the materials in the condition it fulfils requirements.

4. Disposal and landfill operator:

This actor should treat the flue gas residues produced by the new PYROPHOS plant. This actor does not have a specific interest for the value chain implementation. However, this service could affect the economic and environmental viability of the value chain.

5. Public actors:

These actors foster and facilitate the PK-fertiliser production with new regulations as it is the case in Altenrhein with the recovery obligation.

5.4.4.5. Value proposition and benefits of the PK-fertiliser value chain

Economic aspect:

In terms of extra revenues and savings related to the material value chain in Altenrhein case:

- The PK-fertiliser recovered is planned to be sold (with the transport) between 100 and 300 €/t by the WWTP. WWTP plans to reach a potential sale revenue of around 1 381 840 € per year;
- 300€ is supposed to be not realistic; although there is a strong market dependency, the price for TSP in 2021 is around 300-400€;
- This value chain avoids disposing of 10 000[24] tons of sludge in cement works, which results a lower disposal cost (savings ≈ 840 000€/y).

The total of savings and revenues are estimated at 2 221 840 € per year, or **578 € per ton**.

Based on data collected, the production of PK-fertiliser should imply the following extra costs:

- The PK-fertiliser production requires 1 400 tons of potassium (KOH) and flue gas treatment chemical, which are estimated at 935 640 € per year.
- The process should produce flue gas residues to dispose of (≈213 440 €).

[24] According to assumptions of the new sludge value chain in Altenrhein case

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- The WWTP has invested around 20 000 000 € to implement PYROPHOS plant. With a depreciation period of 10 years and an interest rate of 6%, this investment should cost 2 212 000 € per year.
- The maintenance cost of the process is estimated at 3% of the total investment costs (≈600 000 €/y).

These calculations lead to a PK-fertiliser production cost of **1 007 € per ton** without considering public fundings.
The investment depreciation is an important proportion of the production cost (around **54,8%**). The value chain cannot be directly profitable after its implementation. It is necessary to consider the energy balance and calculate the return of investment of the technology (ROI).

Based on data shared by the case study, cost and benefits related to the energy consumed and produced by the PYROPHOS plant is summarised in the Table 10.

Table 10: Energy balance of the PYROPHOS plant in Altenrhein case

Energy revenues and savings (€/y)	
Electric power sold	415 840
Heat sale to district heating	634 800
Heat production from heat pump avoided[25]	275 545
Sub-total revenues and savings	**1 326 185**
Energy costs (€/y)	
Electric power consumed	214 360
Natural gas (to start up)	5 520
Sub-total costs	**219 880**
TOTAL	**1 106 305**

In terms of energy, the potential benefits of the PYROPHOS plant can be estimated at 1 106 305 € per year by considering avoided costs.

By considering the energy balance, a first economic study estimates the benefits of the value chain at **1 560 665 € per year** without considering the investment depreciation, which appears to be more profitable than the previous situation where the WWTP had to pay 569 600 € to incinerate sludges. This calculation leads to a ROI estimated at 13,4 years, which is quite a normal period for a new equipment in the water sector and makes the value chain viable economically.

These calculations are based on many assumptions made in June 2021 that still have to be confirmed later in the project. The LCC of the value chain with a focus on the processes will be carried out in D2.2.

[25] This raw represents he costs that WWTP should have paid to produce heat for the dryer by using heat pumps. Equation = [(Heat to produce) / (Energy efficiency factor)]* (Electricity price)

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Environmental aspect:
Compared with the pre-existing value chain of sludge, the environmental impact of the value chain will be noticed on the following aspects.

- Avoided impact of incineration

Before the PYROPHOS plant implementation, 10 000 tons of dried sludge should have annually been incinerated in cement industry, which represents around **20 000 tons of CO_2 eq. that should have been emitted each year**.
However, these results remain uncertain as assumptions still have to be confirmed. The carbon footprint of the PYROPHOS plant still has to be studied to confirm the positive impact of its implementation (please refer to the D2.1).

- Transport

With 11 111 tons of sludge transported to Lafarge-Holcim, the transport should have emitted around 75,2[26] tons of CO_2 each year.
However, the new value chain generates new transport of raw materials which are summarised in Table 11.

Table 11: Material transport emissions in PK-fertiliser

Travel and materials	Volumes (t/y)	Distance (km)	CO_2 eq. emission[27] (tons/y)
Supply of flue gas chemicals	208	150	2,6
Supply of KOH in big bags	1 400	200	23,7
Flue gas residue disposal	580	150	7,4
Sales of fertiliser product in big bags	3 840	50	16,2
TOTAL			**49,9**

Based on the data collected, the potential carbon footprint avoided in terms of transport emission is estimated at **25,3 tons of CO_2**.

The environmental impact of the value chain is planned to be positive. However, this conclusion cannot be confirmed without the results of deliverable 2.1, which aims to assess the life cycle of the phosphorus, the improvement of power production, the efficiency improvement of heat pumps and the replacement of fossil fuel by use of renewable in district heating.

5.4.4.6. Drivers and barriers to implement the PK-fertiliser value chain

Drivers
The following drivers are based on feedbacks collected from the case study:

[26] Figures related to 10,000 tons of sludge transported to LH site.
[27] The estimation is based on an average of travel carbon footprint for a truck with 20 tons payload (≈ 0,0846 kg CO_2/t.km

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- Recovering phosphorus (political and legal aspects):

In Switzerland, recovering phosphorus will be an obligation for all WWTP from 2026. This regulation is an important driver to develop synergies between WWTP in order to mutualise processes and increase stream volumes, and to deploy the reuse of phosphorus based on the sewage sludges.

- ROI and energy (economic aspects):

The process related to this fertiliser value chain generates also a significant amount of heat that can be reused in other processes on site and in district heating. This co-benefit reduces the ROI of the process and helps the economic viability of the implementation.

Barriers

- Frontier issue (political and legal aspects):

Because of a lack of homogenised legislations in Europe, the case study met some difficulties to involve stakeholders in the value chain implementation. These frontier issues will also hinder the value chain operation due to transport and difference of policies and regulations according to countries.

- Limited need (environmental and economic aspects):

Over-fertilisation of fields can be an environmental issue in some regions in Switzerland. Lakes can be polluted because of a high P-content. The lack of phosphorus demand and the increase of phosphorus production in the country will negatively affect the fertiliser market in Switzerland, and closest countries. Corrective actions will have to be found in order to make these fertiliser value chains economically viable.

- Process competition (technological and economic aspects):

Currently, processes in phosphorus recovery are under development and will be in competition in coming years. The most promising process is still unclear which implies a lack of visibility for WWTP investment.

- Fertiliser regulation (legal aspects):

Concentration of heavy metals in fertilisers is more restrictive in Switzerland than other European countries which hinders the fertiliser value chain implementation. Furthermore, the regulation for recycled P-fertilizer are more stringent than for (imported) mineral fertilizer

5.4.4.7. Business case of the PK-fertiliser resource

The business canvas of the value chain presented in the Figure 52 summarises values assessed and highlights advantages and disadvantages for deploying the value chain.

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Ecosystem of stakeholders

Main actors:
PK-fertiliser producer: WWTP
Fertiliser trader
Sludge producer: several other communities and WWTPs

Intermediary actors:
Transport is managed by the fertiliser producer

External actor:
End-users: farmers and gardeners
Chemical suppliers and landfilling operators

Key activities
Treat and pyrolise sludges
Processing fertiliser
Transport

Key resources
Digester, dewatering process
Dryer
Pyrolisis
Trucks

Stakeholders relationship
Classic business relationship
Common objective to centralise processes and volumes

Economic Value
Sales of energy | Energy savings
Sales of PK-fertiliser | Avoided cost in sludge disposal
ROI ≈ 13,4 years

Cost structure
CAPEX: 20 212 000 € (high estimation)
Chemicals: 935 640 €/y | Transport
Maintenance cost: ≈600 k€/y | Disposal cost ≈ 213 440 €/y
→ Total production cost: 1 007 €/t | Energy ≈ 219 880 €/y

Revenue stream
Sales revenue ≈ 1 382k€/y | Sludge disposal avoided ≈ 569 - 840k€/y
→ Total production revenue and saving: 578 €/t
→ Energy revenues and savings ≈ 1 326 185 €/y

Environmental Value
Avoided incineration
Co-benefits with energy reuse
Production of a circular resource

Impact of the organisations
WWTP: WP2 |
Transport: -25,3tCO_2 eq./y
Incineration avoided: 20 kt CO_2eq/y (tbc)
Heat produced: 22 210 MWh/y
El. produced: 3 616 MWH/y
PK recovered: 6 900 tons/y

Global impact
PK-fertiliser has a lower environmental impact than phosphate rock

Territorial Value
New synergies between regional organisations at each step
Raw materials independence

Public funding
Subsidies from national and international authorities to implement the process

Public non-financial benefits and costs
P recovery obligation

Frontier issues

Figure 36: Business canvas centralised on the PK-fertiliser resource from pyrolysis

The key to success of this value chain is its double benefits. Thanks to the co-benefits between the materials recovery and the energy production, the value chain could be economically viable with an acceptable ROI in the water sector, and could provide a positive environmental and territorial values. These conclusions will be confirmed in D2.1 and D2.2. Nevertheless, economically viable or not, the real driver of the value chain replication remains the P recovery obligation that is applied in Switzerland.

Circular economy is a matter of scale, especially when it comes to materials like sludge. This value chain should be replicable in areas where communities can centralise the sludge treatment in a same site. The replication should be fostered by the obligation of nutrient recovery, but hindered by the market that is still unclear because of the lack of local demand.

5.4.5. Policy recommendations to foster Altenrhein case replication

The previous value chain analysis highlighted several policy recommendations to foster the replication of the PK-fertiliser value chain:

- P-mineral and raw material supplier:

As frequently noticed in circular economy, the traditional supply chain can hinder the new value chains development. In this case, the phosphate rock is still cheaper than the phosphate produced from WWTPs. Unfortunately, it directly affects the market value of the recovered resource which makes the value chain uncertain or not viable. More governance or regulations related to the importation of the phosphate from mines, and promotion of the recovered materials should foster circular value chain viability.

- Fertiliser regulations:

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As seen in Altenrhein case, one of the main drivers for implementing P-fertliser recovery process was the governance that obligates WWTP to recover nutrients by 2026. Furthermore, the restrictions for P-fertiliser recycled should be standardised and/or homogeneous with mineral fertiliser restrictions.

- Subsidies:

With the significant investment cost for the solution, public funds are necessary to continue to deploy good practices before regulations and technological development makes the value chain more viable.
As seen in Altenrhein case, the value chain is viable because of its co-benefits (materials and energy). Subsidies should focus on the implementation of processes that allows the recovery of several types of streams.

- Raise awareness about nutrient potential:

The low interest from society for the P-recovery is due to the invisible role that the phosphate has in the environment and the unattractiveness of sewage treatment[28]. The majority of food consumers are not aware of issues regarding phosphorus, at least in view of it being an essential finite resource nor its environmental effects[29]. However, acceptance among the farming community and important market players will be decisive for the value chain exploitation. This current public perception can hinder the deployment of the value chain. It is necessary to raise awareness about the phosphorus use.

[28] Schipper, W. Phosphorus: Too Big to Fail. Eur. J. Inorg. Chem. 2014, 10, 1567–1571. [CrossRef]
[29] Withers, P.J.; van Dijk, K.C.; Neset, T.S.S.; Nesme, T.; Oenema, O.; Rubæk, G.H.; Schoumans, O.F.; Smit, B.; Pellerin, S. Stewardship to tackle global phosphorus inefficiency: The case of Europe. Ambio 2015, 44, 193–206

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5.5. CS5 – Spernal (UK)

5.5.1. Description of the CS

Originally, Spernal is a traditional wastewater treatment plant, south of Birmingham in the United Kingdom. For years, wastewater was treated in a traditional way, with an effluent and a sludge stream as output.

Now, this demonstration plant, is showing an alternative, integrated, way of looking to a wastewater plant, where Spernal will incorporate different technologies to design a new plant. An anaerobic membrane bioreactor (AnMBR) completes with a membrane degassing unit to recover dissolved methane will be in operation to treat the settled wastewater. This results in a cleaner effluent with residual nutrients, which can then be recovered in a downstream ion exchange (IEX) process and new residual flows, such as recovered nutrients. Combined, this will lead to a reduce in energy costs and carbon impact and possible new application for recovered residuals, with high potential in new markets with a higher value.

5.5.1.1. Challenges

Circularity and sustainability are major challenges for British wastewater plants and Spernal in particular. A reduction of energy, and moreover carbon impact is needed for a sustainable future. For Spernal, this means the need for a cleaner effluent and a more precise recovery and reuse of residuals.

At the Spernal wastewater plant, the residual stream of sludge has been dewatered on site for years, and afterwards been brought to the agriculture, where is it used as a fertiliser. Despite many countries already having regulations on bringing sludge to the agricultural sector, it is in the United Kingdom still allowed. However, bringing sludge untreated to land is not a sustainable way of treating sludge due to its contamination with inorganic and organic pollutants. Therefore, a circular solution is needed for a safe recycling of valuable content (e.g. nutrients) in these residuals.

5.5.1.2. Circular solution

Within the circular solution, two extra process steps are added, the ANMBR (ANaerobic Membrane BioReactor), to clean wastewater after the primary settler and to produce biogas, using an UF membrane for water/sludge separation and the IEX (Ion Exchange) nutrient recovery plant, to remove and recover nutrients. These steps together filter the sludge from the wastewater to recover biogas and nutrients. After, the remaining sludge is treated as before, with an usage as fertilizer in the agricultural sector.

In the Spernal demo case, both ANMBR and IEX are implemented in the value chain. This has two major advantages: extra production of BioGas and the possibility to filter nutrients from the wastewater, such as Ca-PO_4 (calcium phosphate) and $(NH_4)_2SO_4$ (ammonium sulfate). For this new value chain analysis, the focus will be set on the anMMR and the IEX recovery units.

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5.5.1.3. *Status of the demo case*

At this moment, the status of the demo case remains on pilot scale. The technology is currently being tested. This means that all data that is collected, is collected from the before situation and not from a full-scale plant.

5.5.1.4. *Limitation of the study*

Due to the focus of the case study on the technology development, data shared on the Spernal case is mainly about the technology which is not the scope of this deliverable.

More information about residuals or materials streams will be collected later in the project. At this stage, this section can only show the qualitative description of the sludge value chain.

5.5.2. Pre-existing sludge value chain

The situation of the sludge stream before NextGen is shown in Figure 37.

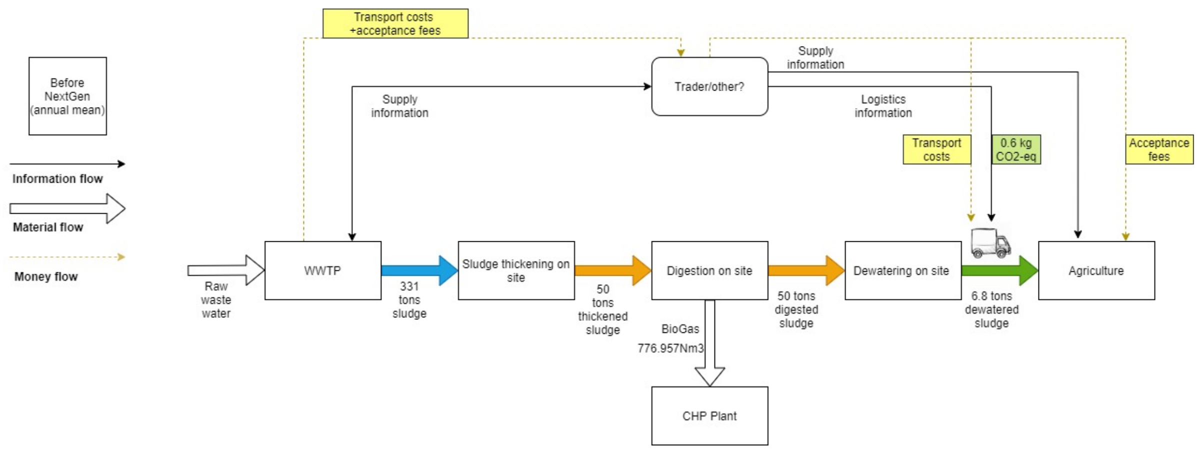

Figure 37: Pre-existing Spernal value chain

Streams' description:

The pre-existing situation is a regular and traditional wastewater treatment plant. Wastewater goes into the process, and the outputs are an effluent and a sludge stream. The effluent is discharged to the river. Sludge that is extracted from the wastewater purifying process, is thickened on the Spernal site and the digested. In the digestion process, BioGas is produced with an annual volume of 776 957 Nm^3, which is then valorised in a CHP Plant (Combined Heat and Power). The remaining 50 tons of stabilized sludge is dewatered on the Spernal site, and afterwards brought to agriculture, where it finds a usage as fertilizer.

Stakeholders' ecosystem:

In this value chain, different major stakeholders can be identified:

- Spernal wastewater treatment plant
- A trader, the stakeholder that arranges the transport to agriculture
- Agricultural sector, who have an interest in using the fertilizer as a plain alternative for other fertilizers.
- British citizens, who are served by the WWTP

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Economic aspect:
No data was available for the analysis.

Environmental aspect:
No data was available for the analysis.

5.5.3. New sludge value chain of Spernal case

5.5.3.1. Assumptions for the value chain analysis

This new value chain analysis is based on the current pilot plant of Spernal. Very limited data is available, as no measurements are finished yet.

5.5.3.2. Scheme of the value chain

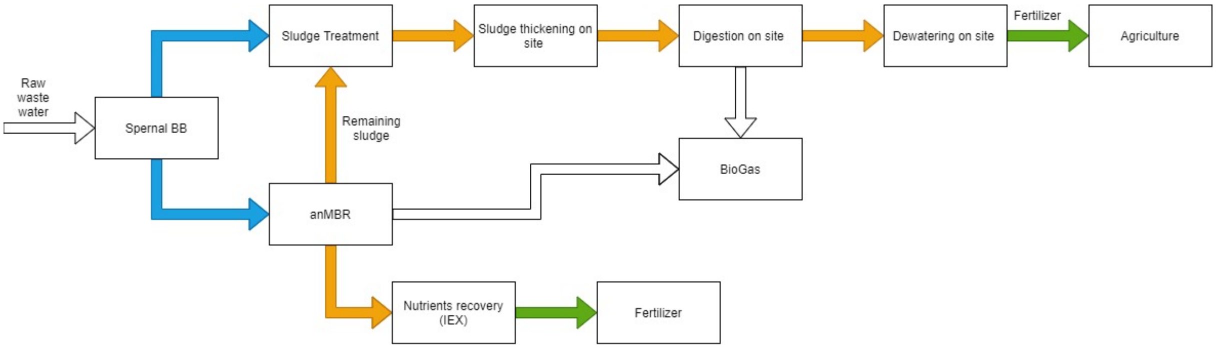

Figure 38 - New Scheme for the Spernal Value Chain

In this new value chain, part of the wastewater that comes from the primary settling is processed through the ANMBR. This ANMBR produces extra BioGas from the wastewater. After the ANMBR, the IEX filters recover nutrients from the wastewater. Sludge from primary settling and AnMBR is treated equally as in the situation before NextGen.

Possible applications
For the future application of the BioGas and nutrients, assumptions are needed. For that reason, some possible scenarios are worked out.

BioGas
1. Using the BioGas for the electrical grid and reusing the heat at the Spernal plant
2. Splitting the BioGas in methane and CO2 and using methane as fuel
3. Returning the BioGas in the natural gas network

P nutrients:
1. Blending with phosphorite to make fertilizer
2. Mixing with manure to create a more valuable manure

N (ammonia) nutrients:
1. Sending the ammonia to local farmers. The question is here whether the ammonia has a value for the farmers, or an acceptance fee needs to be paid and whether farmers are willing to accept the ammonia all year round, or just seasonal.

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2. Concentrating the ammonia

5.5.3.3. Stakeholders' involvement

No data has been shared about the stakeholders' ecosystem related to this value chain.

1. Spernal wastewater plant
2. Agricultural sector (farmers)
3. Transport organization
4. British citizens, who are served by the WWTP
5. Possible other users of either BioGas or nutrients, currently unknown.

5.5.3.4. Value proposition and benefits of the value chain

Economic aspect:

No data was available for the analysis

Environmental aspect:

Based on the description of the case study, the value chain could provide the following main environmental benefits:

- High biogas production in the AnMBR, combined with the BioGas from digestion
- Valorisation of N and P nutrients
- Reduction of total sludge volume

No data was available for the analysis.

5.5.3.5. New business cases

This business model of the new value chain of sludge for Spernal is presented in Figure 39.

Ecosystem of stakeholders Main actors: Spernal WWTP Farmers (To be defined)	**Key activities** Filtering sludge Filtering nutrients	**Key resources** AnMBR Trucks IEX
Intermediary and external actors: Transport company British citizen (To be defined)	**Stakeholders relationship** Potential collaborative relationship	
Economic Value Potential new revenues related to nutrient sales (refer to the CS1) Potential savings related to the reduction of sludge amount	**Environmental Value** Potential usages of recovered nutrients	**Territorial Value** New synergies between regional organisations
Cost structure Investment ANMBR Investment IEX Annual transport cost	**Impact of the organisations** Reduction of carbon footprint expected (More information related to the technology in WP2)	**Public funding** No data
Revenue stream Potential sale revenue to fertliser industry and farmers No data	**Global impact** No data	**Public non-financial benefits and costs** No data

Figure 39: Business canvas centralised on the sludge value chain

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Thanks to the ANMBR technology, nutrients show a great potential to be used in more high value fertilizer products but a specific application for these nutrients has still to be found.

5.5.3.6. Barriers and drivers to implement the value chain

Driver

Drivers are environmental ambitions, related to the Spernal plant. As for the UK, sludge is still allowed to be used in agriculture. To be ahead of future legislative changes, this plant helps moving towards a more sustainable plant.

Barrier

A barrier for implementation of this value chain is that the demo case is still in pilot phase and yet not all data is available. This makes it difficult to make valuable assumptions on implementation. Besides, the value chain would create more potential if an application is found for recovered nutrients, not only for environmental reasons, but also for economic reasons. After all, the economic value needs to be profitable, to guarantee a stable value chain.

In terms of regulation, there is still no application found for the nutrients, other than fertilizer industry, which is legally not possible throughout Europe. This could be a barrier in the replication of the demo case to other MWTP. On the other side, multiple options are available, that do have a potential on replication.

5.5.4. Conclusion on the replication of the value chain and business potential

Although it is difficult to make statements about the replication on full scale, the opportunities seem to have a good potential in replication elsewhere. The resources that are needed in this value chain are common in the water sector: municipal wastewater sludge is at every MWTP. The technology is relatively easy to adapt at other places.

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5.6. CS6 – La Trappe (NL)

5.6.1. Description

The Koningshoeven BioMakery is fully integrated into the historical monument of the Koningshoeven Trappist Abbey and Brewery. The main economic activity of the La Trappe abbey is the production of beer, however, the monks also produce other products such as cheese, chocolate, and bread. The BioMakery houses the site's wastewater treatment facility, which treats industrial wastewater from the brewery and other production areas and the municipal wastewater from the Abbey and Visitor center.

Previously, the wastewater from the site was discharged to the sewer and treated offsite at the regional wastewater treatment plant. However, in 2018, in order to comply with industrial discharge levels, and in an effort to create a sustainable circular water cycle, the abbey began treating its wastewater onsite in its newly built BioMakery. The BioMakery uses Metabolic Network Reactor technology, developed by Biopolus, to treat the site's wastewater for safe discharge to the nearby canal (or for use in irrigation), helping to maintain the local water cycle. The facility also includes a heat exchanger that recovers heat from the raw wastewater to heat the site's green house(s).

5.6.1.1. Challenges and opportunities

The BioMakery at the site was developed as a cooperative effort by the abbey, the waterboard De Dommel, and Biopolus, with the aim of introducing non-centralized water treatment to treat and reuse wastewater locally to create a sustainable local water cycle.

Biopolus' MNR is a modular and adaptable platform technology designed with the intention of incorporating supplemental processes and technologies to achieve higher levels of circularity. A feasibility study was conducted before the start of NextGen to assess the potential to expand the circularity around the MNR technology using space technologies developed with the micro-ecological life support system alternative (MELiSSA) of the European Space Agency. This feasibility study was performed by SEMiLLA IPStar, a private company created within the MELiSSA consortium with the mandate to implement those technologies in terrestrial applications for civil society.

The BioMakery is a model for decentralized wastewater treatment, to which varying technologies or circular modules can connect, in order to create value from waste. The BioMakery was created based upon the principle of water-based urban circularity, where energy, food, and waste systems are built around a regenerative and sustainable water cycle. The aim is to create a multi-level network of circular processes with extensive cross-connections.

The diagram below illustrates the circular business model of a Biopolus BioMakery, with multilevel networks of circularity. The Biopolus Water Treatment is the MNR technology, while the Biorefinery is a process unit that can breakdown organic wastes to their basic components. These two processes are the primary (platform) technologies to which other supplemental processes and/or technologies can be added to create new nodes of circularity

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(production platforms- ex: Water Factory, Plant Factory, Protein Factory, etc.). These production platforms can produce valuable products.

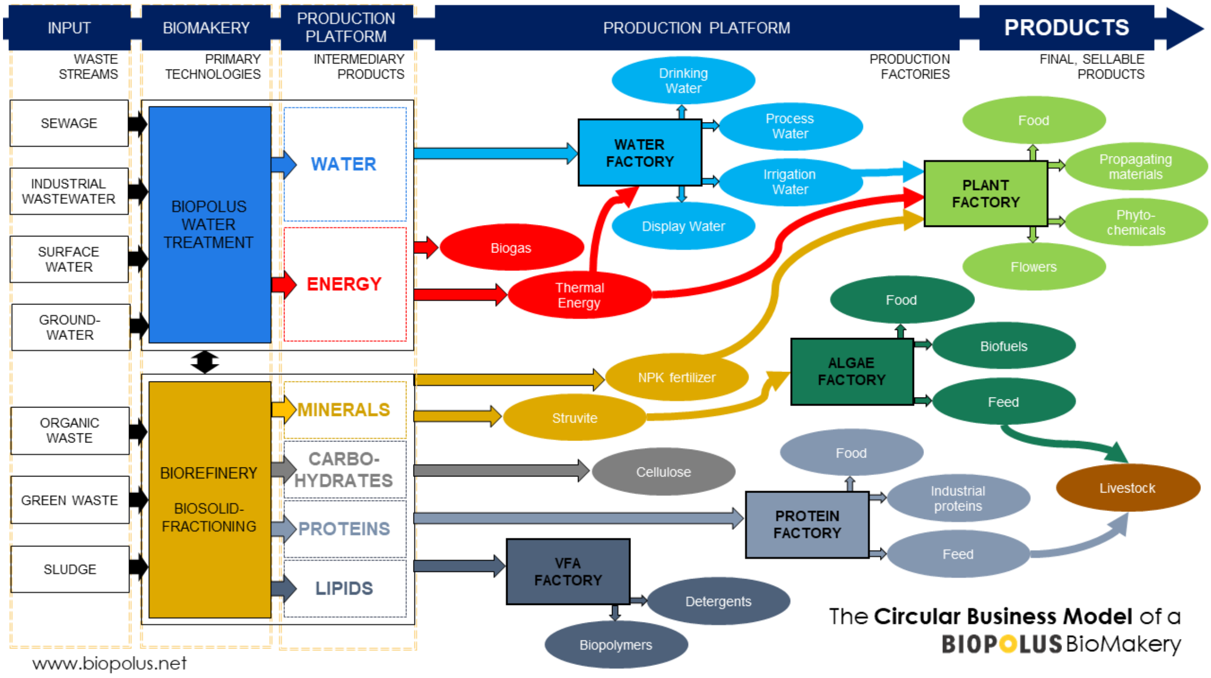

Figure 40: Products from the BioMakery

This line of thought (and the BioMakery business model) can be applied to the La Trappe or other similar sites.

At the La Trappe site for example, the Water Factory is the MELiSSA Membrane technology (with process water being the final product), while the Algae Factory is the Raceway Reactor with the purple non-sulphur bacteria (PNSB) being the final product (as a microbial protein source for animal feed or plant fertiliser). There is already thermal recovery of the incoming raw sewage at the site, and there are discussions regarding potentially adding a Biogas unit (outside of the NextGen project) at a later time. There is also further potential for expansion, with some examples being the biorefinery of green waste and sludge, and/or adding an additional thermal recovery unit to recover heat from the effluent of the water treatment process.

The NextGen project tests two MELiSSA technologies at the La Trappe site. The technologies being tested will create new products from waste, creating new business opportunities while helping to a maintain sustainable water system. The circular processes of the La Trappe BioMakery can help the Abbey and Brewery achieve their circularity goals. The BioMakery concept with varying technologies (including those tested in NextGen) can be used at other sites in the Netherlands and other areas around the globe to help ensure a smoother transition to a circular economy.

5.6.1.2. Circular solution

The main objectives of the NextGen project are to combine the Metabolic Network Reactor (MNR) with various space technologies at the La Trappe site to test the technologies for future full-scale integration with the MNR system.

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The overall goal is to combine these technologies to begin closing the water and material loops at the La Trappe site. By combining the MNR system with MELiSSA membrane equipment, various water products (potable water for beer production and/or process water for bottle rinsing) can be created locally from the site's wastewaters, helping to close the water cycle. In order to help close the materials cycle, a purple bacteria bioreactor can be installed to recover carbon, nitrogen, and phosphorous in the form of a single cell protein (PnSB). The purple bacteria may then be converted into a slow-release fertilizer or further treated for use as a protein source in the agro-food industry.

5.6.1.3. Status of the demo case

Covid 19 caused significant delays to the pilot tests at the La Trappe site. Lockdowns prevented site visits and caused delays in equipment delivery. Covid 19 affected beer production at the brewery and completely closed the visitor center at the abbey for significant periods. These closures caused drastic influent fluctuations of the industrial line at the wastewater treatment facility, which affected the stability of the MNR, resulting in discharge that was not consistently below limits. The municipal wastewater line was completely shut down due to limited flow rates caused by the closure of the visitor center. To this day, the municipal line is offline. The two main facility operators contracted Covid19, which also had an effect on facility operations. Finally, a key member of DeDommel, who was responsible for communications and coordination with the abbey tragically passed away at the end of May 2021.

Due to all the delays, NextGen pilot testing was limited to the industrial wastewater line. The municipal line was not tested.

For the water cycle: Off-line tests were first performed on raw brewery effluent in MELiSSA membrane equipment (UF RO) in France, which showed that potable water could be produced. Due to Covid19, official MELiSSA equipment could not be transported from France, therefore an alternative capillary NF system was introduced through a collaboration with IPStar subsidiary SEMiLLA Sanitation BV and JOTEM BV. Due to the instability of the MNR, the experiment focused on multiple short-term tests. The tests showed a reduced removal of contaminants when compared to the results of the UF RO experiment in France. The inconsistent MNR effluent (with episodes of high TSS) affected the pilot test, reducing the capabilities of the NF. However, the testing showed that the technology can produce process water. A plan for upscaling will be made as a desk study, interpreting the experimental data from the short-term tests.

For the material cycle: As a first step, raw brewery effluent from La Trappe was transported by IPStar team in collaboration with UAntwerpen for laboratory testing (using photoheterotrophic open air raceway reactors). Test results showed positive purple bacteria production and significant removal of COD, N, and P under lab scale conditions. Bacteria production was so high that clogging occurred during phase separation. As the system was originally made for a laboratory setting, installing the system at the site also resulted in some problems. The electronic equipment was damaged in the MNR greenhouse due to high humidity. Adjustments were made to the system to address the clogging and to repair the damaged part. However, these adjustments were delayed due to Covid19. In October 2020

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the system was set up at the La Trappe site for operation. Good results were obtained, and the purple bacteria grew very well on the raw brewery effluent. A sudden change in the composition of the raw brewery water (COD increased to 4g/L (2-fold), TSS increased to 0.3g/L (2 fold), and NTU increased to 250 (1.6 fold)), which reduced the abundance of purple bacteria in December 2020. However, once nominal operating conditions were restored, the system recovered well, and purple bacteria production continued. Plant tests executed in the spring of 2021 have demonstrated the functionality of purple bacteria as slow-release fertilizer.

5.6.2. State of the art of streams before NextGen solution

The material flows at the La Trappe site have evolved a lot through the years from a linear model to another one that is increasingly circular.

Before NextGen, some circularity was introduced thanks to the installation of the MNR system to treat water.

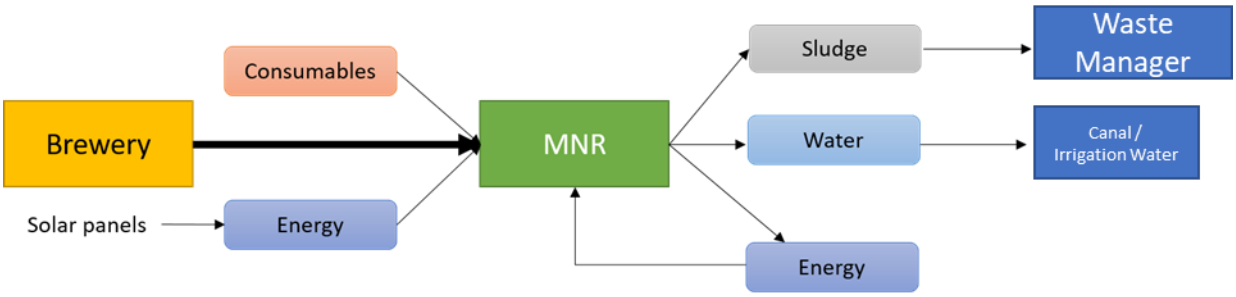

Figure 41: Pre-NextGen Baseline Streams

The MNR system treats the effluent from the Brewery using some consumables and energy from solar panels. The MNR produces clean water that is directed into the canal (to maintain the local water cycle) or it is used as irrigation water on ornamental plants. The sludge is transported offsite by a waste manager and, and thermal energy is recovered from the influent wastewater and directed to the MNR to warm the greenhouse.

The MNR system at La Trappe was shut down for reconstruction in 2019 May – October. Bottlenecks posed by the aeration system required adjustments to the system. The system was adapted and reconstructed to address the aeration problem, and to increase the overall capacity of the brewery line for the planned brewery expansion. Due to these changes, Covid19 delays, and the other problems mentioned, the final commissioning of the facility has not been completed, it is still on-going. Sampling and data collection and interpretation is needed for final authority approval. Because of this, there is very little data that can be included in the value chain assessment report, including the state of the pre-NextGen conditions.

5.6.2.1. Pre-existing value chains and stakeholders

Description of the value chains:

1. Energy:

The energy used by the facility comes from solar panels installed nearby at the abbey. A heat exchanger recovers thermal energy from the sewer line, which is used to heat the greenhouse that houses the bioreactors (with plants).

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2. Water:

Approximately 350 m3/day of industrial wastewater is sent to the MNR system for treatment daily. The water is treated to discharge levels safe for release into the environment. Currently, the water is released to the local canal or used as irrigation water for ornamental plants at the onsite nursery.

3. Sludge:

The sludge from the MNR is removed from the site and brought to Marineterrein in Amsterdam, where it is used to produce compost.

4. Consumables:

Various consumables are used during at the wastewater treatment facility. The following main consumables are used at by the MNR system: sulfuric acid (pH adjustment), Iron (III) chloride (coagulant), and a polymer (flocculant).

Stateholders' ecosystem (key stakeholders):

1. Trappist monastery of the Abbey of Our Lady of Koningshoeven

The La Trappe Abbey & Brewery share historical grounds in Koningshoeven. The monks support themselves and their charity work via the production of various craft products including beer, chocolate, and cheese. The monks work in the production areas and are dedicated to long term sustainable management of their grounds. The monks and a hired facility manager operate the BioMakery.

2. Swinkels Family Brewers

Swinkels Family Brewers is an independent family brewer, who began to collaborate with Brewery De Konignshoeven is 1999. The La Trappe beer is brewed in collaboration with the Swinkels Family Brewery company.

3. Dutch Water Authority De Dommel

The La Trappe Abbey & Brewery falls under the authority of De Dommel. The two have teamed up and signed an agreement for cooperation. The agreement is managed by a board, which consists of the Abbey and the waterboard. De Dommel handles the communications from the abbey side within the NextGen project.

4. Biopolus Institute

The Biopolus institute is the provider of the MNR technology, and the innovator behind the BioMakery business model and concept. The BioMakery's MNR technology is the platform technology to which the other technical solutions of the NextGen project are being tested for compatibility. They provide technology support and circularity consulting.

5. Marineterrein

Marineterrein Amsterdam is a test area and urban district for learning, working, and living in a liveable city. This special and flexible approach is gradually developing the test area into an

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urban district with space for open innovation, special forms of housing, sports, recreation, and greenery. The sludge is currently being transported here for creating fertilizer.

5.6.2.2. Identification and selection of new value chains

The NextGen project tests the application of two new technologies, which can be applied at the La Trappe BioMakery for the creation of high value end products. The addition of a Raceway reactor can reduce the load in the industrial wastewater before it is sent to the MNR system, while also creating a new source of biomass for various products. The Membrane system can be installed post MNR to further treat the effluent to create cleaner water, which can be recycled back into the brewery as a high value resource. The combined application of technologies within the La Trappe Circular System will be reviewed in this analysis together because both new technologies are being tested for compatibility and synergy within the La Trappe circular solution.

5.6.3. Post NextGen value chains

5.6.3.1. Assumptions for the value chain analysis

As discussed in section 4.6.1.3, series delays occurred due to MNR System upgrades, Covid19, and unexpected tragedy. Due to this, the pilot testing of the Raceway reactor and the Membrane system was delayed and reduced in scope. The pilot tests were conducted using industrial wastewater from the brewery. The municipal wastewater line was not available for testing. The pilot tests were adequate for proof of concept, however, analysis of the results and calculations for full scale analysis and implantation are still needed. These analyses will be done in the coming months. This value chain analysis will focus on identification of the value chains, the general attributes, the actors involved, and on how these technologies can be deployed at other sites for similar value chain creation. The analysis needs to be further explored after the results of the pilot test have been thoroughly analysed (including a cost-benefit analysis) and a full scheme has been designed.

5.6.3.2. Scheme of the value chain

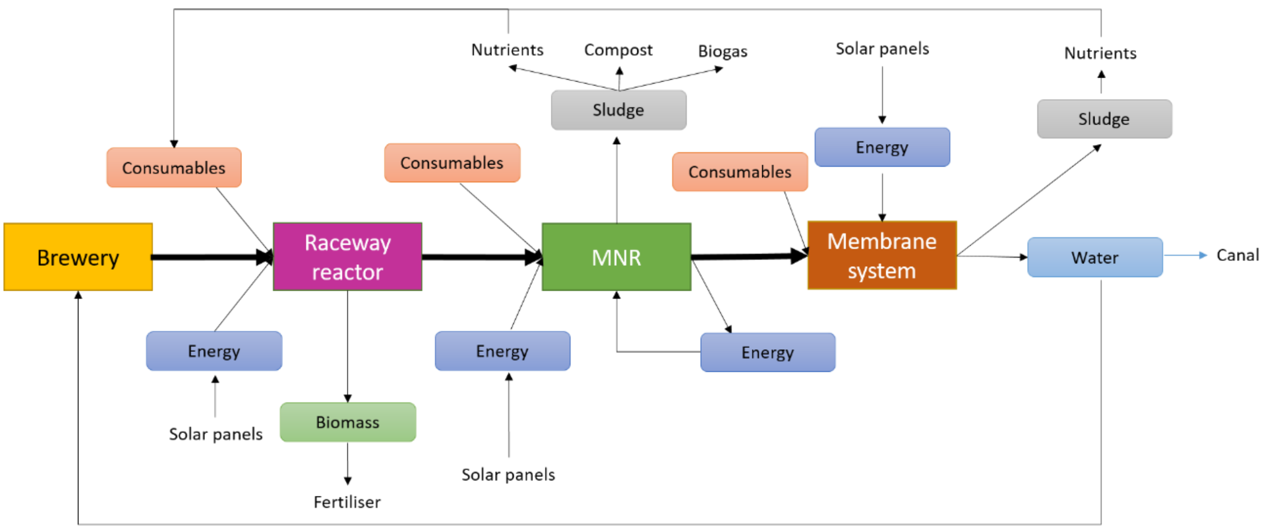

Figure 42: Possible full-scale Value Chain using NextGen technologies

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The scheme illustrated above includes a possible chain of technologies (including the Raceway reactor, MNR, and a Membrane system), which can work together to help close the metabolic loops of the Brewery. The raceway reactor can produce biomass to be used as fertilizer in La Trappe's gardens or sold at the visitor's gift shop. The sludge from the MNR and the membrane system could be used to recover nutrients to feed the raceway reactor and to produce compost and/or biogas. The water produced at the end of the process can be used to clean the bottles in the brewery (or in the process itself) or it can be discharged into the canal as surface water recharge.

Description of the value chains:

1. BioMass: purple non-sulfur bacteria (PnSB)

Conventionally, PNSB are cultivated under anaerobic photoheterotrophic conditions in closed photobioreactors in the presence of light, organic carbon and absence of oxygen. However, costs of such a production system are relatively high (€22.6 kg^{-1} protein). Current developments at MELiSSA, with partner UAntwerp, have shown that PNSB can be cultivated photoheterotrophically in raceway reactors open to air, allowing to reduce the production cost by 68% compared to photobioreactors (€7.3 kg^{-1} protein).

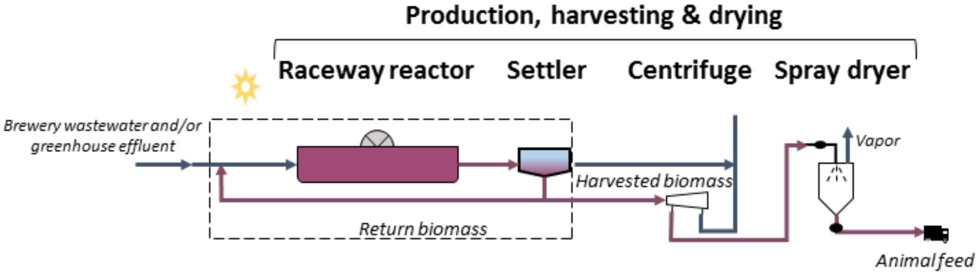

Figure 43: Raceway reactor technology process scheme

The overall process scheme is shown above. The NextGen pilot test focused on the portion within the dotted lines. Downstream processing such as optimization of centrifugation and drying is not included in the project. Blue and purple lines indicate respectively water and biomass flows.

Both off-site and on-site testing showed high growth potential for PnSB. The PnSB grew well on raw brewery effluent, under varying conditions. The COD removal efficiency was between 70-85% for a 0,5-0,7 Organic loading rate (OLR) [kg m^{-3} d^{-1}]. The volumetric removal rate was between 400-550 [mg L^{-1} d^{-1}]. The yield of the biomass was 0,4-0,5 [$gCOD_X$ $gCOD_S^{-1}$], slightly higher than the yield obtained in lab conditions 0,4 [$gCOD_X$ $gCOD_S^{-1}$]. The executed plant tests demonstrated the functionality of PnSB as a slow-release hydroponic fertilizer in vertical farms.

The plants that received solely PNSB as fertiliser had a significantly higher yield (808.68±7.22 [g m^{-2}]) however, the yield was still significantly lower than the plants that received the synthetic nutrients (919.63±3.44 [g m^{-2}]). Interestingly, the plants that received PNSB and the missing nutrients (potassium) performed as well as the plants that received the full synthetic nutrient solution (913.40±131.64 [g m^{-2}]). These results show that the PNSB could be a valid

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fertiliser, however it will perform poorer than a traditional synthetic fertilizer when its used alone (without the complementing elements).

Laboratory testing showed that heavy metals contaminants for Cd and Pb were below EFSA regulations. Hazard analysis and critical control point (HACCP) testing showed levels below EFSA regulations. This suggests that the PnSB can be used as a slow-release fertilizer for ready to use crops. Additionally, it suggests, that the other potential use for PnSB (as an agrofood industry protein source) may be viable as well.

2. Water

The MNR system treats the wastewater in the BioMakery to safe discharge levels. Currently the water is discharged to the local canal, or it is used as irrigation water on ornamental plants located in the onsite plant nursery. The NextGen pilot is testing technologies to create a higher quality water product for reuse within the brewery process itself.

The Membrane testing was done using two different membrane system technologies. The first test was performed in France, in a laboratory setting on raw brewery effluent using MELiSSA membrane equipment (Ultra filtration / Reverse Osmosis). These tests showed that potable water can be produced. This technology was able to create the highest quality of water, which could be used within the brewery process itself.

The second method tested was performed using an alternative capillary NF system at the La Trappe site directly on MNR industrial wastewater effluent. The experiment focused on multiple short-term tests, due to the instability of the MNR effluent at the time of the testing. These tests showed a reduced removal of contaminants when compared to the results of the UF RO experiment. However, the nanofiltration system was able to produce water that was clean enough to be used as process water (boiler water, possibly bottle washing) within the brewery process. The system operated at a water recovery rate of 20-25%.

The UF RO system removed all compounds better than the NF system, however it has a much higher CAPEX and OPEX. Therefore, a cost benefit analysis needs to be completed to create an optimal strategy for water recovery at the site. It is likely that a combination of different technologies should be used to create different water products (outlets) for different avenues of reuse.

3. Sludge:

Sludge is already produced during the MNR process. In a full-scale scenario, where both the raceway reactor and a membrane system are installed into the BioMakery, sludge from the MNR and membrane system can be used to recover nutrients to feed the raceway reactor. The remaining sludge can also be used to produce compost or other products derived from sludge, and/or it can be used to create biogas.

4. Consumables:

Various consumables are used at the wastewater treatment facility. The following main consumables are used by the MNR system: sulfuric acid (pH adjustment), Iron (III) chloride (coagulant), and a polymer (flocculant). Additional consumables are used for the raceway

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reactor: nutrients NH_4Cl, Na_3PO_4/KH_2PO_4 or fresh urine (used in the last experiment); pH control with HCl, or CO_2 dosing, and *Rubrum* inoculum at the start of the experiment.

5. Energy:

The energy used by the BioMakery (all technologies) will come from solar panels installed nearby at the abbey. A heat exchanger recovers thermal energy from the sewer line, which is used to heat the greenhouse that houses the bioreactors (with plants).

Cashflow of the value chains

The Trappist Abbey and Brewery can reuse the treated industrial wastewater (post MNR and Membrane technology) in various ways on the grounds: high value potable water can be used in the brewery process; process water can be used for boiler water (possibly bottle washing); and irrigation water can be used to irrigate the grounds and ornamental plants. By reusing the wastewater, the Abbey and Brewery greatly reduces the amount of drinking water it must purchase for use.

Large scale production of PnSB can create biomass that can be used onsite or sold as a slow-release fertilizer. Depending on how much is made, the PnSB can eliminate the need to purchase fertilizer from an offsite source, and it can also become a potential source of income. PnSB can also be used in the agro-food industry as a protein source. It may be sold if large amounts are produced, or it may be used as fish feed if the Abbey were to engage in fish farming.

5.6.3.3. Stakeholders' involvement

The technologies tested in the NextGen project can create valuable end products from waste streams. A full cost-benefit analysis is needed to determine the size and cost of a full-scale implementation at the site. An analysis for a full-scale set up will be performed in the coming months. However, it is already apparent that full scale implementation will create valuable environmental impact, reducing waste streams, and creating positive circular economy solutions for the region.

The following describes the stakeholders and to what extent they are affected by a full-scale solution.

Main actors:

1. Trappist monastery of the Abbey of Our Lady of Koningshoeven

The La Trappe Abbey & Brewery share historical grounds in Koningshoeven. The monks support themselves and their charity work via the production of various craft products including beer, chocolate, and cheese. The monks work in the production areas, manage the BioMakery, and are dedicated to long term sustainable management of their grounds. The Abbey uses drinking water in their production areas, in the tourist areas, and along their grounds. These waters can be replaced in part by the recycled water products produced in the BioMakery. The monks can use the slow-release fertilizer on the grounds, or they can sell the fertilizer in their gift shop.

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2. Swinkels Family Brewers

Swinkels Family Brewers is an independent family brewer, who began to collaborate with Brewery De Konigshoeven is 1999. The La Trappe beer is brewed in collaboration with the Swinkels Family Brewery company. The company can use the recycled wastewater in their facility, reducing the amount of drinking water they need to buy. The use of recycled water helps provide them with sustainable access to water, while also helping them achieve circularity goals.

3. Dutch Water Authority De Dommel

The La Trappe Abbey & Brewery falls under the authority of De Dommel. The two have teamed up and signed an agreement for cooperation. The agreement is managed by a board composed of the Abbey and the waterboard. As a policy maker, De Dommel can use the La Trappe site as a test bed for circular solutions and new policy and for the promotion of new technologies and strategy.

4. The Municipality of Tilburg

The Municipality of Tilburg is affected as the wastewaters from the site are no longer sent to the central wastewater treatment plant. This reduces the loads placed on the central facility.

Intermediary actors:

1. SEMiLLA IPStar

SEMiLLA IPSTAR Is the technology provider for the space technologies being tested at the La Trappe site. They ran the experiments for the water treatment membrane technologies and the purple bacteria reactors. SEMiLLA will perform analyses for full scale implementation. They work with La Trappe on various cooperative efforts for circular economy education and development.

2. Biopolus Institute

The Biopolus institute is the provider of the MNR technology, and the innovator behind the BioMakery business model and concept. The BioMakery's MNR technology is the platform technology to which the other technical solutions of the NextGen project will connect to in the long term. Biopolus provides technology support and circularity consulting.

External actors:

1. La Trappe Visitors

La Trappe is making a large effort to adopt circular practices and to create a sustainable model of business. In an effort to showcase their circularity, visitors can join a tour to see the installed technologies and to learn about all of the various sustainable practices taking place at the grounds. The visitors have a chance to see first-hand, new technologies, introducing them to the concept of circular economy and hopefully changing their perception of waste. The visitors may be able to purchase fertilizer from the visitor center, which can carry the conversation further if they introduce the products to others.

2. Partner Universities

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DeDommel, SEMiLLA, and the Abbey are involved with various universities (including HAS University) in the Netherlands and other nearby areas. There are graduate students that already partake in various research projects at the BioMakery. The existing technologies and new supplementary technologies can be studied further in local graduate and undergraduate programs.

3. Local schools

Local school programs can visit the site to be introduced to the various technologies at the site. The students can witness first-hand circular economy in action.

5.6.3.4. Value proposition and benefits of the value chain

Economic aspect:

The economic value of the NextGen solutions at La Trappe stem from:

- Reducing the costs related to drinking water bottle rinsing, irrigation, and possibly for beer production.
- Reducing or removing the need to purchase fertilizer for the plant nursery and the gardens around the abbey, thanks to the production of PnSB.
- Potential increase in production at the plant nursery due to better and more available fertilizer and water.
- Potential sales of a slow-release fertilizer (from the PnSB) at the visitor center.
- Potential protein source (PnSB) for a future fish farm at La Trappe.

The various delays have also resulted in delays in data collection. A cost-benefit analysis is needed to size the various technologies and to choose the appropriate membrane technology. The investment costs and the operational costs of a full-scale solution should be compared to the positive economic benefits mentioned above in order to make a conclusion regarding the ROI. An ROI of 8 to 10 years is acceptable for the Abbey.

Environmental aspect:

The environmental value of the BioMakery and the NextGen solutions at La Trappe stem from:

- Reducing the drinking water used for irrigation, bottle rinsing, and beer production, which equates to reduced water stress.
- Reducing the need for wastewater to travel for treatment, which equates to reduced water miles. This means saving energy costs for the transport and treatment of the water.
- Nutrients are extracted from wastewater (sludge), which can be used in the raceway reactor to create PnSB, reducing the need for artificial fertilizers. The slow-release fertilizer is eco-friendly.
- Reducing the CO_2 emission related to the transport of the fertilizers.
- Reducing the Nitrogen and Phosphorus released by the wastewater during its travel, as the wastewater is locally recycled.
- The sludge produced in the wastewater treatment process can be made into various products or biogas, a potential new source of renewable energy.

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5.6.3.5. New business cases

The various problems (Covid, etc.) resulted in delays in data collection, data analysis and full-scale design extrapolation. Therefore, currently it is difficult to calculate the full-scale costs and to extrapolate out the economic impact. There will be value created, but the overall economic value is not yet clear.

1. For the membrane system, the economic value will depend largely on the assigned value of water, the natural resource that the NextGen solution is focused on saving, recycling. The environmental impact of the solution is quite extensive, and as such, the economic value of the solution will change / increase as water shortages and climate impacts change the economic value of natural resources, and as the cost of environmental benefits are weighed in.
2. For the raceway reactor, the economic value of the purple bacteria will largely depend on the final products produced (slow-release fertilizer, protein source) vs. the CAPEX and OPEX of the production system. The inclusion of the raceway reactor to the BioMakery, reduces the overall wastewater load going into the MNR system. This can help reduce the operational costs of the MNR system.
3. A full-scale design of both technologies should be analysed individually, but also together as part of a cooperative system within the BioMakery. The synergies are important to examine as they may help reduce operational costs, increasing the economic value created.

In order to assess new business cases for the full-scale La Trappe solution, the following business model canvas was created.

<table>
<tr><th>Ecosystem of stakeholders</th><th rowspan="2">Key activities
Upcycling wastewater to create various water products for reuse at the site.
Production of PnSB from waste to create a slow-release fertilizer, protein source for agro-food industry.
Thermal recovery for heating the green houses.</th><th rowspan="2">Key resources
Water
BioMass (Nutrients)
Thermal energy</th></tr>
<tr><td><u>Main actors:</u>
La Trappe Abbey & Brewery & Swinkel Family Brewers (producers)
Municipality of Tillburg (municipality)
Dutch Water Authority De Dommel (reg. authority)</td></tr>
<tr><td><u>Intermediary actors:</u>
SEMiLLA IPStar (technology provider)
Biopolus Institute (technology provider)</td><td colspan="2" rowspan="2">Stakeholders relationship
Collaboration and co-benefits distribution
Classic business relationship</td></tr>
<tr><td><u>External actor:</u>
La Trappe Visitors, Partner Universities, Local Schools</td></tr>
</table>

Economic Value Reduced water costs; reduced fertilizer costs; biomass (protein source) sales; reduced heating for greenhouse	**Environmental Value** Water savings, nutrient recovery, lower emissions of N, P in water	**Social Value** Positive affect on public health and well-being	**Territorial Value** Synergetic use of waste streams to create valuable resources
Cost structure Investment and operational costs for the various technologies	**Impact of the organizations** Reduced impact for water consumption, reduced impact for fertilizer use	**Non-profit mechanism** Tours and programs for public awareness of circular economy solutions	**Public funding** Potential subsidies from local authorities to cover investment costs
Revenue stream Potenial to sell fertilizer, protein source for the agro-food indurstry	**Global impact** Increased climate change resilience, sustainable water cycle		**Public non-financial benefits** Advancement of circular economy principles

Figure 44: La Trappe NextGen solution business model canvas related to multistreams

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The La Trappe NextGen solution builds upon the BioMakery, implementing new technologies to create higher valued products (potable water vs. irrigation water) and new products (biomass) from existing waste sources (industrial wastewater).

The investment costs of the new technologies and the operational costs must be offset by the value of the products created. The products created (various high quality water products, slow-release fertilizer, and thermal energy) can be used onsite, reducing the need to purchase these items from others. New sources of income can be created from selling the slow-release fertilizer, or from selling the PnSB as a protein source to the agro-food industry. The biomass can also help support a new business in fish farming, where fish feed is produced onsite and not purchased from an outside source. The fish farm can create another source of income for the abbey.

In addition, the values associated with the extensive environmental benefits and the social impacts should also be considered when deciding on whether to proceed with the full-scale solution.

The full business potential is not yet clear but adding in the environmental and social benefits creates a strong case for the solution. As water shortages and climate change becomes more pressing, the economic values of natural resources will also increase. The Netherlands has committed to going circular by 2050, therefore investment in circular infrastructure is likely to become necessary over time to meet government mandates.

5.6.3.6. Barriers and drivers to implement the value chain

Drivers

There are a number of drivers that make the case for the full-scale La Trappe NextGen solution:

- The solution is in line with the Netherlands Circularity Strategy for the country going fully circular by 2050.
- The La Trappe Brewery will create resiliency in its beer production, by creating a more sustainable source of water for production and bottling.
- The La Trappe Abbey can use any remaining water at the site for irrigation.
- The La Trappe Abbey can use the slow-release fertilizer on the grounds and on ornamental plants. Pilot testing showed the functionality of PnSB as fertilizer, with no traces of contaminants that were above limits. Therefore, over time, it may also be used in farming situations, assuming legislation allows for it.
- PnSB as protein source can be investigated further, in order to create a new product for sale or use at the site.
- The NextGen solutions can help the Abbey obtain its goal to become fully sustainable.
- The natural water cycle around the Abbey will have a greater chance of recovery if less water is extracted by the brewery. This will help the overall condition of the environment around the Abbey.
- Circular solutions that create valuable products from waste will help promote a shift in people's mindsets regarding the need for a transition to a circular economy.

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Barriers

Barriers for the project primarily exist because the SEMiLLA technologies are new, with proof-of-concept pilot testing completed, but without full-scale realization. In order for this to happen, a full-scale design is needed, where the CAPEX and OPEX are calculated for various scenarios, in order complete and optimize the design of the full system. Depending on this extrapolation, and the cost-benefit analysis results, the return on investment may take longer than the 8-10 years the Abbey would like. This barrier can be overcome by applying for supplemental funding to help reduce investment costs to the Abbey. Once a full-scale solution is up in running at La Trappe, the "technology bundle" found in the La Trappe BioMakery can be applied in other sites, especially in areas with similar industrial wastewaters (breweries, etc.).

The MNR technology of the BioMakery is slowly gaining traction internationally, with WWT facilities in operation and under construction at the Abbey, in Vietnam, China, and in the Middle East. With the successful integration of SEMiLLA technology at La Trappe, the integrated business concept of the BioMakery can gain recognition as a circularity driver. This will hopefully encourage other facilities using MNR technology to expand their facilities with circular technologies (including those tested in NextGen) to benefit from the full business model of the BioMakery.

5.6.3.7. Policy Recommendations

The permitting process for the La Trappe BioMakery was especially long because the wastewater treatment facility was placed on the historical site of the La Trappe Abbey. The extensive approval process highlights the potential problems that can exist when building a facility for decentralized circular processes within a dense urban zone.

Currently, urban lands are zoned for various uses: residential, industrial, commercial, agricultural, etc. In order to promote decentralized nature-based circular solutions for reuse locally, zoning laws must be adapted. Exceptions are needed for buildings /solutions that "fit" the local environment (are aesthetically pleasing) and that meet health and safety requirements. For example, exclusions zones are typically required for wastewater treatment facilities. However, in order to create local metabolic hubs for circular economy, exceptions must be made for nature-based solutions like the BioMakery. The compact, odor free, green house like environment of a BioMakery is ideal for the urban setting. The EU should encourage adapting existing zoning policies for new technologies and solutions.

Circular technologies aim to create value from waste. When wastes are used to create new sellable/usable products, questions regarding ownership, liability, and responsibly are all brought into light. Who owns the waste? Who is liable when handling the waste? Is the waste provider liable for the quality of the product? Who is responsible for permitting? How are the materials shipped? These and other questions need to be answered to promote circular economy. European wide standards and guidance is needed.

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5.6.3.8. *Limitations of the study*

As previously discussed, series delays occurred due to MNR System upgrades, Covid19, and unexpected tragedy. Due to this, the pilot testing of the Raceway reactor and the Membrane system was delayed and reduced in scope. The pilot tests were conducted using industrial wastewater from the brewery. The municipal wastewater line was not available for testing. The pilot tests were adequate for proof of concept, however, analysis of the results and calculations for full scale analysis and implantation are still needed. These analyses will be completed in the coming months. At this time, the overall solution of the BioMakery with the various SEMiLLA technologies was reviewed. A more detailed analyses is recommended to be completed for the individual value chains when more data is available.

5.6.4. Conclusion on the replication of the value chain and business potential

As water scarcity becomes more prevalent, even in places like the Netherlands, new circular water management systems must be created. By reusing water, we reduce the need to extract virgin water, allowing nature to replenish its aquifer systems. By treating wastewater to desired reuse levels (creating various water products), we can reduce treatment costs, while still reducing the amount of virgin water we need to extract.

The BioMakery, with different pre and post technologies, can treat wastewater to desired levels. Multiple effluent streams can be created for the different water products. By adding other technologies, such as a raceway reactor, nutrients can be extracted to create new products, such as PsNB from waste. The biomass can be used to create a slow-release fertilizer, or as a protein source in the agro-food business. Heat extraction can be included to create a source of heat energy. The sludge produced by the MNR is being used now to produce compost. In a full system scenario, some of the nutrients can be cycled back to feed the raceway reactor.

The concept of the BioMakery can be replicated globally and designed specifically for a particular region. The various circular modules (technologies) can be designed for the region (depending on what wastes they have, what resources they need). Since all things are connected to water, the MNR system creates a good platform for circular technologies to connect to.
The prospect of creating value from waste is desirable (EU circular economy directive) and the need to reuse water is very important, especially in areas where water scarcity is a major concern. Therefore, replicating the BioMakery and its business model is strongly encouraged at a large scale.

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5.7. CS 7 – Gotland (SE)

5.7.1. Description of the CS

5.7.1.1. Challenges

In recent years, the island of Gotland has experienced a severe water crisis, negatively affecting tourism and small-scale industries.
Water shortages hinder economic development due to strict regulations for building of new houses and the start-up of new business that consume water.

5.7.1.2. Circular solution

A Testbed is currently under development in southern peninsula called Storsudret (annual water consumption of 300,000 m^3). It's an integrated system based on:

- Rainwater harvesting from drainage ditches and artificial surface water dams or automatic controlled balanced accumulation in natural lake
- Artificial infiltration to groundwater
- Groundwater dams for subsurface water storage
- Wastewater reuse
- Climate efficient energy based on solar energy

The value chain regarding the water before NextGen is presented in the following figure.

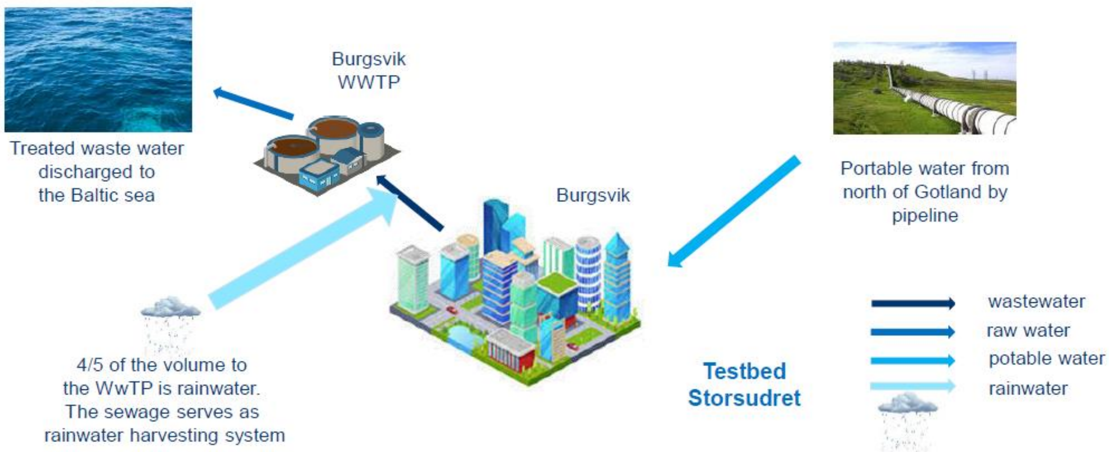

Figure 45: Pre-existing value chain of the Gotland case

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The expected value chain after the installation of the testbed is presented in Figure 46.

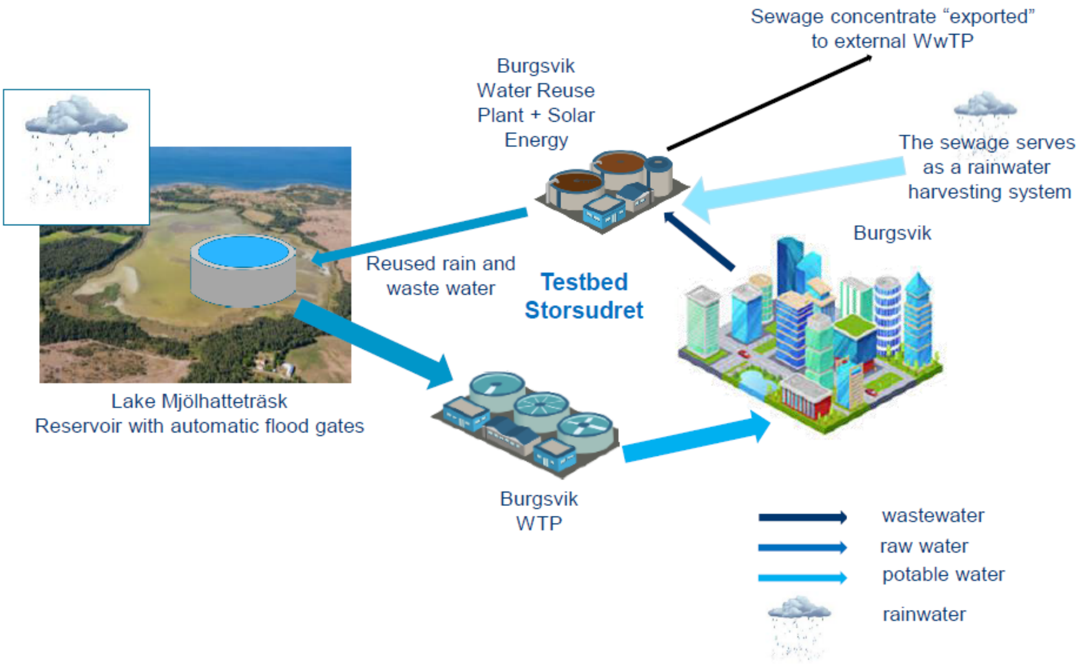

Figure 46: Value chain of the Gotland case expected after NextGen solution implementation

The main objectives of the implementation are:

- Rainwater harvesting using automatic floodgates to replenish aquifers and monitoring of aquifer levels.
- Decentralized membrane treatment of raw wastewater to reduce volumes treated at the central WWTP.
- Climate efficient wastewater reuse powered by solar energy to overcome carbo footprint drawbacks
- Optimized membrane filtration for produce drinkable water from challenging surface water.
- Storage of water in subsurface dams.

5.7.1.3. Status of the demo case

Currently, the system is not fully installed. Besides, the project foresees the installation of a pilot plant that is going to treat a volume of water that is not representative enough to stablish a business case based on it.

The analysis of the value chain is therefore limited to findings from WP4, available in section 6. It describes the stakeholders' ecosystems and the main drivers and barriers encountered by the Gotland case.

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5.8. CS 8 – Athens (EL)

5.8.1. Description

The Athens Urban Tree Nursery is part of Goudi Park, an area which lies in the heart of Athens. It is a mixed-use area, comprising of urban green and urban agricultural spaces, as well as administration and residential uses. The area is in the process of redevelopment and the regeneration will boost the local economy and improve the life of the 4 million citizens in the Attica region. The nursery belongs to the municipality of Athens, it comprises of 4 ha of vegetation and supplies all the urban parks and green spaces of Athens with plant material. It uses potable water from Athens' Water Supply and Sewerage Company (EYDAP) for its irrigation. Furthermore, the nursery is the staging area for all of the pruning waste from all of the Athens urban green spaces. The green waste is not treated, only stored on site. Over time a part of the green waste is transferred to the Athens landfill. The nursery uses fertilizers supplied by the local market.

5.8.1.1. Challenges and opportunities

The summers in Athens are hot and dry. Recent studies show increasing tendency towards drier conditions, with increased variability of extreme rainfall events. Overall precipitation is expected to decrease as longer dry spells and reduced rainfall intensity has been observed. Temperatures are projected to increase in the Athens area in the order of 7-8°C by 2100[30].

With the longer, hotter, drier summers, green areas are more important than ever to reduce the urban heat island effect. Lush green parks also create a positive environment for both the citizens and the local wildlife. Access to blue green urban spaces has positive effects on the mental and physical health of urban citizens. The green spaces also help provide homes for wildlife.

However, green areas require both water and nutrients to remain healthy and vibrant. Athens currently lacks adequate nutrient rich soil, and the reduced rainfall and drier conditions mean more irrigation to keep green areas lush.

How can we increase urban green areas, without increasing the pressure on drinking water supplies, and without using harmful artificial fertilizers? That is the challenge of the case study: developing a circular solution that can help create a sustainable source of irrigation water and nutrients.

5.8.1.2. Circular solution

The Athens NextGen solution will demonstrate how, through sewer mining, wastewater can be extracted locally from sewers to be treated and further processed to create valuable sustainably sourced resources, which can be used to nurture Athens green spaces. The

[30] : https://www.climatechangepost.com/greece/climate-change/

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solution is in line with the Athens Resilient Strategy for a circular approach to water services by 2030.

The pilot test takes place at the Athens Urban Tree Nursery, where wastewater is extracted from the municipal sewer line via a pumping station into a storage tank. The wastewater is then treated using a modular hybrid unit, which uses Membrane Bioreactor (MBR) technology for wastewater treatment and Ultraviolet radiation (UV) for water disinfection. The pilot system produces approximately 25 m3/day irrigation water that can be used to irrigate the local tree nursery.

The wastewater treatment sludge will be collected, dewatered and mixed with treated pruning wastes from the nursery. The raw materials (400 L/ week of sludge and 300 L/ week of green waste) will be continuously mixed in a Rapid Composting Bioreactor, where the closed and aerated system will speed up the degradation process to create an eco-friendly compost in approximately 2 weeks. Roughly 200 kg of high-quality compost will be available biweekly for use.

In addition to water and nutrient recovery, a thermal recovery unit will also be installed at the pilot site to recover approximately 10kWh thermal energy from the treated wastewater. This heat will be used to boost the Rapid Composting Bioreactor, for added system efficiency.

The overall goal is to create healthy and vibrant green spaces in the city of Athens. The pilot test will show that by upcycling two available waste streams: wastewater (& sludge) and green waste, Athens can have a sustainable solution for irrigation water and nutrient rich compost.

5.8.1.3. Status of the demo case

As part of the NextGen project, a pilot scale system is tested and analysed. Due to Covid19, the implementation of the pilot setup was delayed. The pilot setup is partly installed and will be fully operational by July 2021. The pilot test results are being closely monitored and analysed for full scale solution design. The implementation of a scaled-up solution will partially depend on the results of the pilot test results.

A full-scale implementation of the solution would first result in a system that is 10 times the size of the pilot setup being tested within the NextGen project. The value chain analysis is for the planned full-scale implementation.

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5.8.2. Pre-existing streams before NextGen solution

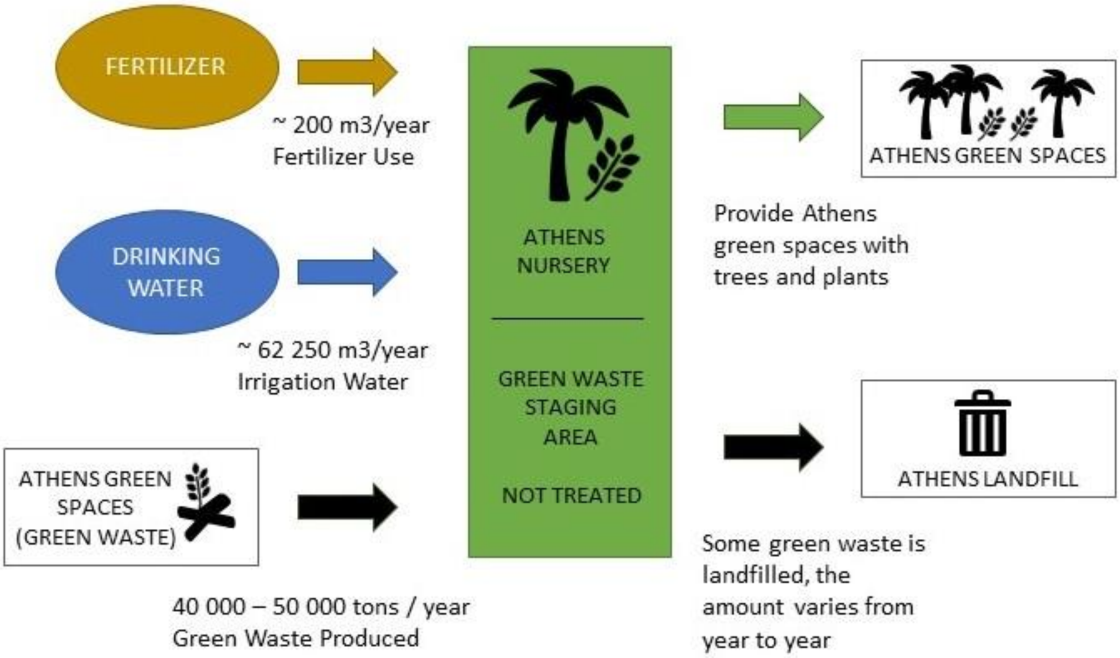

Figure 47. Pre-NextGen Baseline Streams

5.8.2.1. Pre-existing value chains and stakeholders

Description of the value chains

1. Fertilizer:

Approximately 200 m^3/year of fertilizer is used annually at the Athens Plant Nursery. The fertilizer is obtained from the local market. The specific fertilizer is chosen based on price and availability. The fertilizer is used as a nutrient source for the plants at the Athens' nursery. The approximate cost of the fertilizer is 13 000 €/year.

2. Drinking water:

Approximately 62 250 m^3/year of drinking water is used annually at the Athens nursery. The water is obtained from the Athens' Water Supply and Sewerage Company (EYDAP), a semi-private, semi-public company. The potable water price is 1,17 €/m^3, meaning the approximate cost of the drinking water used by the nursery is 73 000 €/year.

3. Green waste:

A total of 40 000 – 50 000 tons of Green Waste is collected annually. Some of the waste is stored at the Nursery, some of it is landfilled. If the full scale NextGen solution is being considered, approximately 60 tons/year (300 m^3/year assuming a density of 5 m^3/ton) of the green waste that is accumulated in the Athens nursery could be used for creating compost. The disposal costs of pruning waste are 1,9 €/m^3, therefore the landfill costs saved by using the green waste, and not landfilling it equates to approximately 570 €/year.

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Stakeholders' ecosystem (key stakeholders):

1. Athens Plant Nursery:

The Athens Plant Nursery belongs to the Athens municipality. The Nursery covers approximately 96 acres, 40 of which are used in the production, development, and maintenance of the plants. The remaining area is used for general purposes such as administration buildings and the offices of the Municipality of Athens. The Nursery supplies all the urban parks and green spaces of Athens with plant material. The pruning waste of the urban parks is accumulated at the Nursery. Some of this waste is sent to the Athens landfill. The Nursery purchases potable water from the Athens' Water Supply and Sewerage Company (EYDAP).

2. Athens landfill:

The Athens landfill is located in Fyli approximately 25 km from the Nursery. A part of the green waste from the Nursery is transferred to the Athens landfill. The disposal costs of the pruning waste to the landfill are 1,9 €/m^3.

3. Athens's Water Supply and Sewerage Company (EYDAP):

The water company is semi-private and semi-public, and it supplies the Nursery with potable water for irrigation. The cost of the potable water for the Nursery is 1,17 €/m^3.

4. Local fertilizer suppliers:

The Nursery purchases fertilizers from local merchants, depending on pricing and availability. These merchants are located in the west of Athens which means the fertilizer must travel about 10 Km to the nursery.

5. Citizens of Athens:

The citizens of Athens benefit from the plants supplied by the Nursery to the city's green spaces. Lush green parks create a positive environment for both the citizens and the local wild life. Access to blue green urban spaces has positive effects on the mental and physical health of urban citizens. The green spaces also help provide homes for wildlife, which the citizens can enjoy. The green spaces also reduce heat island affects, reducing the impacts of hot, dry summers.

6. Athens electrical grid:

The nursery gets electrical energy from the urban network. The industrial price for electricity in Athens is 0,2 €/kWh.

7. Petrol oil suppliers:

The Nursery uses petrol oil for heating, purchased from various petrol suppliers. The petrol supplier is chosen based on availability and cost. The approximate price for petrol is 0,875 €/lt. The nursery pays approximately 3500 €/ year for petrol.

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5.8.2.2. *Identification of new value chains post-NextGen*

The value chains associated with the Athens NextGen project are interconnected and rely on one another. The NextGen solutions will work to replace existing value chains (drinking water & fertilizer) with upcycled waste chains (green waste, wastewater, and sludge) to create a circular and sustainable solution for Athens green spaces. Because of this, the entire process will be analysed together. The value chains associated with the sewer mining unit, the rapid composting unit, and the heat recovery unit will be reviewed.

5.8.3. Post NextGen value chains

5.8.3.1. *Assumptions for the value chain analysis*

While the NextGen pilot testing has not been completed, design data was used to estimate the values of a full-scale design. The full-scale design is 10x the size of the pilot test. The following analysis will look at how a full-scale system would impact the stakeholders and the general ecosystem.

The fill-scale design creates more irrigation water than what the nursery currently normally uses. However, the extra water can be used in other nearby green areas, and it can also be used during drier summers, when more water is needed than normal.

5.8.3.2. *Scheme of the value chain*

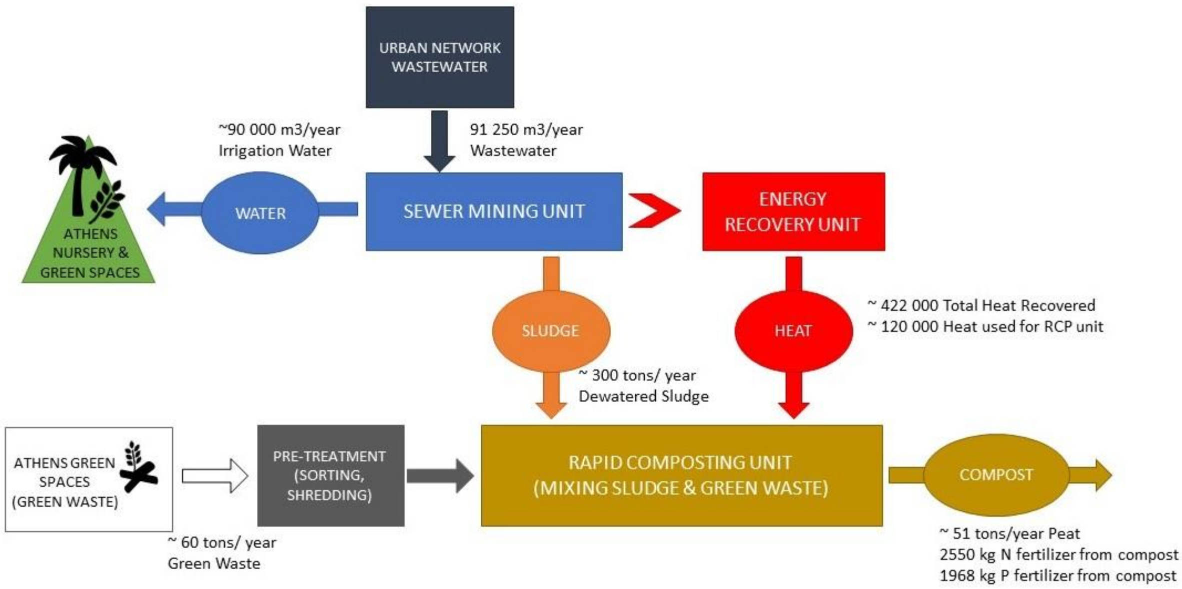

Figure 48. Full scale value chain (10 times the size of the pilot scale)

Description of the value chains

1. Irrigation Water from Wastewater

The sewer mining unit(s) is currently installed and fed wastewater by the main wastewater sewer pipelines that pass by the Nursery. The wastewater is treated and disinfected by the MBR hybrid unit to create high quality water, suitable for irrigation and for aquifer recharge

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(in the winter). Approximately 90 000 m3/year irrigation water will be produced annually, which can be used at the Athens Nursery and in nearby green areas. More water will be available than what the Nursery currently uses for irrigation. As a by-product of the treatment process, approximately 300 tons of dewatered wastewater sludge will also be produced annually.

2. Thermal Energy

A heat recovery unit(s) will be installed to recover heat from the treated wastewater (effluent). Approximately 422 000 KWh/ year of thermal energy can be recovered annually. Around 120 000 kWh/ year can be used to help boost the rapid composting unit. The remaining thermal energy can be used to heat or cool the nearby buildings.

3. Compost stream

The full-scale Rapid Composting Unit can take the two waste streams (green waste & wastewater sludge) to create a valuable compost.

Athens parks and green areas produce a huge amount of green waste, approximately 40 000 – 50 000 tons of green waste is produced every year! A full scale NextGen solution only uses around 60 tons of this waste yearly to create a highly quality compost. The compost is created by mixing the 60 tons of green waste with approximately 300 tons of dewatered wastewater sludge (from the sewer mining unit) in a Rapid Composting Unit. The city can save the landfill costs (~570 €/year) of the green waste produced.

By combining the two waste streams, the fill scale NextGen solution can produce approximately 51 tons of Peat annually, the equivalent of 2550 kg N fertilizer and 1968 K P fertilizer. Currently the Athens Nursery spends approximately 13 000 €/year on fertilizer, this may be replaced by the peat. The effectiveness of the compost, and its ability to replace the fertilizer will be tested during the pilot study.

The production of compost from green waste and sludge can be expanded exponentially to create large amounts of valuable compost, for use or sale throughout Athens and/or Greece. The Athens wastewater treatment plant produces approximately 2 000 - 3 000 m^3 of wastewater sludge a day. Large scale rapid composting unit(s) can be installed to mix and treat the readily available WW sludge with the readily available green waste to create large quantities of peat. The value of this and other circular solutions from these waste streams should be investigated further as the results of the pilot test become clear.

Cashflow of the value chains

The Athens Nursery can purchase irrigation water, compost, and thermal heat from the full-scale NextGen solution. The amount of potable water purchased from Athens's Water Supply and Sewerage Company (EYDAP) will be greatly reduced. It will no longer be used for irrigation; it will only be needed at the on-site facilities. The need to purchase fertilizers will also be reduced, although it is not yet clear exactly how much less fertilizer will be needed. The production of thermal heat may reduce the amount of petrol that needs to be purchased for use at the Nursery. The NextGen solution will need to purchase electricity to run the machinery from the Athens electrical grid.

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5.8.3.3. Stakeholders' involvement

The NextGen solution takes three biological waste streams (wastewater, sludge, and green waste) and upcycles them using three different technological solutions to create valuable sustainably sourced resources. The creation of valuable resources from wastes will create a positive impact on the city of Athens. The irrigation water and the compost can be used at the Nursery and in urban green areas. The recovered thermal energy can be used to boost the RCB unit and to heat and/or cool local buildings.

The following describes the stakeholders and to what extent they are affected by the full scale NextGen solution.

Main actors:

1. The Athens Water Supply and Sewerage Company (EYDAP SA)

This stakeholder serves both the water sector and the wastewater sector of Athens. The harvested wastewater comes from the sewer lines of the company (reducing the water treated at the Athens main treatment facility), and the irrigation water created by the project will replace the potable water the company would normally supply. The company can use the NextGen circular solution to help create an autonomous, local, modular, and scalable solution, for water preservation and resource recovery, which can be applied in other water scarce cities.

2. Athens Urban Tree Nursery.

The Nursery has a high interest in the creation of these value chains. It will directly benefit from the high-quality irrigation water, the compost/ fertilizer, and the recovered thermal energy.

3. Other local buildings close to the Nursery

Thanks to the energy recovered with the circular unit, local houses could benefit from the heat produced by the Nursery and reduce its energy cost. They could have a high interest in the implementation of the value chain. The existence of these buildings and their proximity with the Nursery are determining for the creation of the synergy.

Intermediary actors:

1. NTUA - National Technical University of Athens.

The NTUA manages the NextGen solution and monitors the performance of the systems through the collection and analysis of data for system optimization and for potential further expansion.

2. Biopolus Institute:

Biopolus is providing the Rapid Composting Unit and the Heat Recovery Unit. They are responsible for commissioning and testing the systems, and for fine-tuning the process based on pilot testing results. Biopolus will train local municipality workers to run the systems.

3. Chemitec:

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Chemitec is providing the sewer mining equipment, and is responsible for commissioning, and for fine-tuning the equipment based on operational results. Chemitec is also responsible for training the municipality workers to run the sewer mining equipment.

4. EYDAP:

Athens's Water Supply and Sewerage Company (EYDAP) is responsible for constructing and installing the small pumping station of the configuration that extracts the sewage from the urban network to be treated on site.

5. Petrol oil suppliers:

The Nursery will need less petrol oil to heat its buildings, if the thermal heat will be used to heat the buildings and greenhouses.

6. Local fertilizer suppliers:

The Nursery will need to purchase less fertilizers from local merchants.

7. Athens electrical grid:

The Athens electrical provider will be used to power the sewer mining unit, the RCB unit, and the heat recovery unit.

External actors:

1. Citizens of Athens:

The availability of good compost and irrigation water in times of draught, means the municipality of the Athens can maintain and even upgrade their green spaces. The citizens directly benefit from lush green spaces in their city, which means they are likely support this circular sustainable solution. Citizen support creates a stronger case for funding the initial investment of the NextGen solution.

2. Nature:

The natural water reserves in and around Athens can regenerate, thanks to the reduction of water needed for irrigation. In the meantime, healthier and more numerous green spaces mean wildlife can return and flourish in the city.

3. Athens landfill:

The landfill will receive less green waste from the Nursery since some of it is used to create high quality compost.

5.8.3.4. Value proposition and benefits of the value chain

Economic aspect:

The economic value of the NextGen solution stems from:

- Reducing cost (1,17 €/m3) related to drinking water for irrigation (72 750 €/year);
- Reducing heating costs (0,875 €/lt); for Nursery buildings or other local houses related to thermal energy gains;

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- Potential increased production of trees/ plants at the nursery;
- Reducing fertilizer needs, purchase less fertilizers annually (13 000 €/year); and,
- Saving landfilling cost (paid by the Nursery) for the green waste (570 €/year).

As the pilot study is not yet fully working it is difficult to extrapolate out the actual costs of a full-scale solution and the full impact from the newly created resources. The overall economic value is not yet clear. The investment costs and the operational costs of a full-scale system have to be compared to the positive economic benefits mentioned above in order to make a conclusion regarding the ROI. It is not yet clear who would pay for the initial investment costs (or whether it would be at a local or regional level). The operational costs scheme is also not yet clear. New agreements must be made regarding the future economic scheme of the solution.

Environmental aspect:

The environmental value of the NextGen solution stems from:

- Reducing the drinking water used for irrigation, which equates to reduce water stress.
- Reducing the need for water to travel for treatment, which equates to reduced water miles. This means saving energy costs for the transport and treatment of the water. The approximate electricity required for the treatment of drinking water is 0,19-0,41 kWh/m^3, while the estimated electricity needed for the treatment of wastewater is 0,36 kWh/m^3. The electricity needed for the drinking water network 0,09 kWh/m^3, and the electricity needed for collecting and pumping wastewater 0,03 kWh/m^3.
- Nutrients are extracted from wastewater (sludge) to be used to create compost, reducing the need for artificial fertilizer. The created compost is eco-friendly, and can be used in local green spaces.
- Reducing the CO2 emission related to the transport of the fertilizers.
- Reducing the Nitrogen and Phosphorus released by the wastewater during its travel, as the wastewater is locally recycled.
- Green waste is upcycled to create compost, instead of being landfilled.
- Increasing the quality and the number of green spaces in urban areas.

Estimated environmental impact of a full-scale system:

- 300 tons / year of dewater sludge is upcycled for use in compost production (instead of disposal as a hazardous waste);
- 40 - 50 tons / year of green waste can be used for compost production (instead of being landfilled);
- 51 tons of Peat can be produced annually based on circular process instead of potential linear process of the fertilizer producer, the equivalent of 2550 kg N fertilizer and 1968 K P fertilizer;

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- 422 000 KWh/year thermal energy can be recovered annually; 120 000 kWh/year can be used to boost the rapid composting unit and the rest could be used to heat buildings
- 90 000 m3/ year of irrigation water will be produced for use at the nursery, in local areas.

5.8.3.5. *Barriers and drivers to implement the value chain*

Drivers:

There are several drivers that make the case for the Athens NextGen solution.

- The solution is in line with the Athens Resilient Strategy for a circular approach to water services by 2030.
- The citizens of Athens will benefit from greener parks and spaces. Blue/ green spaces have a positive effect on human health and wellbeing. These green areas have positive effects on climate change resiliency and help reduce urban island effects, which make the nursery and its streams increasingly important in urban planning.
- Circular solutions that create valuable products from waste will help promote a shift in people's mindsets regarding the need for a transition to a circular economy.

Barriers:

There are several barriers that may make the solution more difficult to realize.

- The initial cost of investment for the equipment and machinery.
- The operational cost to run smaller decentralized water treatment units (sewer mining units) is higher than the cost for running the large and established central WWTP.

5.8.3.6. *New business cases*

As the pilot study is not yet fully working, the full costs and the positive economic impact is difficult to extrapolate out. It is clear that there will be value created, but the overall economic value is not yet clear. The economic value will depend largely on the assigned value of water, the natural resource that the NextGen solution is focused on saving, recycling. The environmental impact of the solution is quite extensive, and as such, the economic value of the solution will change / increase as water shortages and climate impacts change the economic value of natural resources, and as the cost of environmental benefits are weighed in.

In order to assess new business cases for the solution, the following business model canvas was created.

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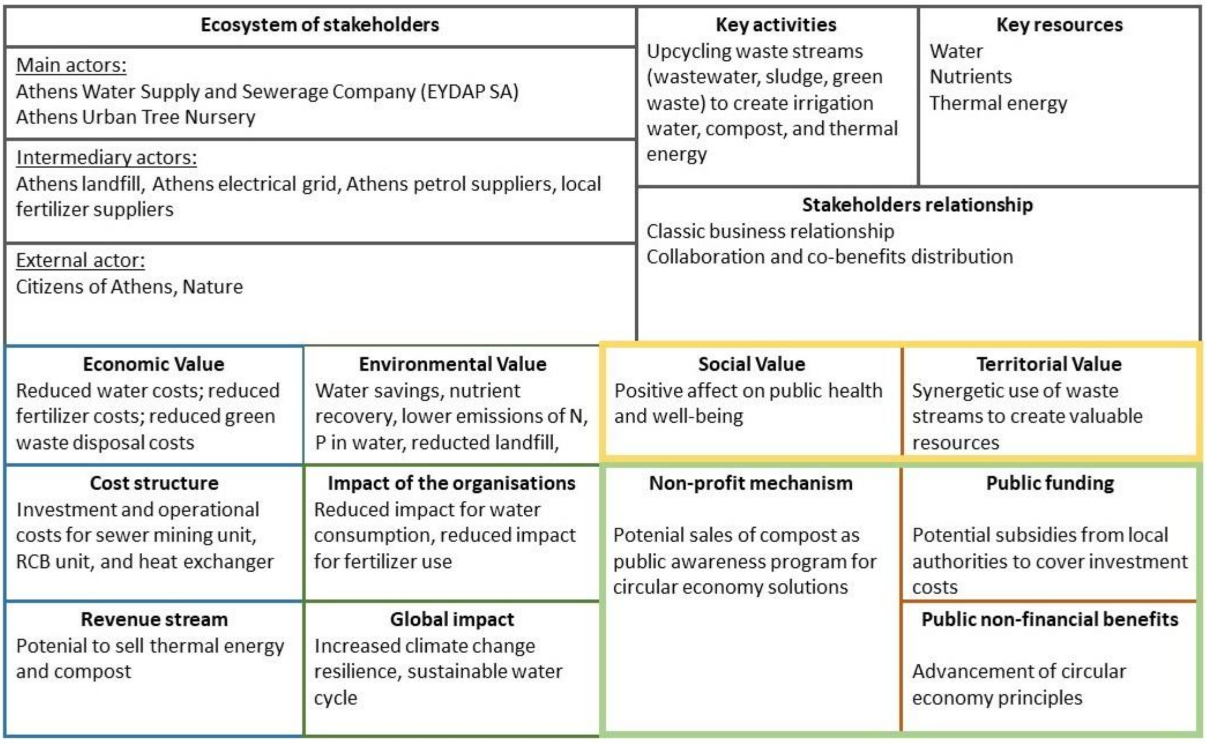

Figure 49 Athens NextGen solution business model canvas

The Athens NextGen solution uses sewer mining and circular technologies to create valuable resources from wastes. The investment costs of the machinery and the operational costs of running the machines must be offset by the value of the products created. The products created (irrigation water, compost, and thermal energy) can be sold to the actors.

However, the values associated with the extensive environmental benefits and the social impacts should also be considered when deciding on whether to proceed with the solution.

The full business potential is not yet clear but adding in the environmental and social benefits creates a strong case for the solution. As water shortages and climate change becomes more pressing, the economic values of the resources will also increase. Environmental mandates may make the solution a necessity in the future. Government subsidies, tax credits, and environmental R&D campaigns may fund the initial cost of the investment, making a strong business case for operating the solution and selling the products.

A new branch can be created within the Athens Water Supply and Sewerage Company (EYDAP SA) that works specifically with sewer mining for water recycling. The company can place these localized entities in areas of high irrigation needs and water scarcity spots. The sludge can be transported to the nursery, where larger rapid composting bioreactors can be used to create even more compost for use throughout Athens green spaces. There are lots of possibilities that may come from the Athens NextGen solution, each option should be reviewed to see where there is a greater environmental need and where potential economic benefits exist.

5.8.3.7. Limitations of the study

The study was completed based on design assumptions for the pilot study. Due to Covid19, the pilot study was delayed and therefore there is no adequate data yet to confirm the design

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assumptions. As data becomes more available, the design assumptions can be confirmed, which can then be extrapolated out for a full-scale system.

5.8.4. Conclusion on the replication of the value chain and business potential

With water scarcity becoming more prevalent, new circular water management systems need to be developed. Water reuse is an innovative way to address water scarcity, whereby wastewater is treated to the desired reuse levels, reducing the need for virgin water extraction. The use of sewer mining to treat and reuse water locally allows for efficient use of water resources. The added benefit of the heat recovery system harvests thermal energy, which can also be used locally to heat or cool buildings. By including the rapid composting bioreactor, the sludge derived from wastewater treatment can be mixed with green waste to create valuable compost. The prospect of creating value from waste is desirable (EU circular economy directive) and can be replicated in cities worldwide. It is especially relevant in cities where water scarcity is a major concern.

The production of compost from green waste and sludge can be expanded exponentially to create large amounts of valuable compost. This is especially true in the Athens case. The Athens wastewater treatment plant produces approximately 2 000 - 3 000 m^3 of wastewater sludge a day. The green spaces produce 40 000 – 50 000 tons of green waste yearly. Large scale rapid composting unit(s) can be installed to mix and treat the readily available WW sludge with the readily available green waste to create large quantities of peat. This valuable material can be sold throughout the Athens region and/ or Greece.

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5.9. CS9 – Filton Airfield (UK)

5.9.1. Description of the CS

The 143-ha site is located in the Bristol northern fringe and forms a connection between the Bristol city northern boundary and the conurbations wider northern fringe. The main feature in this site is the runway, which is 2,467 m long and 91 m wide.

The site was bought by YTL, a large Malaysian company with global operations, including Wessex Water in the UK and YTL Developments (UK) Ltd who are developing the site.

5.9.1.1. Challenges and/or opportunities

The former Filton Airfield has been recognised as one of the most important brownfield development opportunities in the UK.

A masterplan has been approved. The investment project includes a strategic Surface Water System (SSW), ensuring reliable drainage and allow local use of captured rainwater and water reuse

Within the NextGen project, a circular economy concept in Filton Airfield is demonstrated through rainwater harvesting and wastewater reuse, low-grade heat recovery and nutrients recovery.

5.9.1.2. Circular solution studied

The case study includes three types of circular solution:

- A rainwater harvesting system that should be implemented on a commercial building on residential buildings,
- A technology that could recover heat from sewages,
- Eco-friendly sanitation systems that could recover nutrients (e.g. phosphorus, urea)

5.9.1.3. Status of the demo case

Due to the case study advancement, the value chain analysis can only be applied to the value chain of the rainwater harvested on the commercial building.

Not enough data have been collected yet for other value chains that should implies nutrients and energy.

5.9.2. Limitations of the study and scope of the study

Scope:
The energy balance and the LCA of the processes will be studied in detail in the WP2 deliverable 2.1. The value chain analysis of this section will focus on transport and incineration avoided thanks to the new value chains.
The scope of the value chain analysis is limited at the rainwater reuse on the YTL Arena area due to data available.

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Assumptions:

The Table 12 presents common assumptions that have been made for the value chain analysis.

Table 12: Water demand and common assumptions for the value chain analysis

Toilet flushes		
Toilet flush (3/4 of flushes)	6	L
Urinal flush (1/4 of flushes)	3,6	L
Number of visitors in YTL Arena	20 000	capita
Flushes frequency	2	Flushes/capita/d
Irrigation		
The volume of irrigation water	5	l/m^2/d
Irrigation frequency (May to October)	1	Irr/week
Brabazon Park	12	ha
Rainwater supply		
Arena roof	30 000	m^2
Annual rainfall amount	0,811	m/y
Runoff coefficient[31]	0,85	NA
Supply and water disposal at Bristol[32]		
Price of water supply	2,29	€/m^3
Price of wastewater management	1,92	€/m^3

5.9.3. Pre-existing water value chain

5.9.3.1. Pre-existing sludge value chain

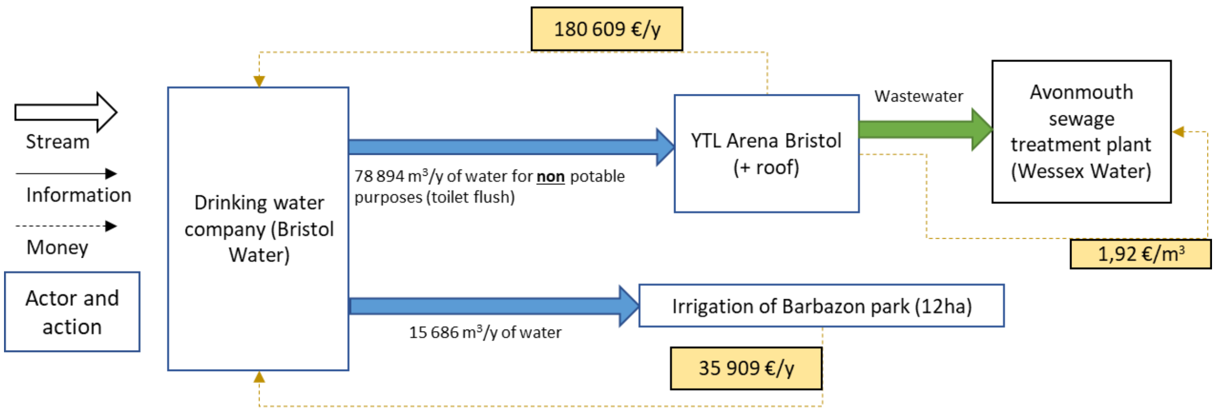

Figure 50: Rainwater reuse value chain from YTL Arena expected by Filton Airfield Arena

Streams' description:

Before NextGen, Filton Airfield actors was only using drinking water for non-drinking water application such as toilet flushing, golf irrigation or park irrigation.

Toilet flushes in YTL Arena represents a consumption of water of around 78 894 m^3 per year, and the irrigation of green spaces reaches 75 814 m^3 per year. The Arena discharges the excess runoff (estimated at 20 680 m^3/y) into a sewer drainage system.

[31] Roof selection for rainwater harvesting: Quantity and quality assessments in Spain
[32] https://www.wessexwater.co.uk/your-account/your-bill/our-charges

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Stakeholders' ecosystem:

The ecosystem of stakeholders studied in this section involves:

1. YTL Arena:

YTL Arena is an indoor arena with 17 000-capcity located in Bristol. This arena uses a huge amount of drinking water for the non-potable use.

2. Green spaces:

Brabazon Park are close to YTL Arena and consume water for irrigation from May to October.

3. Drinking water company: Wessex Water

This actor provides drinking water to Filton Airfield area.

4. Avonmouth sewage treatment plant: Wessex Water

This plant is also managed by Wessex Water, and treat wastewater that comes from Filton Airfield case study.

Economic aspect:

Due to a lack of data, cost estimations related to the water management are based on previous assumptions presented in section 5.9.2 and not on real expenses. These estimations are summarised in Table 13.

Table 13: Overall costs estimations related to the water management

Costs estimations (€/y)	
YTL Arena toilet flushes	180 609
Filton Golf irrigation	137 650
Brabazon Park irrigation	35 909

These estimations shows that the water consumption and management can be a significant cost for YTL Arena and for actors in charge of the Brabazon Park and Filton Golf.

Environmental aspect:

Due to the lack of information about the value chain, the water consumption of drinking water for non-drinking water application is the only indicator followed in this value chain analysis.

In the pre-existing situation for the YTL Arena water management, it has been estimated that around 154 708 m^3 of drinking water is consumed each year for non-drinking water applications (toilet flushes and irrigation).

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5.9.4. Rainwater reuse value chain

5.9.4.1. *Rainwater harvesting description*

This value chain study focuses on the rainwater harvesting (RWH) system placed on the large roof (30,000 m^2) of an indoor arena, which aims to reduce the mains water consumption. It considers water demand of toilet flushing and irrigation.

5.9.4.2. *Assumptions for the value chain analysis*

The following assumptions are based on the study made by the University of Bath[33]:

- The mains-only supply cost is estimated at 0,46 €/y
- The most favourable tank size is 600 m3 for the YTL Arena
- Visitors per day at YTL Arena: 20 000
- 50% of the rainwater will be reused in toilet flushing
- 50% of the rainwater will be reused in Brabazon Park irrigation. In order to reuse results from the economic assessment study, only Brabazon Park will be considered in this value chain analysis.
- The Water Saving Efficiency (WES) has been estimated at around 25 % according to the previous conditions.
- RWH filter coefficient: 0,9

5.9.4.3. *Scheme of the rainwater harvested value chain*

Assumptions set above leads to a new scheme presented in the Figure 51.

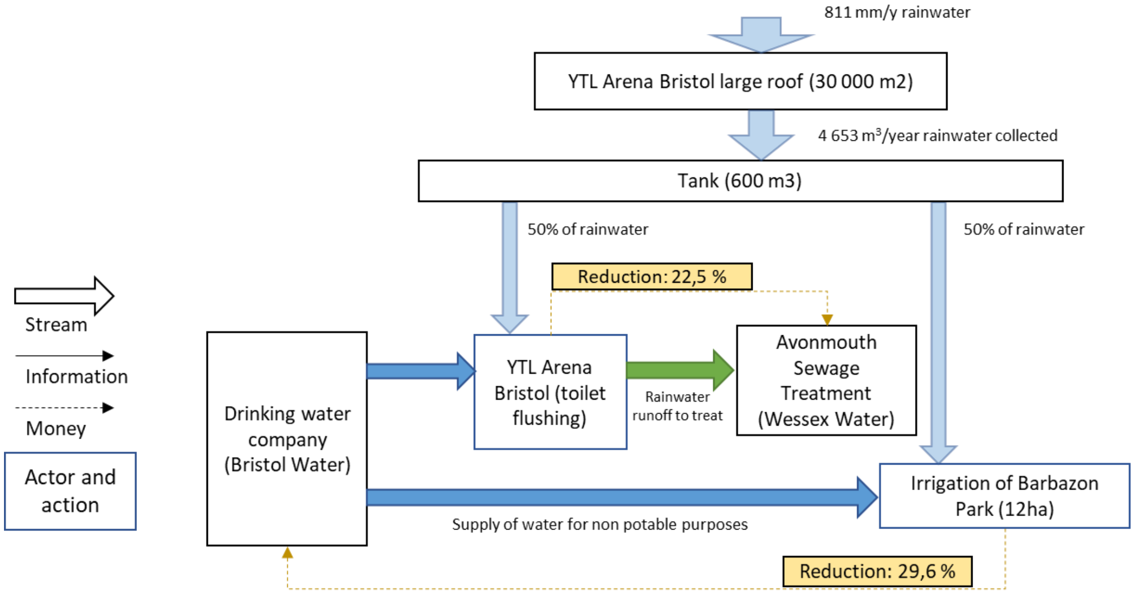

Figure 51: Rainwater harvesting value chain scheme

[33] Optimal storage sizing for indoor arena rainwater harvesting: Hydraulic simulation and economic assessment

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5.9.4.4. Stakeholders' involvement

Main actors:

The following actors should have a specific interest and should be involved in the operation of the value chain:

1. RWH system owner: YTL Arena:

YTL Arena is the most central actor in this value chain as the rainwater will be harvested on its rooftop and treated on site. This actor is interested by the rainwater harvesting due to its large roof, its water consumption and its proximity with green spaces to irrigate. Its involvement is necessary for the value chain implementation.

2. Brabazon Park:

In Filton Airfield case, this park is owned by YTL. In another situation, the green space could be owned by another actor. Green spaces require a lot of water for irrigation purposes which implies significant mains water costs. The actor in charge is really interested by rainwater supply if this water is cheaper than mains water. According to the economic opportunity, this actor could be involved in the system investment.

3. Weather/climate:

The weather can highly influence the technical and economic viability of the value chain. Long dry period causes the pollution build-up on the roof, which can affect the water quality, and a lack of rainwater supply.

Intermediate and external actors:

1. Drinking water company and WWTP: Bristol Water and Wessex Water

These actors have a medium interest for the value chain unless they are involved in the reuse project and/or the value chain operation. These actors can directly influence the economic viability of the value chain with the volumetric charge per cubic metre for the water supply or the wastewater treatment.

2. Visitors and customers:

Visitors' opinion can foster the YTL Arena to harvest rainwater.

3. Public actors:

These actors could foster and facilitate the value chain implementation with governance and fundings.

5.9.4.5. Value proposition and benefits of the rainwater value chain

Economic aspect:

The study of University of Bath highlights the need of an economic analysis of a large rooftop RWH system to maximise the benefits. The implementation of RWH has two main benefits: first, it saves mains water, and second, it decreases the amount of rainwater runoff.

- Mains water consumption reduction

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Water prices, rainfall conditions, and discount rates are the three major factors contributing to the economic viability of RWH systems

The sensitivity analysis made by the University of Bath shows the following results:

- At higher water price (>1.24 €/m3, baseline), the unit rainwater cost remained below (0,46–1,26 €/m3) the mains water cost (0,46–1,37 €/m3) under the given conditions. The results confirm that the economic performance of RWH systems is sensitive to variations of mains water prices
- Except for dry years where the mains-only supply cost (0,46 €/m3) is lower than the unit cost of rainwater, the unit rainwater costs is lower than mains-only supply cost. During the wet years, the maximum achievable savings is 12.3%, depending on the scenarios.
- The discount rate between 0% and 15% affect the unit water cost of the RWH system.

The payback period analysis of the RWH system with a 600 m^3 tank revealed that a 5% discount rate and a water price of 3,5 €/m^3 would be enough to make the RWH system cost effective and that the capital cost could be returned within 11 years.

However, the current unit water price is around 2,29 €/m^3 at Bristol which implies a potential ROI of 22 years according to the study.

- Rainwater runoff treatment reduction

Harvesting rainwater on the rooftop reduces the water discharged in sewage network by the YTL which implies a reduction of charges to treat this water. Based on assumptions, 22,5 % of water runoff could be harvested and used that could decrease the YTL bill. No more data has been shared on this concern. However, it remains the second main economic benefit for the value chain implementation.

Environmental aspect:

The implementation of this value chain reduces the consumption of mains water for irrigation and non-potable purposes. RWH system studied here should potentially collect around 4 653 m^3/y that could reduce aquifer stress[34], energy and chemical consumptions to produce drinking water, and chemicals (e.g. chlorine) released in irrigation.

5.9.4.6. Drivers and barriers to implement the rainwater reuse value chain

Drivers:

The following drivers are based on feedbacks collected from the case study.

- Mains-water supply reduction:

[34] Advantage that can be discussed according to the situation

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As seen above, RWH systems reduces the potable supply which can lead to economic and environmental benefits (less chemicals for dosing, less energy in polishing water, etc). WWTP should have a reduction in treatment costs as the water will be raw as opposed to treated.

- Urban management:

Managing water in local areas allow the maintenance of parks or the creation of water features such as lakes, which can enhance the liveability of the community and increase values of adjoining properties.

- Positive influence:

Harvesting rainwater can be an ecologic argument for YTL Arena in terms of communication.

Barriers

The following barriers are based on feedbacks collected from the case study:

- Uncertainties:

The economic performance of RWH systems is sensitive to several parameters such as:

  - The low drinking water price that can hinder the deployment of the value chain.
  - The RWH system is climate dependent. The duration of the wet period could play a crucial role in enhancing the economic performance of RWH systems.

In terms of water quality, long dry period causes the pollution build-up on the roof which can affect the quality of the water.

- Customer perception:

Related to the water quality, customers are not used to see grey water in their toilets which can be a barrier in terms of acceptability for the rainwater harvesting implementation.

- Upfront cost for secondary pipework system:

In the case of building development, the cost is attributed to the real estate developer, but the saving is experienced by the customer in the long run. Customers do not currently see value and are not ready to pay more for the solution, which could offset the upfront cost. This therefore ends up being a loss to the developer.

- Reliability of technology:

Because of a short experience in terms of RWH systems, insurances are necessary to implement RWH systems which can hinder the replication of the solution.

- Economic interest for the water company:

Drinking water company will have a reduction in demand which NextGen view as being on benefit for the actor ecosystem. However, the demand reduction will mean a loss of revenue for drinking water company in areas where water scarcity is not a challenge.

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5.9.4.7. *Business case of the rainwater resource*

The business canvas of the value chain presented in the Figure 52 summarises values assessed and highlights advantages and disadvantages for deploying the value chain.

Ecosystem of stakeholders	Key activities	Key resources
Main actors: RWH system owner: YTL Arena End-user: Brabazon Park (owned by YTL) Weather	Collect and treat rainwater	RWH system (filter, pumps, etc) Pipes
Intermediary and external actors: Drinking water company and WWTP Visitors Public actors	**Stakeholders relationship** Potential collaborative relationship (co-investment, water share, etc) Classic business relationship	
Economic Value Mains water consumption reduction | Savings in runoff water disposal Water sales to non-potable water consumers (potential) **ROI ≈ 11 - 22 years**	**Environmental Value** Reduce drinking water consumption	**Territorial Value** New synergies between regional organisations
Cost structure High CAPEX and new OPEX for the RWH system Potential reduction of drinking water charges ≈ 20 – 30 % Reduction of runoff water disposal cost ≈ 22,5%	**Impact of the organisations** Potential rainwater harvested and drinking water consumption reduction 4 653 m^3/y	**Public funding** Subsidies from national and international authorities to implement the process
Revenue stream Potential saving according to the mains-water unit tariff Potential sales of water from RWH system owner to other actors in the area	**Global impact** Reduction of consumption of water for non-drinking water purposes (Potentially less chemicals released in fiels)	**Public non-financial benefits and costs** Lack of regulation

Figure 52: Business canvas centralised on the rainwater resource collected by the RWH system

Different scenarios could be envisioned based on the YTL Arena situation. The rainwater collected could be sold to other non-potable water consumer in the area for irrigation or toilet flushing, but also for vehicle washing, heater and cooling systems. In the Filton case, YTL owns green spaces, and the business case is more oriented to make savings than revenues.

At some stage, the case study may consider supply to the Brabazon Park only if the business case can support it, but no clear plan is set at this stage due to the complexities of crossing network rail tracks with an additional service, additional pipe lengths, pumps, etc.

Ideally all rainwater collected would be used for Arena and Hub use (ie irrigation of landscaping with YTL Arena boundary, toilet flushing, cooling water, etc.) and avoid the need for supply agreements with other 3rd parties.

5.9.5. Policy recommendations to foster Filton Airfield case replication

The previous value chain analysis highlighted several policy recommendations to foster the replication of the rainwater harvesting value chain:

- Governance and regulations for non-drinking water purposes

A significant amount of drinking water is used for irrigation, washing and many other non-drinking water purposes. Considering the water stress and the energy used to treat water,

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potable water used in non-potable water purposes should be measured and highlighted to foster the deployment of good practices like harvesting rainwater.

- Water supply cost

As seen in barriers section, the price of the water supply is too low in comparison with non-potable water. Increase charges for potable water supply used in non-potable water purposes should encourage rainwater recycling and the development of other reuse technology.

- Building regulations

Building regulations or planning policy could include stormwater harvesting regulations. Government or local authority legislation could foster rainwater reuse systems replication by mandating alternative source of water for new buildings.

- Subsidies

With the investment cost of the reuse solutions and uncertainties for economic actors, incentives through grants at a local or national level are still necessary to offset capital expenditure before regulations and technological development makes the value chain more viable.

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5.10. CS10 – Timisoara (RO)

5.10.1. Description of the CS

The water system has undergone significant transitions in the last decades with new drinking water and wastewater treatment plants as well as leakage reductions in the distribution systems.

The Timișoara water system is operated by AQUATIM SA (which is a regional water company, owned by local public bodies). The water supply and waste system has undergone significant transitions in the last decades with new drinking water and wastewater treatment plants as well as leakage reductions in the distribution systems. These last developments have been possible through structural funding for various infrastructure water systems, made available for Romania within Structural EU funding programmes (ISPA, POIM, etc.).

In 2000, AQUATIM SA identified in the ISPA (Instrument for Structural Policies for Pre-Accession) programme a financing opportunity for the rehabilitation of the treatment technology of the wastewater in Timişoara, so that the quality of the effluent shall observe the European standards set by the Council Directive EEC 91/271 of 21 May 1991, concerning urban wastewater treatment. The total budget of the programme was over 45 million Euro, out of which 70% was a grant. Around 30 million Euro were allocated for the rehabilitation of the WWTP.

The technology upgrading led to the construction of modern mechanical and biological treatment facilities, provided with state-of-the-art equipment. With these new technologies, the European and national effluent quality requirements were met. A development of the technology with respect to the advanced treatment and also an extension of the treatment capacities were therefore achieved.

Timis county represents 24 WWTPs, which process 43,4 million m^3 of wastewater per day. Timiș county is located in a trinational region with Hungary, Serbia and Romania. The new WWTP for Timișoara city (the largest within the county) is designed to treat 440 000 PE.

5.10.1.1. Challenges and/or opportunities

The (past and current ending in 2023) rehabilitation of the WWTP in Timisoara minimized the environmental impact (water, air, and soil pollution) and helped improving the health and safety of the neighbouring population and the plant personnel. An important step to lining up with the more demanding environmental quality and safety standards of the EU was thus achieved.

The challenge addressed by Romania region is to extend the wastewater network and water supply network in the territory. NextGen project aims to build-up a new system for the given Romania context, which does not allow to sell the water more expensive than at the present time.

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The main objective for the case study is to make the water treatment more economically viable with additional revenues for the water operator. Using circular technologies is an excellent opportunity to optimise energy consumption and sell by-products produced by the WWTP.

5.10.1.2. Circular solution studied

The pilot-scale should test the implementation of pyrolysis technology (via thermo-catalytic reforming) for aerobically stabilised sewage sludge. The innovative technology to be tested in the case study will result in three main products – biochar, gas and oil – that can be exploited energetically as fuel or soil enhancing agent or sorbent.

Timișoara WWTP plans to study the water reuse of the secondary effluent in urban, industrial, and agricultural application. On this topic, a more active stakeholders' involvement with the public administrations, companies, and other organizations in Timis County (operational area of AQUATIM SA) will be an important step during the nextGen project.

5.10.1.3. Status of the demo case

A new technology was taken over into the classical methods used within the wastewater treatment processes in Romania, a technology which is highly efficient, has a low environmental impact and eliminates the eutrophic compounds.

Due to the late arrival of the case study in the project and COVID-19 situation, the pilot technology has not been implemented on site, the training of operational teams did not start yet and no data is available for the value chain stream analysis.

Timișoara WWTP treats a unique type of sludge in Europe, which makes the estimations and assumptions about streams unrealistic if it is not impossible. Neither test nor analysis on Timișoara sludge using the technology has been carried out for now.

5.10.2. Limitations of the study and scope of the study

Scope:

Due to the advancement of the case study, the scope of this value chain analysis will be limited to the overview of potential value chains that could be implement beyond the project based on limited information available.

Assumptions:

No assumptions have been carried out in this section.

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5.10.3. Potential value chains that will be implemented in Timisoara

5.10.3.1. Ecosystem of the value chain

Streams' description:

Timișoara WWTP treats around 38 000 m^3 of excess sludge per year which contain:

- BOD = 22,000 kg/day;
- Suspended solids = 28,000 kg/day;
- Ammonia = 5.400 kg/day;
- Phosphates = 1.600 kg/day.

These sludges could have a high potential to produce by-product and energy. The efficiency of the new treatment plant is proved by the values of the following indicators and the comparison of the appearance of the influent and effluent is also spectacular.

- CCOCr = 94-96% (average inlet 320 mg/l, average outlet 38 mg/l)
- BDO = 91 % (average inlet 137 mg/l, average outlet 13 mg/l)
- Suspended solids (SS) = 92-95% (at an average entry of 120 mg/l, average outlet 8 mg/l)
- Total ammonia = 85% (average inlet 40 mg/l, average outlet 8 mg/l)
- Total phosphor = 84% (average inlet 5 mg/l, average outlet 0,8 mg/l)

Currently the sludge is dehydrated and sent to the landfill. WWTP Timișora plans are to install a pyrolysis system for sludge treatment that is the pilot project will offer valuable information about this process.

Main actors:

1. Resource producer: Aquatim SA

This actor represents one of the largest water utility companies in Romania and the largest producer of sludge from a WWTP in Timiș county. Aquatim is a regional public utility company. Aquatim SA has a services contract with the Intercommunity Development Association (ADI) consisting of the administrative units: Timișoara City, Timiș County, the towns of Jimbolia, Deta, Sânnicolau Mare, Buziaş and Ghiroda village. Aquatim SA is a licensed operator for water and sewerage services in the Timiș County, as certified by the Romanian National Regulating Authority for Public Utility Community Services.

In terms of energy, Aquatim SA and its WWTPs have high interest and influence to implement the energy value chain to reduce energy consumption/invoice and energy footprint by using the resulted gas to produce the energy.
WWTPs, with drying processes and all pumps of water supply system, are important consumers of energy. In the context of increasing costs for energy, Aquatim SA is interested by identifying potential (re)sources to cope with this situation in a sustainable way, also considering the national and European targets for emissions reduction.

In terms of water reuse, Aquatim SA has also a high interest and influence in the value chain implementation. However, this value chain implies more barriers. The pre-feasibility study (under development) for potential wastewater reuse delivered by Timișoara WWTP, showed

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that energy cost will play an important role in the cost of wastewater reuse because of the WWTP location which is downstream while several potential users are located upstream.

Once demonstrated, Aquatim SA plans to present the pilot project in Timisoara to other regional water operators/utilities in Romania, as a case study for their decision to implement new other projects (mainly using the National Plan for recovery and resilience (PNRR, with principles statued in European MEF).

2. Landscape gardening company

Horticultura SA Timişoara headquarter is located at approximate 4 km from WWTP Timișoara. Since 1998, Horticultura SA is a joint stock commercial company with the local council of Timișoara municipality as the only shareholder.

The main activities are structured as follow: maintenance of green areas and parks within Timișoara city, production of planting materials, commercialization of plants and flowers, manufacturing urban furniture and playgrounds equipment.
Concerning the production of ornamental plants, Horticultura has a production unit of approximate 0,64 ha greenhouses.

Horticultura could be interested to test the biochar resulted from pyrolysis process and might use energy produced by their ownwater reuse system. Being a Local Council company, at this moment they cannot pay for the products used, but all invoices can be compensated in the Local Council- Municipality accounts.

3. Agriculture actors

R&D Station for Agriculture (SCDA) Lovrin belongs to the University of Agronomic Sciences and Veterinary Medicine (USAMV) Timișoara and it is located at approximate 50 km far from Timișoara. Being an R&D institution the interest to test if biochar could improve soil quality.

Concerning the biochar value chains, SCDA Lovrin is directly interested by his product which could improve the soil characteristics especially as they could test the soil and the plant.

Concerning water reuse, SCDA Lovrin is interested to install an irrigation system (that do not exist today) with the treated and disinfected water from WWTP Lovrin. The precipitation pattern has changed, and agricultural crops do not have enough water during the vegetation season therefore irrigation system should interest all farmers around.

Intermediary, facilitators and external actors:

1. Public authorities

Concerning the water reuse, public administration in Timisoara (responsible for using the potable water watering the green areas and parks in Timisoara) shown their interest but has not shown commitment in delivering real solutions.

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Concerning the energy aspect, the local municipality Timișoara that pays the utilities for Horticultura could play an important role in the energy value chain creation as it has legislative and regulation power at local level.

2. Facilitator: Business Development Group (BDG)

BDG is a management consultancy company, with over 25 years' experience in contributing to the local and regional development in Romania and Central & Eastern Europe, by involving stakeheolders in the area, in various sectors.
BDG's activity is focused on sustainable local development by creating a competitive institutional and economic environment, coherent policy adaptation to EU requirements and legislation and development of functional institutional and legislative frameworks, to stimulate business development and private-public partnerships.

3. Haulier:

The transport is important in material value chain. They could be paid the end-user or the producer of the by-product.
Interest: The haulier could be moderately interested by the value chain as it could create a new stream to manage in the region.
Power: This actor has a medium influence on the value chain creation as there are many offers of hauliers in the region,

4. Technology provider: FHNW

The technology provider can assess the technical feasibility of the technology implementation and thus makes the value chain creation possible. FHNW has a moderate influence (except for low TRL technologies) but is really interested by this kind of initiative.

5. Other stakeholders on the territory

Several other potential partners in water reuse (as a detergent producers) shown interest and delivered several sets of data, but being a multinational company, the cooperation procedures shown delays.
Another type of local Timisoara stakeholder (a beer producer) shown during the steps of development the feasibility study, (Sub-Task 1.2.5) little flexibility for cooperation, as they declared that water efficiency use is considered high, as the company owners considered the water re-use topic an important one, but few years ago.

5.10.3.2. Potential benefits related to the value chains

No data is available about the environment impact of the value chains.

The environmental benefits are mainly referring to a better water resources management and the sludge management. Although the area has not yet suffered from severe droughts, the climate change and precipitation pattern change are contributing to increase of aridity in the region. Reusing the reclaimed water will support a better soil management.

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Positive results of the sludge innovative management developed in this case study should lead to a global extension for a better treatment sludge and reuse either in agriculture sector or for energy production.

The main environmental benefits expected from the project implementation are the following ones:

- Reusing biochar resulted from sludge treatment, which could avoid the use of raw materials and reduce sludge disposal. Biochar can increase soil quality and is also a solution to store the carbon in the soil.
- Improving the surface and ground water management
- Reducing direct discharge in the river and reuse water, which should reduce the pressure on the river, riverine flora and flora, and enhance a better biodiversity and microclimate management.

In social aspect, this type of incentives should secure water supply resources for the future. And in economic aspect, circular value chains should provide an income stream for Aquatim SA thanks to sells of biochar and non-potable water. For farmers, the use of non-potable water for irrigation where there is no irrigation system in place could increase yields and profit, while for industry, the use of wastewater would lower production costs if the reused water will be cheaper than the fresh water.

5.10.3.3. Drivers and barriers to implement Timisoara value chains

The following drivers and barriers are based on feedbacks collected from the case study:

Drivers:

- Benefits perspectives (economic aspect):

As explained in the challenges faced by the case study, the circular economy can be seen as an opportunity to develop the wastewater treatment network in Romania.

- Circular policy (policy aspect)

Romania has transposed the UN Sustainable Goals and elaborated the 2030 Sustainable Development Strategy that will benefit in the next programming period 2021-2027 of European and National funds for implementation of projects, including for circular economy in the water sector.
The European momentum created for the circular economy, the emissions reduction and the greening of the economic and public activities.

- Taxes (economic and policy aspects)

Romania has increased costs for sludge disposal and incineration for electricity production.

Barriers:

- End-of-waste status (legal aspect):

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All materials used in industries need approval and certificate. Administrative processes are difficult, and actors would need supports for these procedures (examples for resources). Using waste as raw material is a challenge for stakeholders to create these new value chains.

- Market barriers (economic aspect):

Regarding the biochar, there is still not a market for this resource in Romania. There are some companies that import biochar under various commercial names and some promotional articles in specialised agriculture magazines about its benefits for the soil.
Regarding the water reuse, the agricultural research stakeholder (owner of local orchard) shows a real interest, but the water reuse chain is still too expensive. It requires to be supported by local subsidies).

- Quality and quantity (technical aspect):

The quality and quantity of the by-products obtained in the pilot project (as well as predictions of a full-scale project in sludge circular economy) are hard to estimate at this level, since the final results of the pilot are not known.

5.10.3.4. Business case of the biochar resource

In this section, the business canvas focuses on the biochar resource as it is the most promising and documented value chains expected by the case study. The business canvas of the value chain presented in the Figure 52 summarises values assessed and highlights advantages and disadvantages for deploying the biochar value chain.

Ecosystem of stakeholders	**Key activities**	**Key resources**
Main actors: Biochar and energy producer: WWTP Timișoara Fertilizers traders Agricultural farms Landscape gardening companies	Pyrolise the biomass coming from wastewater treatment	Pyrolysis equipment
Intermediary and external actors: Transport companies Public authorities Facilitator: Business Development Group (BDG)	**Stakeholders relationship** Classic business relations Common objectives with communities to avoid sludge disposal	
Economic Value Pyrolisis technology allows: Sales of by-products Electricity costs reduction (heat and electricity production) Avoided costs for sludge disposal	**Environmental Value** Avoid sludge disposal Increase soil quality Store carbon in the soil	**Territorial Value** Reduce landfilling activities Pilot could be replicated for all WWTPs in Timiș county
Cost structure High CAPEX OPEX: Maintenance and operation of pyrolisis equipment Electricity conumption	**Impact of the organisations** Reduce electricity consumption and emissions for WWTPs	**Public funding** Subsidies from national and international authorities to implement the process
Revenue stream Sales of biochar Disposal savings Energy savings	**Global impact** Storing of the carbon in soils and reduction of landfilling	**Public non-financial benefits and costs** Promotion of circular economy

Figure53: Business canvas centralised on the biochar resource from pyrolysis

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The key to success of this value chain is the sales of biochar produced by the pyrolysis system. If the tests for agricultural and landscape project would be positive than a new business line could be set for Aquatim SA.

To test the market of Aquatim SA biochar resulted from the pilot implementation, agricultural and landscape design actors will be contacted by Aquatim SA by the end of the project or as soon as the pilot is implemented.

5.10.4. Policy recommendations to support Timisoara case implementation

The previous value chain analysis highlighted several policy recommendations to support the implementation of value chains studied in Timisoara:

- Subsidies:

With the significant investment cost for the solution public and European funds are necessary to continue to deploy good practices before regulations and technological development makes the value chain more viable. If the implementation succeeds, the value chain could be viable thanks of its co-benefits (materials and energy). Subsidies should focus on the implementation of processes that allows the recovery of several types of streams for all new projects.

- Policies and regulations:

Romania has a sludge management strategy and taking into account the Romanian 2030 Strategy for Sustainable Development the Operational Program setup for the next programing period 2021-2027 the two strategies should be taking into account. Circular economy in the water sector will contribute to the targets of Romanian, European and International Sustainable Goals.

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6. Social Value Assessment: findings from La Trappe and Gotland

The analysis of Gotland and La Trappe case study under the social value perspective will allow to identify drivers and barriers to the implementation of value chains linked to governance issues. It is also an opportunity to identify incentives that are helpful for the deployment of solutions.

6.1. Methodology

The Gotland and La Trappe case studies were used as part of an interview campaign to identify social values and benefits created by circular solutions, as part of the WP4 qualitative study. The two case studies were selected as they displayed a significant level of interest and investment in outreach and engagement activities. The Gotland case study (Sweden) investigates rainwater harvesting and water reuse. The La Trappe case study (The Netherlands) investigates water reuse and materials recovery. Full details of the two case studies are available in D1.2.

We identified relevant stakeholders for each case study. To include a diverse range of views towards each case study, the interest/power matrix method was used to differentiate stakeholders into four categories: context setters, key players, crowd and subjects (Johnson, Scholes and Whittington, 2008). Matrices were used in the recruitment process to prioritise stakeholders to be initially interviewed (high power, high interest). Snowballing was then used to fill stakeholder's gaps in the matrices. The criterion to include a particular stakeholder was based on their involvement in the project and with the local community as well as their knowledge of the case study. Final matrices are displayed in Figure 54 (Gotland case) and Figure 55 (La Trappe case).

We collected qualitative data in an interview campaign with 31 key stakeholders. Some stakeholders are missing from the study (such as farmers' association members and the case study host) due to availability restrictions.
Semi-structured interviews were conducted, and questions were designed to investigate legitimacy perceptions towards the Gotland and La Trappe case studies, following the legitimacy lens introduced in section 2.1.3. The legitimacy lens was structured based on four legitimacy categories: moral, cognitive, pragmatic, and regulative (full details of the theoretical background are available in D4.2, part B). Interviews were arranged by key informants and the researcher by email. Interviews were conducted remotely via video call and were audio recorded.

Interviews were transcribed into text files and a qualitative analysis software package (NVivo) was used to support a thematic analysis (Spencer et al., 2014). The legitimacy framework was used to pull out interviewees' experiences from the transcripts that relate to the four legitimacy categories.

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All data was collected, stored, and analysed in accordance with GDPR. Copies of the anonymised data set will be made available on Cranfield University's online research data repository (10.17862/cranfield.rd.13553717).

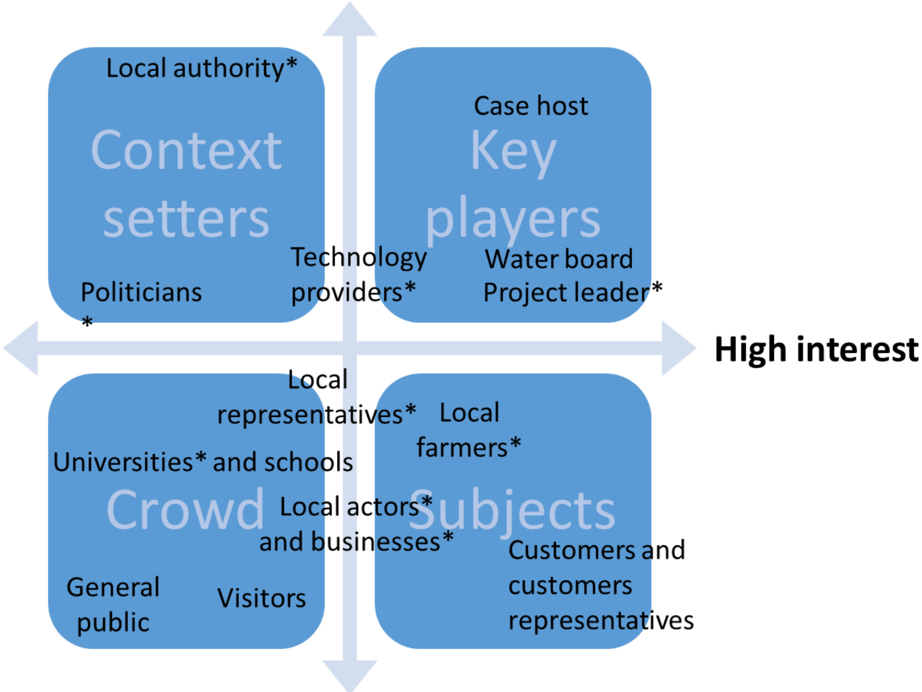

*Figure 54 - Interest-power matrix for the Gotland case study (the stakeholders who were interviewed are mask with *)*

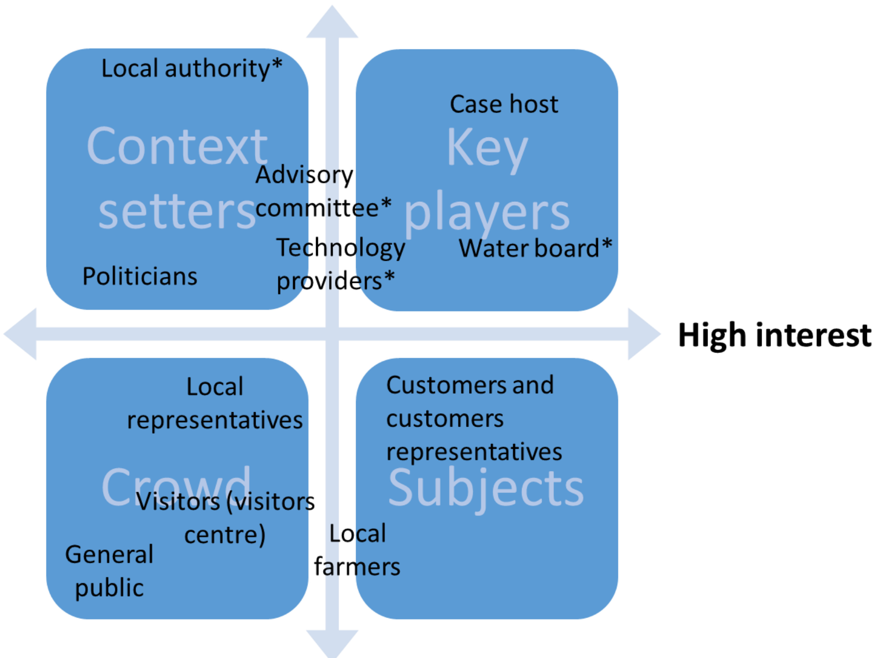

*Figure 55 - Interest-power matrix for the La Trappe case study (the stakeholders who were interviewed are mask with *)*

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6.2. Qualification of Social value

In this section, we detailed elements that seemed to provide legitimacy to the La Trappe and Gotland case studies and highlighted the associated social values and benefits. The two first sections reflected on the four value propositions (economic, environmental, social, and territorial values) detailed in the business model canvas (section 5.6 and 5.7). The first section explored good practices (stakeholders' networks and channels for communication and involvement) while the second section detailed the perceived benefits that the case studies provided to various stakeholders. The last section explored elements that drove and challenged the case studies.

6.2.1. Sharing good practices

In this first section, we referred to the social capital concept detailed in previous section and shared good practices about stakeholders' networks and channels for informing and engaging various stakeholders, that were observed at the case studies.

6.2.1.1. Stakeholders' networks

The stakeholders' networks were heterogeneous (Figure 56 and Figure 57). They included **governance** stakeholders (e.g., local authorities and politicians), **education** stakeholders (e.g., universities, local schools and art summer schools), **management** stakeholders (case hosts, project leaders), stakeholders **visiting** the case studies (e.g., tourists, visitors of the visitors centre, visiting companies), **customers**, **advisory** stakeholders, **technical** stakeholders (e.g., highly skilled advanced technology and data providers), **communication** stakeholders (e.g., journalists, book authors, communication managers), and **local** stakeholders (e.g., local inhabitants, local businesses, farmers, NGOs). The network included stakeholders from **attractive sectors** (e.g., space) and results suggested that the case studies allowed for the cooperation between different sectors (e.g., beverage and space sectors). Finally, the distant network included **nationally known** stakeholders (e.g., King).

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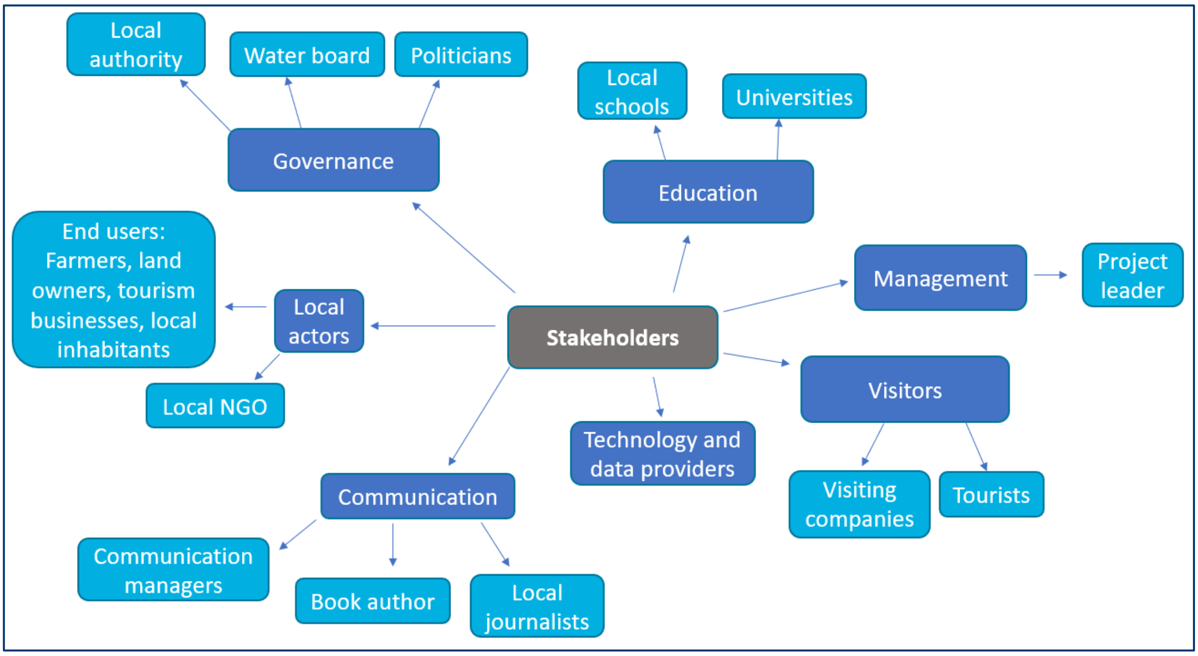

Figure 56 - Stakeholders' ecosystem for the Gotland case study

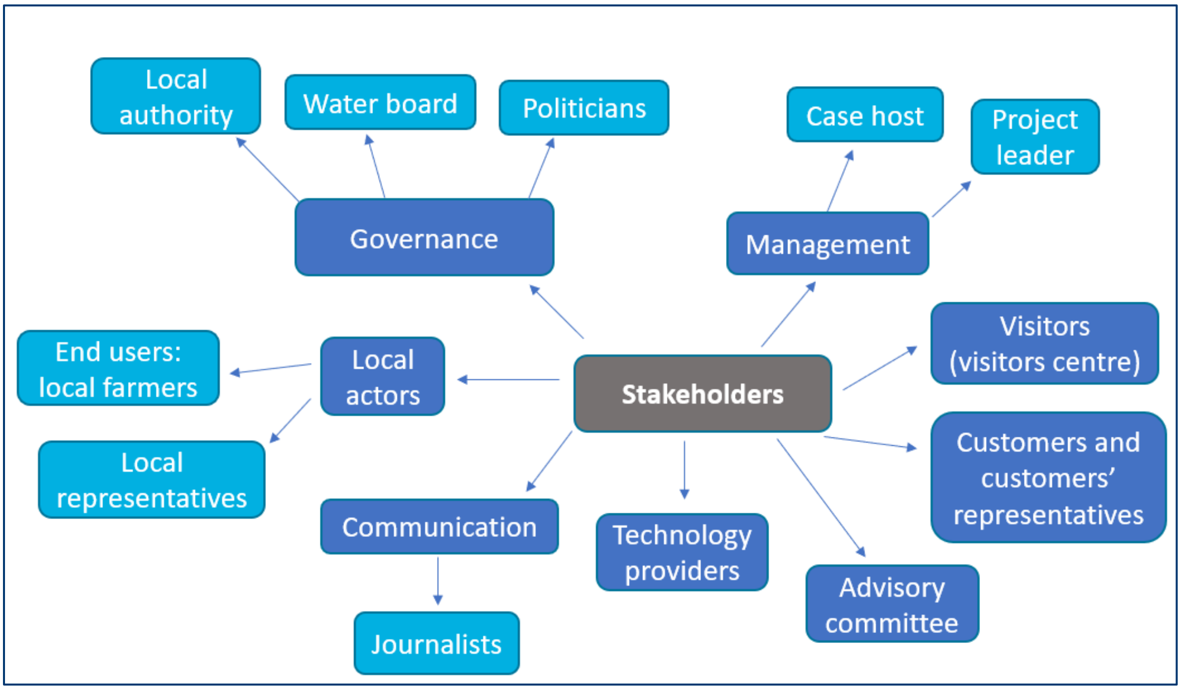

Figure 57 - Stakeholders' ecosystem for the La Trappe case study

The results suggested that the initiators and stakeholders of the case studies had an inner drive towards the CE and have had previous interactions, thus highlighting the importance of **long-term partnerships**.

Moreover, it seemed essential to have an already formed and **legitimate local network** (e.g., farmers, local inhabitants) for the case studies uptake and success.

With regard to stakeholders' roles, the network included stakeholders playing a role in the **international upscaling**, stakeholders **adding local knowledge** to the case studies and stakeholders **solving local issues.** Moreover, the networks included **legitimate and trusted local** stakeholders **connecting stakeholders together** as well as stakeholders who have established local and global connections (e.g., at the EU scale).

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Looking forward, results suggested that such case studies could help connect the hosts of the case studies with local actors (e.g., farmers, local inhabitants).

Finally, networks also included similar environment, and water related projects, which acted as a driver for the establishment of the case studies.

6.2.1.2. Channels for communication and involvement

Various channels were used to inform and involve various stakeholders. Table 14 summarises those **channels and their functions**. The results suggested that the involvement was essential for maintaining a positive image of the case studies. A **successful outreach strategy** was seen to be directed towards the **locals** before publishing any information in the media (Gotland). The development of the case studies resulted in emerging ideas such as the creation of research and innovation centres.

Table 14 - Channels used to inform and engage various stakeholders

Channels used to inform and engage	Functions (non-exhaustive list)
Community of Practices (CoPs)	Sharing experiences (see WP3 deliverables).
Meetings with technical and political stakeholders	Ensuring the technical and regulative feasibility of the case studies
Meetings with highly engaged local stakeholders (landowners)	Contribution of the landowners to technical and outreach strategies
Meetings with local inhabitants (Gotland)	Bringing awareness, answering questions, serving local's willingness to get involved
Book publication (Gotland) Exhibition (Gotland)	Informing local inhabitants
'Environment cafes' (La Trappe)	Informing local inhabitants
'Board of ideas' (La Trappe)	Reflecting on local inhabitants ideas
Visitors' centre (La Trappe)	Informing and interacting with the public
Interviews with the local radio and newspaper	Informing local inhabitants
Articles in international media	Informing the public

6.2.2. Benefits of the CE

As mentioned in section 6.2.1, it is essential to identify incentives (i.e., benefits) that can encourage the uptake of the CE in the water sector. In this section, we detailed the **perceived benefits** (economic, environmental, social, and territorial values) provided by the case studies **to a wide range of stakeholders** including the case studies' hosts, data and technology providers, water boards and municipalities, local businesses and inhabitants, farmers, the society, and the environment (Table 15). Notable benefits were educational (e.g., new skills development), related to marketing (i.e., better attractivity), the CE deployment, leisure opportunities (e.g., swimming), the development of the local economy, the regulative development (e.g., case studies information to fed regulations) and the influence of the case studies on the awareness and behaviours towards circular solutions.

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Table 15 - Benefits of the case studies to various stakeholders

Recipients	Benefits
Case studies hosts	Improved water quality and treatment systems Improved marketing and storytelling (reference to the spatial sector and sustainability) Economic gains (tax cut, savings from recycling) Skills development (case operation)
Technology providers	Knowledge exchange, increased exposure Development of the technologies in another country and sector, test of the technical and market feasibility of the technologies Economic gains (products sales)
Local authorities	Knowledge (e.g., regulative information to update policies) and skills development Decreased water price
Local inhabitants (*visitors and tourists)	Increased water availability, leisure opportunities (swimming) Economic gains (employment opportunities, decreased water price) Demographic growth (housing development) Regulative benefits (reduced water restrictions) Increased awareness of and interest in the CE, the local environment, and its related issues* Influenced public behaviour to take care of water and wastes* Educational opportunity for schools and universities
Local businesses	Business activities development (increased water availability and reduced water restrictions, increased number of visitors and tourists) Better attractivity due to the sustainability reference
Farmers	Regulative benefits (reduced irrigation restrictions) Increased activities (longer growing periods, reliable water system)
Society and environment	Improved water quality, reduced pollution, increased local self-sufficiency, prevention of extreme events Improved ecosystem resilience, air quality as well as planet and humans health, climate change mitigation, improved water and waste management Encourages the development of CE solutions

6.2.3. Drivers and challenges of the CE

In this section, we presented the challenges and drivers of the case studies. The challenges included regulative, financial, and competitive challenges and related to safety concerns and concerns over public perceptions, stakeholders' qualification, the appropriateness of the CE concept and a narrow calculation of CE benefits. The drivers were financial, regulative, led by societal expectations for sustainability and included experiences of climate crisis events, prevalence of similar projects and competitive advantages.

Results highlighted **safety concerns** over the presence of bacteria, with increasing concerns when stakeholders have had **negative experiences** (e.g., contaminated sludge).
Results highlighted that **regulations** were created **prior to the CE concept** development and therefore formed a barrier to the case studies, predominantly at the experimental stage, and

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further when implementing the case studies and marketing products derived from wastewater.
Financial challenges included **high investment costs**, the increase in **water prices** for local actors and the risk for the scheme to remain at the 'project' phase if financial supports stop.
Public perception was seen as a challenge if the case studies did not meet public expectations, had negative impacts on local inhabitants or were not inclusive (i.e., serve a limited area).
Results suggested that the case studies were challenged by **competitive technologies** that are more established, efficient and adapt better to the current market and infrastructure system.
Regarding the CE as a recent concept, results suggested that some stakeholders **challenged the appropriateness** of the concept and may lack the appropriate experience to design and operate such case studies.
Finally, the current **narrow** focus of CE **benefits calculations** (e.g., water prices) could adapt to more comprehensive (i.e., considering regional parameters) and **holistic benefits calculations** (e.g., resilient ecosystems, air quality, overall impacts on water resources) and become a **driver**.

The drivers were **financial** as the case studies were seen to reduce fines for non-compliance with wastewater quality regulations and provide a financial case that ensures companies economic viability and environment protection. The openness to innovation of the host countries and the presence of programmes providing financial support for CE projects were additional drivers.
The **regulative drivers** included existing regulations (e.g., ban on wastewater discharge) and emerging regulative initiatives fostering the uptake of the CE (e.g., EU policy framework).
Additional drivers included the **experience of water restrictions** and associated economic impacts as well as the **awareness of sustainability** and climate change, and the **consumers demand** for sustainable products.
The **prevalence of CE projects** in similar sectors (e.g., food and beverage sectors) and environment projects in the case studies regions seemed to drive the case studies.
The La Trappe case was **integrated** in the living space with a popular design, thus contrasting with the 'ugly', usually hidden wastewater treatment plant. Results suggested that such case studies challenged energy-intensive technologies (e.g., desalination) and **traditional technologies** that generate higher costs and are not circular.

6.3. Conclusions

Overall, our results demonstrated that social values included strong and heterogeneous networks of stakeholders, channels for information and engagement, benefits to various stakeholders as well as drivers and challenges to the uptake of circular solutions. Stakeholders' networks included legitimate, trusted stakeholders and already formed local networks, that fostered and provided value to the case studies while channels for information and engagement maintained a positive image of the case studies. The identified challenges need to be addressed and drivers to be developed.

Social values, benefits and drivers came into play at the four steps of the value chain. However, the case studies not only created social values, but fostered economic, environmental, and territorial values. The identified values, benefits and drivers can serve as incentives to engage stakeholders and foster the adoption of circular solutions and the CE in the water sector.

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Those values and benefits might not be directly quantifiable, but it was shown that they provided a competitive advantage. Finally, the identified values, benefits and drivers were important to the success of the Gotland and La Trappe case studies and are likely to be essential for the deployment of the CE in the water sector.

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7. Lessons learned to replicate value chains

This section aims to present the replicability of the value chains according to the success factors set by AquaMinerals experience and present main lessons learned for the replication of NextGen value chains by the end of the project.

7.1. Success factors applied to value chains in NextGen

The Table 16 presents the potential of success of value chains studied in the deliverable. The main success factor “Financed by a third party” defined in section 3.2 is not used in the table due to the lack of data. Some value chains concern resource that are reused on site (e.g. consumables in La Trappe), which makes the success factors categories set by AquaMinerals Not Applicable (NA) to the value chain. Some factors still have to be defined (TBD) by the demonstrator later in the project.

Concerning the maturity factor, it assumed that it is the stage expected of the case study by the end of NextGen.
Concerning the market penetration, most of sludges, non-potable water or regenerated membranes are not considered as products or the market is not ready for their reuse.
Concerning a third-party involvement in the value chain management, many cases still have to define this criterion. WWTPs or end users often play the role of manager of the value chain.
Concerning the number of employees, most of all WWTPs, which are the most important stakeholders in all cases, have more than 50 employees. This allows the involvement in circular value chains implementation.

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Table 16: Potential of value chain according to success factors

Case studies	Value chains	Close to full-scale	Market penetration	Partly performed by a third party	Most important stakeholder has >50 employees	Total
1. Braunschweig (DE)	Struvite	X	X	TBD	X	3
	Ammonium sulfate (liquor)	X	X	TBD	X	3
2. Costa Brava (SP)	Non potable water				X	1
	Regenerated membranes			X	X	2
3. Westland (NL)	Sludge	X		X	X	3
	Aluminium sludge	X		X	X	3
4. Altenrheim (CH)	PK fertilizer recovery		X		X	2
5. Spernal (UK)	Sludge		X	TBD		1
	Biogas (methane)		X	TBD		1
	Calcium phosphate		X	TBD		1
	Ammonium sulfate (solid)		X	TBD		1
6. La Trappe (NL)	BioMass: purple non sulfur bacteria (PnSB)			TBD	X	1
	Non potable water	NA	NA	NA	NA	NA
	Sludge		X	TBD	X	2
	Consumables	NA	NA	NA	NA	NA
	Electricity (solar panel)	NA	NA	NA	NA	NA
8. Athens (GR)	Non potable water	X				1
	Thermal Energy	NA	NA	NA	NA	NA
	Compost	X				1
9. Filton (UK)	Non potable water (rainwater)				X	1
10. Timisoara (RO)	GAC & Biochar			TBD	X	1
	Gas and oil		X	TBD	X	2
	Non potable water			TBD	X	1

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Among value chains analysed in the deliverable and based on the data available, the value chains of Braunschweig and Westland cases fit with 3 success factors out of 4. According to AquaMinerals success factors, these value chains gather conditions to be implemented in a middle term. The case study of Braunschweig gathers two most important success factors which are the maturity of the project (TRL and implementation of technologies) and penetration of the market because struvite and ammonium sulfate are existing “products” and have a quite mature market. It is important to mention that Spernal and Altenrhein cases also plan to implement ammonium sulfate value chains in coming years (not analysed in this deliverable), which could have a high potential.

In order to develop value chains, demonstrators need to be aware of the AquaMinerals failure factors (in section 3.2.3.2) that can be the main obstacles of the value chain implementation. A workshop including demonstrators to present these factors will be carried out by the end of the project.

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7.2. Lessons learned from the project

The Table 17 summarises type of drivers in 3 categories (Economic, Environmental and national policies, and Regulation) and main barriers related to each value chain studied in the project. These results are discussed below.

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Table 17: Summary of main drivers and barriers of value chains studied

		Drivers				Barriers									
Case studies	Value chains	Economic	Environmental and national policies	Regulation	Explaination	Limited amount of production	High investment cost	Competition with traditional resource	Lack of demand	Technical limit	Previous long term contract	Technology under development	Lack of homogenised legislation (EWS)	Technology under development	Environmental dependent
1. Braunschweig (DE)	Struvite	X		X	Due to maintenance cost and the nitrogen load restrictions on fields	X		X					X		
	Ammonium sulfate (liquor)			X	The nitrogen return load in WWTP		X								
2. Costa Brava (SP)	Non potable water		X		The water scarcity in the region			X							
	Regenerated membranes	X			Cost saving by using recycled membranes				X	X					
3. Westland (NL)	Sludge	X	X		More benefits and reduction of carbon footprint						X				
	Aluminium sludge		X		The main driver is to involve the WWTP in a circular project. The LCA still has to be done	X								X	
4. Alternheim (CH)	PK fertilizer recovery	X		X	A potential economic viability and the obligation for WWTPs to recover phosphorus				X				X	X	
5. Spernal (UK)	Sludge		X		Environmental ambitions to stick with potential future legislations										
	Biogas (methane)														
	Calcium phosphate														
	Ammonium sulfate (solid)														
6. La Trappe (NL)	BioMass: purple non sulfur bacteria (PnSB)		X		Solution is in line with the Netherlands Circularity Strategy for the country going fully circular by 2050		X					X			
	Non potable water														
	Sludge														
	Consumables														
	Electricity (solar panel)														
8. Athens (GR)	Non potable water		X		The solution is in line with the Athens Resilient Strategy for a circular approach to water services by 2030		X	X				X			
	Thermal Energy														
	Compost														
9. Filton (UK)	Non potable water (rainwater)	X	X		The reuse of rainwater could avoid costs related to mains water supply		X	X							X
10. Timisoara (RO)	GAC & Biochar	X			The main driver is related to make water treatment more economically viable				X			X	X		
	Gas and oil														
	Non potable water														

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This section describes findings about value chain and good practices from case studies that could foster replication. It includes the main drivers identified and solutions found by case studies to counter potential barriers.

Regulations have proven to be both potential drivers and barriers

Some value chains are inscribed in a favourable framework and case studies made use of new regulations or anticipated on future regulations. Regional circular strategies foster the development of circular value chain and La Trappe (CS6), Athens (CS8), and Timisoara (CS10) benefited from respectively the Netherlands Circularity Strategy, the Athens Resilient Strategy, and the Romania 2030 Sustainable Development Strategy.
The evolution of sludge regulations also brought benefits to Braunschweig (CS1) and Westland (CS3), pushing forward reuse solutions instead of incineration. Tax incentives play the same role in Romania (CS10) as costs for sludge disposal and incineration for electricity production increased, other sources are looked at and circular processes gain new recognition.

On the contrary, regulations could hinder the deployment of materials value chains in certain cases and should be considered challenges for replication. The lack of homogenised legislation in Europe regarding recovered materials and water use treatment create issues that reduce the potential market. Each national standard on any outputs must be studied to replicate a value chain and it slows down the full-scale deployment of the value chain as well as the circulation of output among European countries (Altenrhein (CS4) & Costa Brave (CS2)).

Having on board intermediaries who can link technical and regulative matters is therefore necessary to tackle regulative barriers and identify regulative opportunities.

*The **materials related value chains** are particularly concerned with regulations. New regulations on nutrients act as incentives for research on circular value chains in the case of struvite in Germany (CS1) and phosphorus for which the recovery will be mandatory in WWTP by 2026 in Switzerland (CS4). However, in Switzerland, fertiliser regulation is restrictive on the concentration of heavy metals and, as such, would make the recovery of PK more difficult.*
The end-of-waste status also creates administrative difficulties concerning materials approval and certificate for industries (Timisoara - CS10), making it difficult for recovered material to be recognised and to circulate.

The business case is a high factor in stakeholders' willingness to invest in circular solutions.

A favourable economic perspective is key for the successful deployment of the value chain. In the case of Westland (CS3), Spernal (CS5) and Timisoara (CS10), the benefits perspective and the business potential have fostered the development of the solution. Especially for the Romanian case which expects to make the water treatment more economically viable in order to extend the wastewater network and water supply network in the territory.

The perspective of a reduction of the economic burden is also regarded as an incentive toward the deployment of the value chain: in the case of Costa Brava (CS2), it is the reduction of production costs thanks to recycled membrane. In the case of Altenrhein (CS4), a significant amount of heat is generated and can be reused in other processes on site and in district heating, lowering the energy costs.

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*On the contrary, in some **water-related value chains**, it is sometimes difficult to prove the positive economic impact of the solution. For example, in Athens (CS8), the cost to run smaller decentralized water treatment units is higher than traditional central WWTP, lowering stakeholder's willingness to invest. The economic performance is also uncertain in Costa Brava (CS2) and Filton (CS9), making replication difficult. Furthermore, in Filton, the water company will face potential loss of revenue making it difficult for them to get involved in the deployment of the value chain.*

The integration of local stakeholders in circular value chains allow to raise awareness and identify motivated local partners

Including heterogeneous networks of stakeholders with various roles (i.e., from technical to educational and from local to global outreach), environment projects and various channels for sharing experience has work well to inform and communicate about circular solutions in La Trappe (CS6) and Gotland (CS7). It allows both projects to gather more support locally. It is also a way to raise awareness on circular solution, in proximity with local inhabitants, while directly facing their expectations. In Filton (CS9), RHW have increase the land value and the liveability of the community, fully integrating into urban management and planning. Similarly, the willingness of WWTPs in Westland (CS3) is a huge factor of success as the solution is supported by the local stakeholders' ecosystem.

Overall, a favourable context supports the deployment of circular value chains

Having a strong knowledge of the context is key to ensure the deployment of circular value chains. It contributes to the identification of opportunities and to better understand the target of value chain outputs. In Braunschweig (CS1) for example, phosphorus recovery is supported by supply issues with mineable phosphorus, while water scarcity and high demand of water in some seasons due to tourism (Costa Brava - CS2) have pushed forward water reuse solutions. Similarly, the proximity of green areas from the case study site have allowed to reuse water easily and participated in the feasibility of the solution (Athens - CS8).

The high investment costs are a difficulty that still needs to be addressed

Braunschweig (CS1), Athens (CS8), and Filton (CS9) have risen the initial investment costs as a major barrier in their value chain deployment. Equipment, machinery, and works in Filton (secondary pipework system) need support from local stakeholders to be replicated, questioning the willingness of professionals from the water sector.

The technology readiness level is still uncertain in some case studies

In Westland (CS3), Altenrhein (CS4), and La Trappe (CS6), the lack of visibility for circular processes is still obstacle for now. No full-scale realization has been made yet in La Trappe, while the ROI is already longer than expected. Short experience in circular system can also represent a barrier, as it has been the case in Filton (CS9) for RWH systems. While those difficulties might be solved by the end of the NextGen project, it is still a fact that some of the circular value chains described in this deliverable need more time before being replicable.

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The preparedness of the market remains uncertain for some materials value chains
For Braunschweig (CS1) and Westland (CS3), the amount of production questions the ability for circular value chains output to enter the market. In the case of Altenrhein (CS4), while phosphorus recovery will be mandatory for WWTP by 2026, the lack of demand compared to the inevitable increase of recovered phosphorus production questions the sustainability of the business case in long term in Switzerland.

All those good practices are targeting case studies so they can mutually learn from experience. However, as some of the barriers identified can only be lifted by policymakers, most opportunities come from enabling policies for circular solutions. Considering those findings, the following section present a set of recommendation that foster the deployment and replication of NextGen value chains.

The size matters to achieve circularity according to AquaMinerals

Small amounts of resource are too costly to manage and hinder the economic viability of the value chains. Struvite value chains are limited by this challenge as processes do not produce enough resource compared to the needs or the transport costs. These problematics lead to the implementation of storages (frequently on site) and require gathering several streams from different WWTP in order to guarantee the supply chain for the "next" user of the resource. Companies like AquaMinerals can foster and are necessary for the development of synergies between water sectors and other sectors. However, value chains with high amounts of resources remain more viable and replicable.

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8. Recommendations

This section presents a set of recommendations targeting stakeholders from the overall water sector to support the deployment of circular value chains. These combined recommendations were built from NextGen case studies feedbacks. They have been complemented with findings and results from the literature review and WP5 partners expertise, especially AquaMinerals.

The recommendations set target all NextGen partners, in one hand EU policymakers and national authorities, and in another hand researchers in CE solutions, demonstrators, and technology developers on how to fill the gaps in value chain to pursue circular economy in the water sector.

8.1. EU policymakers and national authorities

Policy recommendations

1. Create regulations and a governance framework for water reuse purposes across Europe

Governance and regulations for water reuse, and especially for non-drinking water purposes are needed to foster the deployment of circular value chains in the water sector. Decisionmakers at all scale (local, regional, national, and European) should focus on providing standards and guidelines promoting water reuse.

A significant amount of drinking water is used for irrigation, washing and many other non-drinking water purposes. Considering the water stress and the energy used to treat water, potable water used in non-potable water purposes should be measured and highlighted to foster the deployment of good practices like harvesting rainwater.

2. Create regulations and a governance framework for material recovery purposes across Europe

When wastes are used to create new sellable/usable products, questions regarding ownership, liability, and responsibly are all brought into light. Who owns the waste? Who is liable when handling the waste? Is the waste provider liable for the quality of the product? Who is responsible for permitting? How are the materials shipped? These and other questions need to be answered to promote circular economy. European wide standards and guidance is needed to ensure and promote the safe deployment of circular value chains.

In the case of P-mineral and raw material supplier, the phosphate rock is still cheaper than the phosphate in the struvite. Unfortunately, it directly affects the market value of the recovered resource which makes the value chain uncertain or not viable. More governance or regulations related to the importation of the phosphate from mines, and promotion of the recovered materials should foster circular value chain viability.

The end-of-waste label is currently governed under national legislation which hinders the reuse of secondary phosphorus-containing products and generate trade barriers between

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countries. Struvite cannot legally be transported across national boundaries unless both countries approve it without a proper registration. The EoW status should be more homogeneous across EU countries.

3. Create incentives to manage the price of the regenerated water

The cost of potable water is usually too low for regenerated water to be competitive, including for non-potable water purposes. Increase charges for potable water or create subsidies to decrease the price of regenerated water could be a mean, for local or national authorities, to promote the use of such water.

Economic recommendations

1. Create economic incentives to promote circular solutions

The need for financial support and additional fundings from public sources has been highlighted in a majority of case study. The analysis of value chains resulted in business cases not yet capable of support themselves. With the investment cost of the reuse solutions and uncertainties for economic actors, incentives through grants at a local or national level are still necessary to offset capital expenditure before regulations and technological development makes the value chain more viable. If the implementation succeeds, the value chain could be viable thanks of its co-benefits (materials and energy). Subsidies should focus on the implementation of processes that allows the recovery of several types of streams for all new projects.

2. Create a framework promoting circular value chains and supporting the transition towards circular value chain for traditional business cases

Traditional, linear, chains/companies are pulling at these new value chains and will even try to obstruct circular chains. Understandable from a business point of view: the assets in these chains are designed for this purpose, in many cases expensive (landfill, incineration line) and remembering these flows actually means a disinvestment. The owners of these assets should be helped to prevent them from becoming loser of the circular economy. This can be done, for example, by simplifying their license to also be allowed to process other flows or, for example, tax measures regarding accelerated depreciation. On the other hand, measures would help to put the installation out of service after the financial write-down. After all, after the financial depreciation of the installation, the cost price becomes very low and therefore even more competitive for the circular alternative.

Social recommendations

1. Raising awareness at all scales to improve willingness to use regenerated water

Communication activities led by the demonstrators should be fostered in all use cases, especially toward local inhabitants, and stakeholders. It provides support at a local scale and promotes a sense of ownership toward circular solutions that in terms, could improve the willingness to use regenerated water.
Appropriate trainings to skill CE stakeholders should be provided, as well as relevant information about the appropriateness of the CE concept and other conceptual models that

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solve the issues that the CE tackles. Public authorities and agencies at all scale would be the best relay to promote regenerated water use.

2. Raising awareness at all scales to improve willingness to use recovered material

In the case of P-recovery, the low interest from society is due to the invisible role that the phosphate has in the environment and the unattractiveness of sewage treatment. Most food consumers are not aware of issues regarding phosphorus, at least in view of it being an essential finite resource nor its environmental effects. However, acceptance among the farming community and important market players will be decisive for the value chain exploitation. This current public perception can hinder the deployment of the value chain. It is necessary to raise awareness about the phosphate use.

Legal recommendations

1. A mixing obligation for (linear) products.

In the aluminium sludge value chain for shaped building materials and in the municipal sludge value chain for the cement industry. With this obligation, linear production companies are required to take (aluminium) sludge from water companies, and need to invest in alternative value chains, which could be a huge driver for circular value chains.

2. A simplification on the rules regarding procurement and competition law procedures.

These kinds of circular chains are based on 1:1 agreement between several parties in the value chain. If these must be put out to tender each time, there is uncertainty about the outcome, there is a particular focus on the short (contract) term, the parties do not provide openness, unnecessarily much time is lost and there is a real chance that sub-optimal solutions will be designed.

3. Promoting building regulations and planning policy adapted for CE solutions

Building regulation adapted for CE solutions are needed to integrate water reuse in urban planning and ensure that water regeneration becomes the norm and not the exception. Building regulations or planning policy could include stormwater harvesting regulations for example. Government or local authority legislation could foster rainwater reuse systems replication by mandating alternative source of water for new buildings.

Currently, urban lands are zoned for various uses: residential, industrial, commercial, agricultural, etc. In order to promote decentralized nature-based circular solutions for reuse locally, zoning laws must be adapted. Exceptions are needed for buildings /solutions that “fit” the local environment (are aesthetically pleasing) and that meet health and safety requirements. For example, exclusions zones are typically required for wastewater treatment facilities. However, to create local metabolic hubs for circular economy, exceptions must be made for nature-based solutions. The EU should encourage adapting existing zoning policies for new technologies and solutions.

4. Raise awareness on all laws that can act as drivers for CE, not only the one that apply directly to CE

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We need to shift the focus from laws that are directly applied to the CE to a broader range of laws as the latter can act as drivers. For example, the implementation of P recovery products in the fertilizer regulation in Germany for safety reasons should directly foster struvite value chain creation.

Overall, findings from the study allow to recommend fostering a framework that incorporates economic, social, and regulative dimensions, as well as networks of stakeholders to support the deployment of circular value chains.

8.2. Demonstrators, researchers and technology providers

Economic recommendations

1. Improve the methodology for benefits calculation

As the return of investment for circular solution is usually longer than traditional technologies, it is necessary to include not only economic benefits, but a broader range of benefits as well. Those include environmental benefits and social benefits (i.e., educational opportunities, carbon footprint reduction, ecosystem resilience, air quality, human health) that are less measurable but as important to foster acceptability and sustainability of circular solutions at a local level.

2. Look for new outputs to extend the value chain

A better understanding of the local ecosystem is necessary to investigate the potential of extension of any value chain. The potential for marketing products derived from wastewater should be investigated in particular.

Social recommendations

1. Promote a methodology to improve the calculation of social values in VC

Stakeholders should not assume that social value is isolated from economic, environmental, and territorial values and from the more quantifiable elements of the business model. A methodology to better asses those values is needed to support the deployment of circular value chains. It would provide new incentives for water reuse to stakeholders.

2. Raising awareness at all scales to improve willingness to reuse water and nutrients

Demonstrators should communicate about their use cases, especially toward local inhabitants, and stakeholders. It provides support at a local scale and promotes a sense of ownership toward circular solutions that in terms, could improve the willingness to use regenerated water.

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Appropriate communications should be provided, and/or events should be organised to integrate stakeholders in the approach and projects. Communication contents are necessary to increase acceptances from users (e.g. farmers, citizen).

3. Stakeholders' awareness about circular value chains implementation challenges

All project partners related to the circular value chains needs to be aware of the efforts (money, time and knowledge) that this kind of projects implies. The use of recovered resources means disadvantages compared traditional resources. Project manager has to take care about the partners awareness in order to facilitate the value chain implementation. Partners should necessary be committed to bring these efforts.

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9. Conclusion

All three types of value chains (Water, Materials, Energy) have been studied in detail in this deliverable to foster NextGen value chain deployment and replication. This deliverable complemented data gathered in D5.1 on circular business models and provides concrete analysis for case studies to assess their business potential. Data collection stopped in September 2021 (M40) of the project, as such, it reflects the status of case studies and their value chains at this time. This deliverable is an opportunity for all NextGen partners to consider circularity from a holistic point of view, highlighting good practices from case studies in the application of circularity principles.

The work organisation involved every WP5 partners, WP4 partners (Cranfield University), and all case studies. The complementary expertise of all participants allowed to conduct an in-depth analysis on most of NextGen value chains that had been identified in previous deliverables. The opportunity to strengthen these deliverable findings will come with the production of new data along the NextGen project.

As seen in the methodology section and then in each case study, data collected for now are of uneven quality. Full-scale value chains still need to be tested in most case studies and all value chains could not be analysed in detail due to lack of data.

However, some value chains already appear more mature and better documented than the others. The detailed analysis of CS1, CS3, CS4 on PK-fertiliser, and CS8 on sewer mining and compost, have highlighted the potential of existing value chains in the NextGen project. The environmental life-cycle and economic assessments (D2.1 and D2.2) will bring forward new data supporting all assumptions made during this study and validating the potential of NextGen circular value chains.

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