Deliverable 9.6

Final market system maps - assessments of barriers to WATERMINING technologies and how to clear these

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[1] R=Document, report; DEM=Demonstrator, pilot, prototype; DEC=website, patent fillings, videos, etc.; OTHER=other

[2] PU=Public, CO=Confidential, only for members of the consortium (including the Commission Services), CI=Classified

Additional note	This deliverable has been prepared based on information provided by case study partners in WATERMINING and stakeholders identified as key informants for the case study. This report, therefore, relies heavily on participatory research and less on peer-reviewed scientific findings.

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Abbreviations

BREF	EU Best Available Techniques Reference Document
CO_2	Carbon Dioxide
$CaOH_2$	Calcium hydroxide
CoP	Communities of Practice
CS	Case Study
EoW	End of Waste
EFC	Eutectic Freeze Crystallization
ESG	Environmental Social Governance
ETS	Emissions Trading System
FAO	Food and Agriculture Organization
FPR	Fertiliser Product Regulation
HCl	Hydrochloric acid
IWW	Industrial Waste Water
$MgOH_2$	Magnesium hydroxide
NaCl	Sodium chloride
NaOH	Sodium hydroxide
Na_2SO_4	Sodium sulfate
PV	Photovoltaic
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
R&D	Research and Development
RD&D	Research, Development and Deployment
WHO	World Health Organization
WP	Work Package
WWTP	Waste Water Treatment Plant
ZLD	Zero Liquid Discharge

Executive Summary

The WATERMINING project aims to bring solutions to improve the circularity of water treatment and the resulting by-products of these processes. Achieving a deep understanding of the barriers potentially hindering the development of circular water solutions is crucial to design policies that enable the deployment of these techniques. To do this, the WATERMINING project organizes Communities of Practice (CoPs), where stakeholders from the WATERMINING case study projects analysed these market barriers and proposal (policy) measures to clear these.

CoPs in the case studies of Lampedusa in Italy and Almería in Spain focused on sea water desalination. The case studies of Faro-Olhão in Portugal, Larnaca in Cyprus and La Llagosta in Spain have been discussed by CoP stakeholders in terms of barriers in circular urban wastewater treatment. The CoP in the Netherlands focused on circular industrial waste water treatment at the Westlake plant at Rotterdam. The barriers defined by the stakeholders in the CoPs were discussed by the WATERMINING partners at the consortium meeting in Palermo (Italy, September 2022), and presented at the WATERMINING Market and Policy workshop in Brussels (Belgium, February 2023).

Addressing the three above-mentioned categories of circular water solutions, common barriers identified across all WATERMINING's case studies are the following. First, stakeholders report a lack of incentives to implement circular solutions, as mainstream linear practices are generally cheaper. This could be addressed by de-encouraging linear techniques by making the disposal of their by-products (such as brine) more expensive. Another solution could be to provide added value to circular solutions through the monetization of their additional products and services. Subsidies can support in lowering production costs or prices of materials recovered from sea- and wastewater treatment to level the playing field with conventionaly derived material.

Another commonly mentioned barrier is the difficulty to introduce products obtained from circular water treatment in the market, both because of a lack of public acceptance and legal constraints stemming from products being regarded as waste. Information campaigns and the revision of current regulatory frameworks to allow these products entering the market would expand the revenue sources from these techniques and improve the circularity of the system. Standardising the circular water treatment technologies in the market could support this, whereby best available techniques reference documents of the EU (BREFs) could be an effective instrument, especially when tapping into an ongoing BREF writing or updating process.

Across the case studies and replication studies it has been mentioned that current legislation in case study countries exclude 'watermined' products from food and/or other applications. Criteria for end-of-waste status of 'watermined' products, which would determine whether a product, such as Kaumera which is produced from urban wastewater treatment, is eligible as a fertiliser in agriculture, are usually determined at the level of the EU, but Member States could interpret these more stringently (Member State-level criteria cannot be weaker than the EU-level ones). In this respect it has been recommended to enhance knowledge exchange across Member States, e.g., by creating an EU-based unit (or competencies within an existing unit) to promote cooperation among EU Member

States and regional authorities concerning the production, sale and use of products recovered from wastewater treatment.

Another common perception stakeholders report is the widespread conservatism in the water sector. Water treatment actors traditionally have a focus on purifying water and supplying this to the market. Generating products from waste streams is often something that market actors are less familiar with. Among other solutions, the 'Dutch model' has been recommended as a way to create national centres for the development of knowledge and technology for water management, which would serve as an R&D accelerator.

1. Introduction

The project WATERMINING contains six case studies across Europe on progressing circular treatment of seawater and wastewater. The objective of the case studies is to generate products and substances from seawater desalination and wastewater treatment that can be usefully utilised in other applications. Under the case studies, the technologies for such 'water mining' are to be prepared for deployment in markets so that they can eventually be applied across Europe on a large scale, and thus contribute to Europe's Circular Economy action Plan (European Union, 2020), and eventually the objectives of the European Green Deal (Europen Commission, 2019).

Gaast & Renz (2022) elaborated on what the relevant markets for WATERMINING's circular solution look like, both with a view to the market for purified water and those for the products 'mined' during circular sea- and wastewater treatment. For the case study contexts, a market system analysis was carried out during 2020-2021 which resulted in so-called market maps. Case study partners, with input from market stakeholders, mapped the relevant market for each case study showing the market actors and what the relevant market conditions for their 'water-mined' products look like, in terms of existing policies and other aspects that could support or block market deployment of the case study's circular solution.

Across the case studies, case study partners and stakeholders showed concerns about the relatively high costs of the WATERMINING solutions in comparison with those of conventional alternatives. This, combined with the limitations to adding economic values to the environmental and social benefits of circular water treatment, hinders the economic viability of case study solutions, and thus prevents the implementation of new circular business models. Another aspect is familiarity, or lack thereof, among market actors with WATERMINING products, so that it takes time for markets to trust product characteristics and quality. In terms of legal aspects, the market mapping revealed cases of products produced from wastewater, such as phosphate or Kaumera, which legal status of being waste could prevent their application as, e.g., fertiliser for agriculture.

On the other hand, the market maps made clear that within Southern European societies there is a growing concern about water scarcity, which strengthens the need for producing water from sources such as sea or wastewater, as proposed by the WATERMINING case studies. Moreover, local concerns about the environmental impacts of conventional treatment of sea- and wastewater can become a trigger for circular systems such as zero liquid discharge, which treats water without environmental pollution. Finally, the market mapping for the case study solutions zoomed in on the policy momentum with the introduction of the EU Green Deal and other EU funding opportunities.

While Gaast & Renz (2022) mainly focussed on an analysis of the current state of relevant European markets for water and products generated through circular sea and wastewater treatment, this report focuses on solutions for making these markets ready for adopting WATERMINING solutions. It analyses, again with stakeholders, which are the highest-priority market barriers. Then, actions are identified for tackling these, including via policy instruments. Where possible, policy instruments are aggregated across the case studies for the WATERMINING sectors (seawater, urban wastewater and industrial wastewater), including the suggested level of policy making, i.e. national or EU.

2. Methodology

The framework for conducting the participatory analysis on improving market conditions for WATERMINING solutions was brought by the Communities of Practice (CoP) for each case study. Local, regional, and national stakeholders were invited to each CoP to support the work on the case studies throughout the duration of WATERMINING (about once a year for each case study). In 2020-2021, the CoPs enabled performing market mapping analysis for the case studies (Gaast & Renz, 2022); in 2022, the CoPs hosted discussions for **identifying actions** to improve market conditions for circular water treatment technologies (see Figure 2-1).

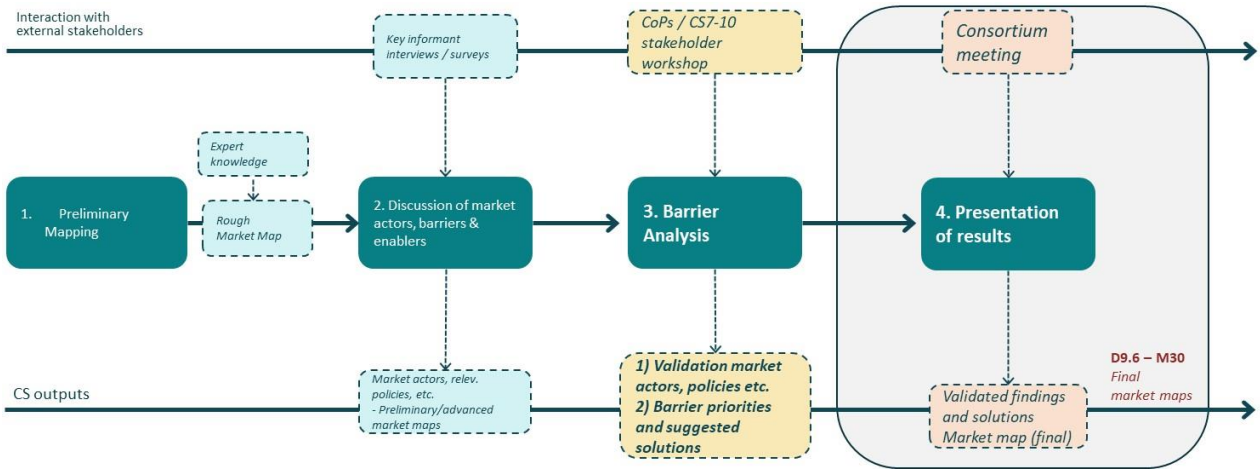

Figure 2-1. Timeline for market system analysis with case study CoPs

For that, the following steps were undertaken:

1. **Familiarise the CoP host with the software tool Mural.** This is an online software tool which enables active participation of stakeholders in both online and physical meetings. It has been used for CoP discussions, as not all stakeholders could be present physically. By logging into the Mural platform, stakeholders could add their inputs to the discussion (see Figure 2-2). CoP organisers could post questions through the platform, to which stakeholders could respond by writing their comments on sticky notes. While serving online group discussions, Mural could also be used for a purely physical meeting; participants could then use their laptops to feed the working screen, with the results becoming visible for all (on the laptop screen and the larger screen in the meeting room). JIN provided all case study partners hosting CoPs with training on using Mural.

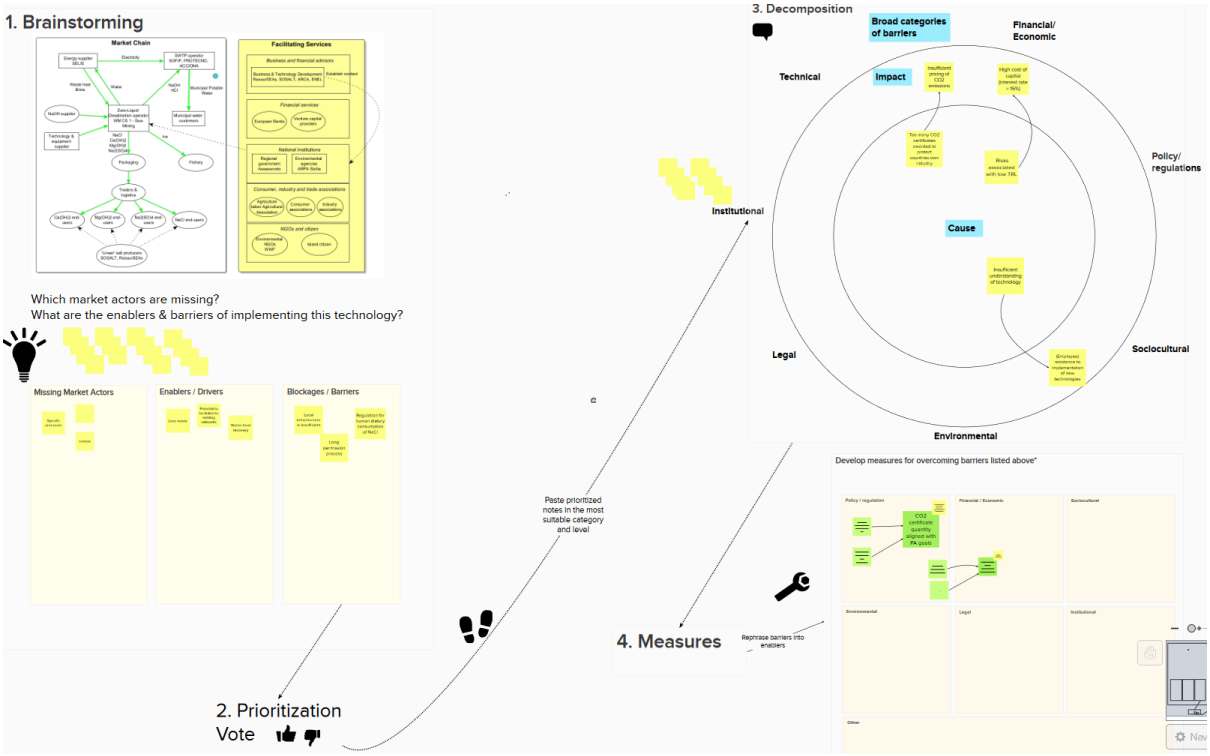

Figure 2-2. Example of Mural screen

2. **Revisit market maps.** As market conditions may change, stakeholders were first asked to revisit the market maps prepared beforehand (Gaast & Renz, 2022). With help of the Mural, CoP participants could add actors to the market value chain, as well as relevant aspects to the case study's policy or business environment (e.g., a new policy or regulation). In cases when Mural was not used, the CoP host added this new information to the market map.

3. **Revisit barriers and enablers.** Based on the revisited maps, stakeholders revisited the barriers identified before, i.e., whether other barriers were identified or existing barriers were addressed. The same activity was done for updating enabling factors/drivers as identified in earlier CoPs. Figure 2-3 illustrates how the new information in steps 2 and 3 was collected and categorised.

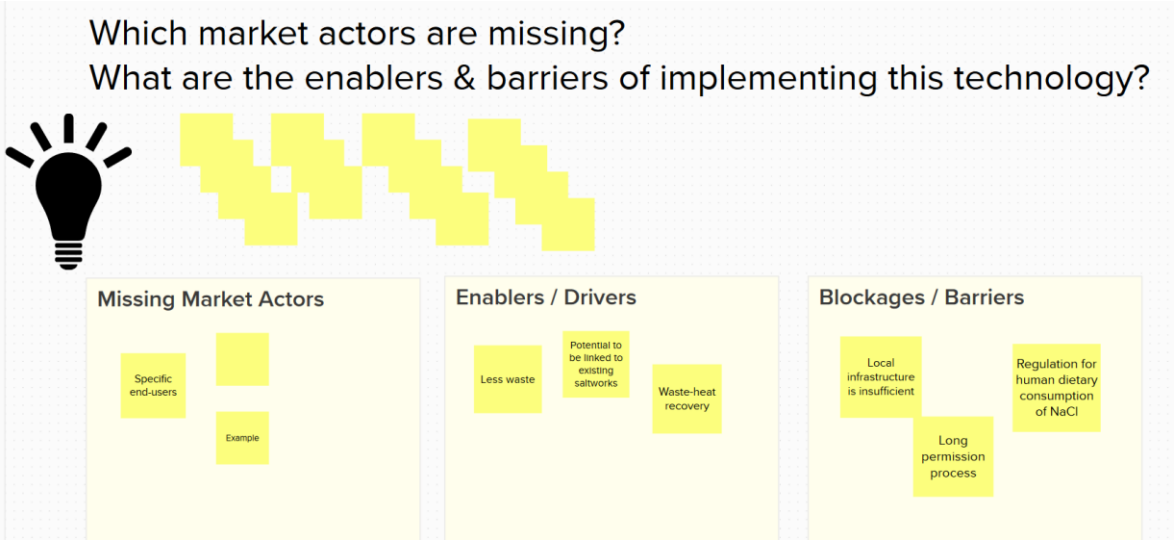

Figure 2-3. Result of new information added to the market map through Mural.

4. **Prioritization of barriers.** With the market map revisited and updated, the CoP discussion moved to a voting procedure where stakeholders could indicate which of the market barriers they found most important to tackle. This was not meant to indicate that other barriers are not important, but this ranking helped to inform policymakers where to focus on when attempting to accelerate the market deployment of WATERMINING solutions. The voting functionality is included in the Mural software.

5. **Barrier categorization and analysis.** After having identified the most pressing barriers, CoP participants moved to the analysis of each barrier. This was done (again enabled by Mural) by categorising a barrier (policy, regulatory, social, cultural, environmental, legal or institutional of nature), assessing the impact of each prioritised barrier on the case study solutions (why is it important?) and analysing its root cause (see Figure 2-4). Knowing the latter supports policy actions, as solving the root cause of a problem is often more effective than addressing symptoms.

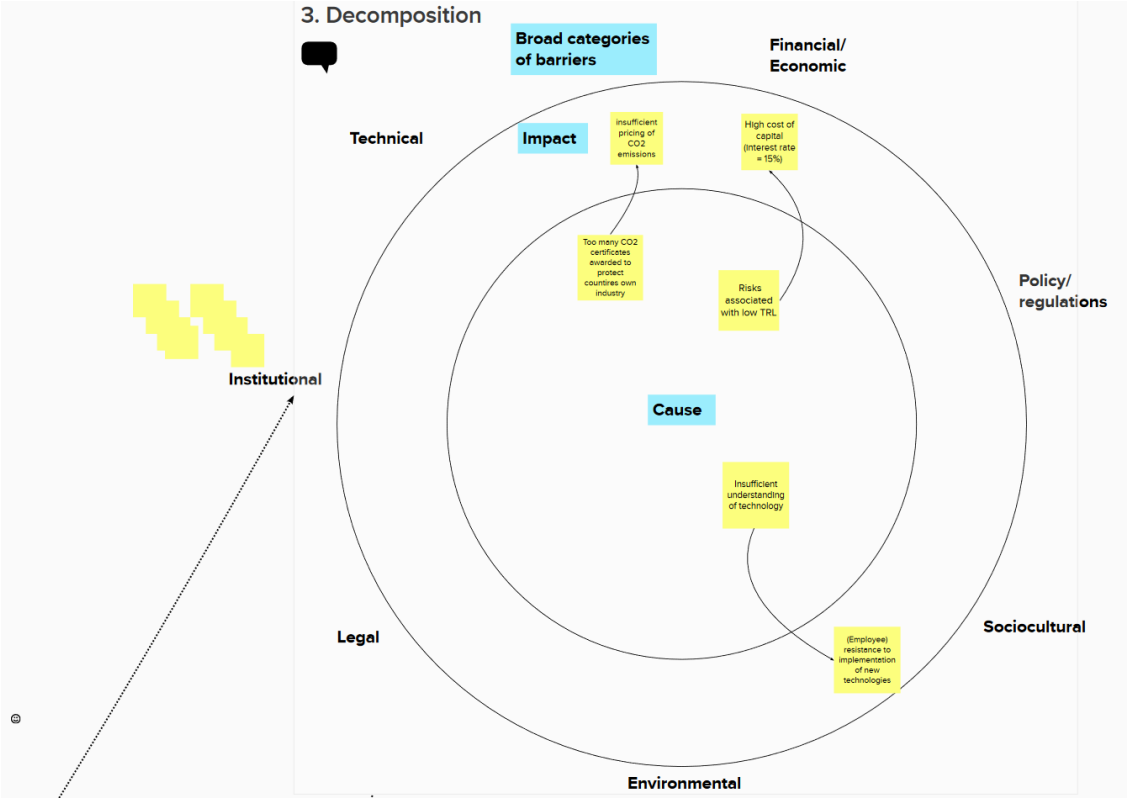

Figure 2-4. Mural screenshot of barrier root cause analysis

6. **Developing measures to overcome barriers.** With this detailed barrier analysis, participants could now move towards identifying policy measures to clear them. First, participants could refer to earlier identified enabling factors that they already indicated to exist in the market and analyse how these enablers could counterweigh a barrier. Second, participants were asked to identify new, additional measures that they consider needed for clearing a barrier within their case study context. This resulted in case study level packages of measures to support the deployment of WATERMINING solutions.

7. **Analysis of case study results concerning commonalities on a subsector level and validation with case study partners.** At the WATERMINING project meeting of September 2022 in Palermo (Italy), the measures developed in the previous step were validated by workshop participants. To do this, the research team of WP9, along with the case study partners, combined the measures across the case studies for sector-level packages (seawater desalination, urban and industrial wastewater treatment). In cooperation with the Jerusalem Institute of Policy Research, concrete policy instruments were identified for each measure (see Figure 2-5). These policy instruments were also discussed with Palermo workshop participants for validation.

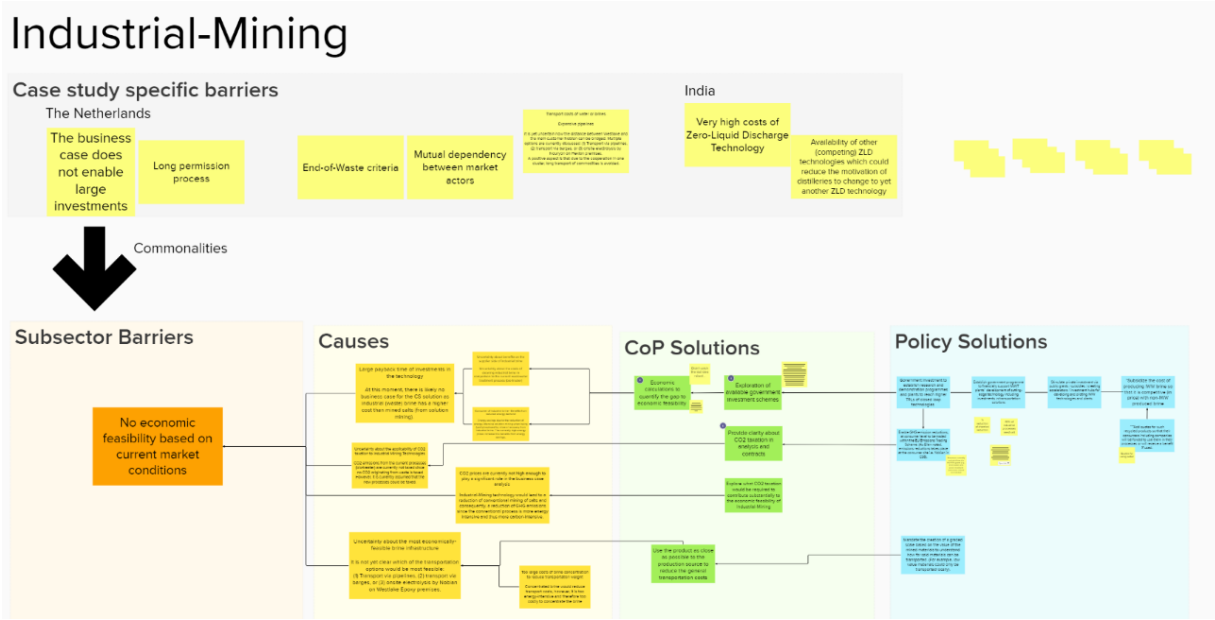

Figure 2-5: Industrial-Mining example of a) combining specific case study barriers with subsector barriers (Industrial Mining), b) describing the causes of the barriers, c) identifying solutions during a CoP meeting together with stakeholders, and d) policy solutions provided by the Jerusalem Institute for Policy Research

In this report, the results of the abovementioned steps are presented for the case studies, grouped per sector. In addition, the steps above have also been conducted for replication studies in Germany, Greece and Israel. Regarding these replication studies, it must be noted that they do not have a CoP similar to the six case studies in WATERMINING, so separate meetings were held with stakeholders in the three countries.

3. Seawater desalination – barriers and measures

3.1. Case study – Lampedusa, Italy

3.1.1. Introduction

The case study at Lampedusa belongs to the WATERMINING category of seawater desalination, aiming at providing clean water and recovering valuable minerals and products. This case study combines techniques to remove all liquid waste from the process of seawater desalination (zero liquid discharge) to (internally) reuse recovered resources and to integrate waste heat in the plant. Next to municipal drinking water, the purified water will be used as tap water for local internal consumption and cooling water for diesel engines of power facilities nearby the project. The scope of the market system analysis for the Lampedusa case study consists of two main product categories:

1. Water – The technology recovers usable water from seawater for internal use as a coolant and ice as a by-product of the Eutectic Freeze Crystallization (EFC) process[3].

2. Recovered salts – The technology includes the 'mining' of different salts, such as sodium chloride (NaCl), magnesium hydroxide ($Mg(OH)_2$), calcium hydroxide ($Ca(OH)_2$), sodium sulphate (Na_2SO_4), hydrochloric acid (HCl), and Sodium hydroxide (NaOH). These salts can be sold to different end-users.

The technology itself has a high replicability potential as it can be used on other European islands and beyond. A market map for the case study was published in Gaast & Renz (2022).

3.1.2. Barrier analysis and suggested measures to address these

On 10 June 2022, the second meeting of the Community of Practice (CoP) was organised for this case study with the participation of 16 stakeholders. The main topic was to build further on the advanced market map (established at the first CoP held in 2021 (Gaast & Renz, 2022)) and to identify a set of barriers that stakeholders would prefer to be addressed first for the successful market deployment of the case study technology. For that stakeholders revisited the barriers already indicated at the first CoP and where considered necessary newly identified barriers were added. From this list, stakeholders voted for the following barriers as the most urgent ones to address:

[3] For more information about EFC, see Mazli, Samsuri & Annuar (2021).

- **Uncertainty about the ownership of the extracted seawater**: stakeholders considered this issue a barrier that generally applies to all market actors partaking in extracting seawater. Currently, desalination plants in Italy are not limited in the quantity of seawater they extract from the sea. Participants compared this with the situation as it is in, for example, Israel where legislation is such that when seawater enters the land (and a desalination plant in particular), it is part of the resources the country can legitimately extract. The CoP recommended that any party extracting seawater needs to have a monitoring system in place to measure how much seawater it extracts. This way, the government could issue a levy or tax for the amount of extracted seawater. The CoP also discussed ownership of the products extracted from seawater, as it concluded that brine used to be legally considered as waste to be disposed of instead of being a valuable resource.

- **Restrictive regulation for using sodium chloride for human consumption:** The CoP highlighted the issue that according to the *Codex Alimentarius*,[4] a salt or any other product that is a by-product of a chemical process cannot be declared as being of food-grade quality. This implies that brine 'mined' for circular seawater treatment cannot be used for human food consumption. CoP participants suggested that legislation be modified to allow human consumption of sodium chloride if it meets all safety and quality requirements of the *Codex Alimentarius*. In those cases, sodium chloride could receive the status of food for human diets.

- **Uncertainty about the Involvement of governmental authorities:** The CoP mentioned that, for case study stakeholders, it is uncertain which governmental authority can address legislation about the circular economy and wastewater treatment. Would this be at the level of the EU, the national government or even regional/local governments? It also turned out to be difficult for case study partners to engage policymakers in the case study work and the CoP, as invitations were mostly left unresponded. Yet, stakeholders emphasised that eventual government involvement, such as the regional government Assessorato and the environmental agency ARPA Sicilia, are important for the success of the case study technology, as they have the authority to approve the use of products made from waste and govern environmental permitting procedures.

  CoP participants recommended contacted other regional governments such those at other islands with similar conditions as Lampedusa, such as Pantelleria. With more islands interested, local governments could exchange information and knowledge, thereby enhancing their engagement in taking the case study technology forward elsewhere. It was also suggested to engage more citizens in order to build momentum around the case study and the social and envronmental values that it addresses (e.g., water scarcity), which could also trigger the interest of local governments.

- Finally, stakeholders pointed out that the **environmental benefits from the case study are very difficult to monetise**. This is particularly due to the fact that conventional brine disposal

[4] The Codex Alimentarius is a set of rules and regulations developed by the Codex Alimentarius Commission, a Commission (divided into numerous committees) established in 1963 by the Food and Agriculture Organisation (FAO) and the World Health Organization (WHO). The commission's primary aim is to protect consumers' health and ensure fairness in international trade (FAO, 2023).

is not sanctioned. Stakeholders argued that the case study's economic feasibility would be strengthened if use of conventional brine were sanctioned. CoP participants recommended conducting such circular vs linear business model analyses in order to better inform policymakers, as well as private sector investors, such as those interested in corporate social responsibility considerations. Next to sanctioning conventional brine treatment, the case study's business model would also be strengthened by tapping into new markets for the case study's products. For this purpose, relevant industries would need to become more familiar with, e.g., recovered sulfates.

3.2. Case study – Spain – Almería

3.2.1. Introduction

The focus of the case study at Almería (Spain) is on the desalination of seawater with help of renewable energy sources. For this circular treatment of seawater, a demonstration plant has been manufactured and operated, using techniques such as nanofiltration, a multi-effect solar thermal evaporation plant and a crystalliser. The case study has a 'light' focus on thermal desalination and a 'heavier' focus on the integrated system of renewable energy production and using residual heat for water desalination. The purified water will be applied for irrigation in agriculture. In short, the focus of the market system analysis (Gaast & Renz, 2022) is on:

- An integrated system of renewable energy production, using residual heat for water desalination,
- Thermal desalination, and
- The supply of treated water to the agricultural sector.

3.2.2. Barrier analysis and suggested measures to address these

In the second CoP, held at Almería on 23 February 2022 (21 stakeholders attending), the discussion on market system mapping at the first CoP continued with a specific focus on prioritising barriers for (policy) measures. First, barriers identified for the advanced market map Gaast & Renz, 2022) were revisited, leading to some reformulations of barrier descriptions and to the addition of new barriers.

From the resulting list of barriers, the following were considered the most important, including stakeholder suggestions for clearing the barriers:

- **Excess bureaucracy**: stakeholders pointed at the 'immense' paperwork required for obtaining government funding for a project investment similar to that of the case study. For small and medium-sized enterprises in particular, the existing bureaucracy and lack of administrative agility make it complex to obtain licenses for water treatment processes. This

is considered by stakeholders at the CoP a serious roadblock, hence stakeholders recommended the streamlining of the public administration so that application processes become easier, with less paperwork and quicker turnarounds.

- **A lack of demonstration models for future users of innovative technology projects**: Stakeholders at the CoP pointed out that the water sector is generally conservative with actors, especially those in the irrigation communities, being familiar with traditional ways of water treatment and not easily ready to adopt alternative techniques, despite these being potentially beneficial from a societal perspective. Explaining market actors about these benefits is therefore often not sufficient to convince them. Instead, demonstrations of the integrated technology, as operated by the case study, are useful, as this enables actors to familiarise themselves with the technology and its products, including the water quality levels. Stakeholders reported that generally there is a lack of such demonstration projects so that progress along the technology learning curve from research & development to market deployment is generally lacking for this type of water treatment solution. Stakeholders thus recommended more funding for demonstration models to show end users the benefits of the technology and how potential risks can be addressed.

- **Slow implementation of renewable technologies**: Stakeholders pointed out that, in the region of Almería, scaling up the use of renewable energy technologies, such as for seawater desalination, is currently hampered by a lack of incentives. Stakeholders pleaded for more policy-level incentives for using renewable energy for water treatment initiatives such as the case study's, especially in light of the region's vast solar energy endowment.

- **High initial investment costs**: Such incentives would also contribute to clearing another identified key barrier; the relatively high upfront investment costs for the combined solution of renewable energy and seawater desalination (compared to conventional technologies).

- **Suboptimal water sector governance**: Stakeholders at the CoP pointed out that while Ministries in Spain have well-defined objectives, communicating these to the governing administrative bodies and agencies, including for the water sector, is often insufficient. As a result, the implementation of the government's Hydrological Plans in the regions often lags behind planning or only takes place partially. Therefore, stakeholders prompted to streamline the water sector governance with better integration of national-level plans and regional-level implementation.

- **Illegal water extraction**: As already came to the fore at the first CoP (Gaast & Renz, 2022), there is currently a widespread practice of illegal water tapping by end users. As a result, a considerable amount of desalinated water is not paid for. These missing revenues deteriorate the business case for circular, renewable energy-based water treatment. Thus, stakeholders called for creating an inventory of water withdrawals in Almeria (to explore which part of the distributed water is not paid for), and based on that information, regulate water extractions.

- **Lack of investment in R&D by private companies**: Stakeholders explained that in Spain most funding for research and development is provided by the government, while the

contribution by private sector entities is very small. This phenomenon is a limiting factor when developing solutions such as those proposed by the case study.

3.3. Replication case study – Seawater desalination in Greece

Next to the two WATER MINING case studies for seawater desalination, a replication study has been carried out in Greece. The latter is not based on an actual case study with a concrete technology development, but focuses on the conditions should the case study solutions be implemented in Greece The choice for this replication study was triggered by the large demand for desalination units in Greece, particularly for the numerous island communities where small desalination plants are in place. At the same time, access to fresh water is one of the main problems for the population of these islands. There are also links to tourism since conventional desalination units have an important environmental impact (brine discharge) which in turn affects several touristic sites. Application of zero liquid discharge would be an attractive solution for this problem as it eliminates discharge of brine.

As for the replication case studies no communities of practice are organised under WATERMINING, a dedicated workshop was organised on 30 June 2022, with 16 stakeholders attending, including representatives of the desalination companies from Athens and Cyprus (Sychem, TEMAK, WATERA HELLAS, and Caramondani Group), members of the Municipal Water and Sewage Companies of Chios, Ios and Poros, members of the Ministry of Environment and Energy (Greece), of the Water Development Department (Cyprus), and the Greek Capital Water Supply and Sewerage Company. They prioritised the following market system barriers:

- **Marketing of recovered products in the market**: Stakeholders explained that, while the proposed solution for seawater treatment produces goods such as sodium chloride, municipal water and sewage companies in Greece have no clear incentive to sell these in the market. Since their status is that of not-for-profit companies, there is no need for increasing revenues and thus tapping into new markets. It was suggested at the workshop that these companies would be supported in changing their business model so that selling circularly produced goods would be beneficial for them. One way of doing that could be by building public-private partnerships, whereby a private for-profit entity could have the incentive to increase its profits from 'watermined' products.

- **Forest legislation**: A new barrier that was identified at the workshop is that of the forest legislation as part of the environmental licensing for a project, which stakeholders considered very strict regarding the installation of photovoltaics or wind turbines. Stakeholders suggested using the rooftops of the desalination plant for solar PV panels, but that is for now only a partial solution, as the (renewable) energy needed for the desalination plant requires larger (rooftop) areas. Eventually, the forest legislation might have to become less strict for locations of renewable energy installations.

- **Lack of good practice examples of membrane crystallizer technology**: Stakeholders indicated that most of the technologies are well known to the market, except for the membrane

crystallizer for magnesium and calcium recovery, which is currently not in operation in Greece. It was therefore proposed to invest in familiarizing market actors in Greece with good practice examples of similar projects elsewhere in Europe. The information exchange, as done in WATERMINING, could serve as a welcome example for clearing this barrier.

3.4. Policy measures to address barriers to seawater treatment

Across the three case studies discussed above, four common barriers were identified for the project category of seawater desalination. These barriers were presented to participants at the WATERMINING consortium meeting of 20 September 2022 (held in Palermo, Italy), including the owners and facilitators of the case studies. Partners discussed the common barriers and suggested policy measures for each barrier. The preparation for this discussion was done in collaboration with WATERMINING's policy packages team (WP10). The findings were also presented at the WATERMINING Market and Policy workshop of 7-8 February 2023 (Brussels).

For seawater desalination, policy measures were discussed for the following common barriers:

- **The limited economic feasibility of WATERMINING solutions for seawater desalination due to relatively low prices of linear alternatives:** Participants suggested that policy measures would need to focus on monetising the environmental and sustainability benefits of circular seawater treatment solutions. A suggested policy measure is to differentiate between prices paid by consumers with different water consumption profiles. Consumers that use much fresh water would then pay a *progressively high price*. This could be an incentive to increase the use of 'grey' water, *i.e*. water not suitable for drinking, for services such as flushing toilets, instead of fresh water. Furthermore, participants suggested that governments sanction non or less-sustainable water consumption. In this line, ideas suggested were to create a mandatory EU market where non-sustainable water production would be capped, similar to the EU emissions trading scheme (ETS) for CO_2 emissions.

  Moreover, it was suggested that when tendering seawater desalination services, proposals must include investments in renewable energy use and waste heat recovery (as sustainable energy for the desalination process). This would serve as a potential incentive for investments in circular seawater treatment.

- **Insufficient competencies of local governments and excess bureaucracy:** Participants suggested more contacts among local authorities that are in similar situations, such as governments of islands that must cope with freshwater shortages. At Palermo, participants called for better direct information and actions targeting local authorities about, for instance, the results of the WATERMINING case study plants. Such actions could be undertaken by stakeholder coalitions, including businesses as the main users of WATERMINING solutions, to promote sustainable seawater mining to local and regional governments. Generally, the lack of information about solutions for non-sustainable water treatment is considered the most important reason for the lack of action by local authorities. Participants considered this mainly

a local issue to which actions at the EU-level would contribute relatively little, except for supporting research projects with local impacts, such as WATERMINING.

- **Current legislation in case study countries excludes sodium chloride from the food market for human consumption:** Current legislation based on the *Codex Alimentarius* does not allow the declaration of food-grade salts from chemical processes, even if they meet the general food quality requirements. This barrier is to be tackled through modified legislation, which can be supported by exploring best-practice cases more thoroughly. For example, participants discussed a case in Spain where a company received permission from the Spanish government to produce salts from sodium chloride for human consumption, provided that the quality of the salts need to meet the requirements of the *Codex Alimentarius*.

  At the workshop in Brussels, participants underscored the importance of safety and health aspects, whereby it was concluded that the EU can create standards for these across Europe, whereby Member States can decide to have stricter standards. It was concluded that recommending modification of the *Codex* is not likely to be feasible outcome of WATERMINING given that the *Codex* is governed by UN bodies.

- **Lack of demonstration models for future users of innovative water technology projects:** This barrier is considered prohibitive and thus important to tackle because the water market is generally conservative, partially because of the abovementioned aspects of safety and health. Stakeholders generally recommended that more resources are mobilised by governments to support the research, development and demonstration of sustainable seawater mining techniques to build trust and familiarity within the market, similar to WATERMINING's case studies.

4. Urban wastewater mining – barriers and measures

4.1. Case study – Kaumera extraction and valorisation ETAR Faro-Olhão, Portugal

4.1.1. Introduction

This case study investigates the extraction and valorisation of Kaumera from urban wastewater streams next to providing clean water. Kaumera is a new biopolymer with various application possibilities, often in combination with other materials, in agriculture (where it acts as a binder sticking fertilisers to the soil) and the building sector (flame retardant foam, medium-density fibres, etc.). The implication of these multiple applications is that the environmental impacts may differ depending on how Kaumera is used.

Producing Kaumera from waste helps to reduce the excess sludge from wastewater, which reduces the sludge disposal costs for wastewater treatment plants. Kaumera can generally be produced in wastewater treatment plants that operate based on Nereda® technology[5], since the extraction of Kaumera requires Aerobic Granular Sludge – one of the products of Nereda technology. So far, there are two demo Kaumera extraction installations, one of them is located at the Nereda plant in Utrecht, the Netherlands. In WATERMINING, the Kaumera demonstration installation in Utrecht is optimised and is subsequently transported to Faro, Portugal, for further demonstration and operation.

4.1.2. Barrier analysis and suggested measures to address these

A session of the CoP was held for this case study on 28 October 2022, with the participation of 18 external stakeholders (beyond the project and case study partners) and other WATERMINING partners (10 people, see Figure 4-1 for an impression). Participants revisited barriers for this project as identified by them before (Gaast & Renz, 2022) and prioritised the ones to be tackled most urgently for upscaling the cased study solution.

[5] For more information about Nereda, you can visit https://www.royalhaskoningdhv.com/nereda/ Currently, the Nereda technology is applied in 89 plants all over the world which implies that, in terms of the availability of the technology, Kaumera production can, in principle, take place globally.

Figure 4-1. Participants arranged in tables according to the colour they were assigned (filling in the forms on their phones).

The following barriers were prioritised for supporting Kaumera extraction and valorisation:

- **Difficult for Kaumera to compete with conventional products:** Stakeholders focussed on the relatively high production costs of Kaumera extraction that make Kaumera relatively expensive compared to the conventional products that it could potentially replace. Due to the current small scale of production, no or limited economies of scale can be reaped in terms of cost reduction. To address this issue, stakeholders stressed the need for improved (energy) efficiency of the Kaumera extraction process or to generate the energy on-site, so that production costs could be reduced. Scaling up could also be facilitated by increasing market demand for Kaumera, for which market actor need to become more familiar with the product and its benefits. For the latter, marketing campaigns can be effective. Moreover, stakeholders complained that the process of licensing a product as Kaumera can be costly and lengthy, which adds to its relative competitive disadvantage. Finally, participants discussed options to modify the Kaumera end product to better suit the needs of the end user, e.g., adapting the product so that it becomes less solid and more suitable as a fertiliser in agriculture.

- **Control and quality guarantee of Kaumera:** On this barrier, stakeholders pointed out that guaranteeing a stable quality of the extracted Kaumera product has been difficult thus far. They call for more pilot projects for Kaumera extraction to improve quality and to use the project in different practices, including agriculture, for more R&D and particularly for more demonstrations and practical applications.

- **Reluctance in the market to use a product that originates from wastewater treatment:** Concerning this barrier, stakeholders elaborated on the perceptions of potential users regarding Kaumera use. Aspects such as odour, the possible presence of pathogens and organic matter in the product, as well as concerns about wastewater treatment practices of waste management operators were discussed. Stakeholders agreed that awareness building in the market, with clarification to users about the product characteristics and production processes, could help address the perceptions. Visits to production facilities and application sites could, according to stakeholders, contribute to this goal.

4.2. Case study – Urban wastewater treatment Larnaca, Cyprus

4.2.1. Introduction

The case study at Larnaca is about technology R&D and demonstration of phosphorus removal from urban wastewater. This is combined with membrane treatment (powered by renewable energy) and final brine elimination through zero liquid discharge (ZLD). The recovered phosphorous and salts can be sold in the market for different applications, while the purified water is supposed to be used for irrigation purposes in agriculture.

4.2.2. Barriers and measures to address these

On 23 March 2022, 36 participants attended a session of the case study's community of practice (CoP), where 28 were external stakeholders (beyond the project partners and case study owners and facilitators). 18 stakeholders represented Cypriot authorities at different levels. Stakeholders elaborated on the list of barriers as identified in the advanced market map for the case study (Gaast & Renz, 2022) and prioritised the following barriers as the most pressing ones:

- **Difficulty in having a solid business model for the case study's solution**: the stakeholders expressed concern that under current market circumstances, it will be difficult to develop a solid business model for the proposed circular treatment of wastewater. The current price of water for agricultural use is very low, while with the proposed treatment process, the costs of water will increase. According to stakeholders, it is thus inevitable that circular wastewater treatment requires subsidies to cover this deficit. Related to this is the cost of the energy needed for phosphorous recovery and the ZLD treatment, for which stakeholders suggested the generation of onsite renewable energy. Except for the water, a short discussion about the acceptance of the recovered products was held. It was suggested to the Water Mining partner, to consult the local authorities and promote the products to the market after the project.
- **Acceptance of the 'mined' products in the market**: Stakeholders elaborated on the marketing of the phosphorous and salts produced through circular water treatment. Their acceptance in

the market, or lack thereof, is seen as an important barrier to further market penetration. Gaining trust is of key importance, and stakeholders recommended that (local) authorities can play a key role in, e.g., publishing material safety data sheets that can accompany a product when it is supplied in the market. Potential buyers can thus rely on the quality and safety of the product.

- **Legal aspects using of recovered water**: Stakeholders stated that legislation in Cyprus should clearly state the minimum parameters of the irrigation water for each type of crop. If the water produced from a wastewater treatment plant does not comply with these parameters, the plant should be able to propose a process for cleaning the water instead of storing it in lagoons. Furthermore, the stakeholders stated that the penalties when the water does not meet the requirements should be stricter. In general, the revision of the regional regulations was proposed by the majority of the stakeholders.

4.3. Case study – Urban wastewater, La Llagosta – Spain

4.3.1. Introduction

In WATERMINING's case study at La Llagosta, Spain, the focus is on the recovery of phosphorous from urban wastewater (in different ways) and fit-for-purpose water (ranging from street cleaning to agricultural and industrial use). For this circular treatment of wastewater, the demonstration plant uses techniques such as a granular anaerobic membrane bioreactor, a fluidized bed vivianite crystallizer and Biophree. This way, the demonstration plant aims at establishing a pilot-scale next-generation urban wastewater treatment plant for phosphorus and water recovery. Part of the case study analysis is the demonstration of energy recovery from urban wastewater by converting organic matter into biogas.

4.3.2. Barrier analysis and measures to address these

The second meeting of the community of practice for this case study took place on 23 March 2022, with 11 stakeholders (including 6 external stakeholders beyond the case study partners) participating in the discussion. The initial list of barriers identified in the case study's advanced market map (Gaast & Renz, 2022) was first revisited and updated, after which the stakeholders used a voting process to prioritise the following three barriers:

- **Insufficient rules and regulations regarding the use of products originating from waste treatment**: Generally, phosphorous recovered from a wastewater treatment plant is labelled as waste, which complicates its wider use. The meeting discussed that a draft amendment to the EU Regulation 2019/1009 regarding fertilising products in European markets contains a statement in which phosphorous in the form of struvite and vivianite (and in biochar and ashes) will be allowed as a fertiliser, while other recovered phosphorous products are still forbidden. The reason for the latter is that these phosphates have the status of waste and can

only be treated like that. This implies that wastewater treatment plants, instead of selling the phosphorous in the market, must pay waste management companies to handle the waste streams. Yet, this is less expensive than the burning of sludge and/or disposal in landfills.

Another complexity is that waste from wastewater treatment plants is not classified as urban waste, which implies that urban wastewater treatment does not qualify for existing government grants and subsidies. Yet, the CoP suggested using the sludge from wastewater treatment as a biogas through digestion, which could be used as an energy source in agriculture. Moreover, stakeholders argued that sludge from urban wastewater can be used in agriculture as a fertilising product (in contrast to industrial sludge).

In terms of legal policy actions, the stakeholders suggested stronger enforcement of illegal waste discharge laws which would result in a stronger incentive for circular wastewater treatment. In addition, stakeholders recommended that the government increase the control of sludge quality at wastewater treatment plants, thereby reducing the risk of sludge containing heavy metal contents entering the market and contaminating substances. This would, according to the stakeholders, contribute to building trust in good quality sludge from wastewater treatment.

Finally, stakeholders discussed that currently there are no regulatory limits in the country to water consumption, which could lead to additional water demand in case more purified water becomes available. Stakeholders mentioned the case of Tarragona, where it has become mandatory to use recovered water instead of conventional water sources (by changing the water allocation permits). With this measure, overall water consumption does not increase; it just becomes more sustainable.

- **Lack of economic feasibility:** By highlighting this barrier stakeholders pointed to the relatively high costs of circular wastewater treatments compared to conventional, linear water treatments. The stability of the circular business model is furthermore undermined by the irregular water demand, which varies across the seasons (e.g. high demand for irrigation water during the summer) and regions. Investment in scaling up capacity could thus lead to underutilisation throughout the year. Moreover, the costs of water treatment are increased because of the illegal discharge of waste in the sewage system often leading to different effluent quality of the wastewater.

- **Lack of familiarity with case study solution among market actors and end-users:** In general, stakeholders recommended building alliances with companies within the entire value chain of the circular wastewater treatment, to increase familiarity with the products and improve trust in their quality. Also, this better enables market actors to assume different roles in, *e.g.*, wastewater treatment plants becoming producers and distributors of 'watermined' products next to waste handlers. Regarding familiarity and trust, the CoP discussed the case of the Metropolitan Area of Barcelona where demonstrating a waste-recovered product made end users less reluctant to use it. From this, it was concluded that communicating the larger picture of the sustainability of circular wastewater treatment in combination with quality insurance can increase its societal acceptance. To achieve this, open visits by the public to the pilot plant at La Llagosta could be important for building awareness.

4.4. Replication study – Urban wastewater treatment, Israel

4.4.1. Introduction

In this replication study, the lessons from the case studies discussed above in this chapter have been discussed with stakeholders in the urban wastewater treatment sector in Israel. The study focuses on the recovery of the following products from urban waste-water streams:

- Higher-quality effluents (water used for irrigation),
- Direct and indirect application of sludge in agriculture, and biogas production of sludge (direct use/use for electricity generation), and
- Phosphates.

A detailed analysis, including an advanced market map for Israel has been presented in Gaast & Renz (2022), indicating what the market situation would potentially look like, if the case study technologies were implemented in Israel. The analysis of market system barriers is discussed below.

4.4.2. Barriers analysis and measures to address these

On 25 May 2022 a meeting was held with six external participants from Israel and project partners of the Jerusalem Institute of Policy Research. The overall picture obtained is an Israeli water economy that has created a recycling and reusing wastewater system that has been applied to agriculture with great success. Nonetheless, its success has created a conservatism that leaves the water economy behind in certain aspects and exposes it to risks in the event of an 'out-of-balance' situation in comparison to the existing situation. The participants would like the system to break free from such conservatism. It is possible that positioning the issue as one of R&D that will benefit the Israeli economy as a whole (in the spirit of the biotech revolution) could reduce the existing conservatism.

The closed funding system in Israel can be a barrier to innovation. If a government-run water company achieves greater efficiency, it could lose funding, ironically because authorities believe it can reduce the budget. To improve this situation workshop participants want private sector suppliers to take more of a leading role in the innovation process. Additionally, workshop participants would like to see a national centre for the development of water knowledge and technology, such as is found in the Netherlands (see also below), which would also improve the training and education of the next generation of Israeli water experts.

Considering this background, the following barriers have been prioritised by the participants with suggested measures to clear these:

- **Conservatism (lack of professional knowledge)**: While successful with recycling and reusing wastewater for agriculture, Israel currently faces a sense of conservatism towards progress on circular wastewater treatment and its use for other sectors. As a measure, Israeli

stakeholders recommended replicating the 'Dutch model',[6] and so create a national centre for the development of knowledge and technology for water management, which would serve as an R&D accelerator. It would also improve the training and education of the next generation of water experts. In addition, stakeholders suggested updating training programmes for water and wastewater engineers to include innovative approaches (i.e., next-generation education), as well as creating more exposure to new techniques for established workers in the field. This would require more public funding sources for R&D and their pilots, and increased access to and 'direct import' of knowledge and experience, as well as global technologies that have not yet been implemented in Israel or tested in Israeli pilots. It has been acknowledged that not all R&D will lead to successful technology deployment, but that should not lead to cutting off budgets, as this could discourage the development of cutting-edge technology. Finally, under the umbrella of dealing with conservatism, stakeholders recommended transferring responsibility from planning (authorities) to water suppliers, while providing incentives for the suppliers to advance technology. This is a bottom-up model (supplier driven) that might replace or integrate with the current 'top-down' model.

- **Defective and partial standardisation:** Stakeholders indicated that there is a general lack of regulation, training and international knowledge on water and wastewater treatment which has hampered the standardisation and marketing of wastewater treatment products. While Israel has some of this, enforcement is sometimes lacking. Related to this issue would be the introduction of guidelines for water use that takes into account exogenous considerations, such as the use of soil, environmental and health considerations, *e.g*., the reduction of micro-pollutants. In terms of the implementation of such guidelines, training and knowledge-raising activities among those responsible for standardization would be needed. The 'Dutch model' would also work with regulators as it would support training and knowledge-raising among those responsible for standardisation.

4.5. Policy measures to address barriers to urban wastewater treatment

At the consortium meeting at Palermo (Italy, 20 September 2022), the above analysis on barriers to the circular treatment of urban wastewater was discussed with consortium partners, in particular by all case study partners (owners and facilitators) together. The objective of this was to arrive at a set of common barriers and solutions for this subsector. After participants validated and commented on the barriers through an open discussion, solutions for clearing the barriers, including policy solutions were highlighted (WATERMINING partner JIIS introduced the suggested policy instrument, based on WATERMINING's WP10 policy package research). Furthermore, the findings were presented at the WATERMINING Market and Policy workshop of 7-8 February 2023 (Brussels).

[6] The Israeli participants were referring to Wetsus: https://www.wetsus.nl/. Wetsus, located in the Netherlands, is the European center of excellence for sustainable water technology, combining research, education and entrepreneurship functions.

The common barriers and solutions for the subsector were discussed as follows:

- **Possible mistrust of the market players and end users regarding the recovered products:** From the case studies, potential solutions have been identified focussing on guaranteeing the quality of the products, such as material safety data sheets, quality measurements, and mandating minimum standards for fertilisers recovered from waste water for different types of crops. The workshop at Palermo pointed out that from the summer of 2022 onwards the revised EU Fertiliser Product Regulation (FPR) (Fertilizers Europe, 2022) sets a regulatory framework for fertilizer producers, traders and farmers. The revised FPR accepts recovered phosphates, including vivianite, as raw materials.

  Regarding the reluctance of potential users to use products recovered from waste, one participant recommended, based on experience in the Netherlands, that talking about the origin of the recovered product be avoided. Instead, it is recommended to communicate the safety and the quality of the product. As a comparison, it was highlighted that people rarely neither consider that plastics (which are used to carry food in) are currently made from something as unhealthy as oil.

- **Legislative barriers for products made from wastewater:** This discussion focussed, a.o., on Kaumera, for which no EU-wide end-of-waste status exists, as it is too new and experimental to have been anticipated. Participants discussed whether the REACH legislation[7] would need to be adjusted to enable the marketing of products such as Kaumera. This resulted in the observation that Kaumera already meets the definition of a polymer under REACH. Since the extraction process itself does not impact the formation process, Kaumera qualifies as a natural polymer. Hence, no registration of Kaumera would be required.

  It was mentioned that REACH should not be confused with the regulation on End of Waste (EoW), which is more context- and country-specific. It means that the regulation is at the EU-level, but Member States have the possibility to interpret it more strictly. Taking Kaumera as an example, the type of sludge it is derived from can have an impact on its product characteristics. Hence, individual Member States will have to decide on the eligibility of applications of Kaumera. The Market and Policy workshop pointed at the distinction in this respect between EU-level general policy guidance, such as minimum requirements, which is supplemented by Member State or regional governments depending on the national and local contexts.

  To support national and regional governments on this, as well as the EU-level on formulating more general policy guidance, experiences, such as with Dutch market entities involved in the marketing of Kaumera in the Netherlands, would be very beneficial. At the Market and Policy workshop, it was suggested to create an EU-based unit (or competencies within an existing

[7] Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (European Chemicals Agency , 2023).

unit[8]) to promote cooperation among EU Member States concerning the production, sale and use of products recovered from urban wastewater treatment. Such a unit could also help coordinate efforts among the EU, Member State, and regional authorities to advance circular urban wastewater treatment activities.

In addition, the consortium meeting considered EU best available techniques reference (BREF)[9] documents as very important for creating wastewater treatment standards based on circular 'watermining' technologies. The discussion at the Market and Policy workshop added to this proposal that the most effective approach for that is to make an inventory of ongoing BREF processes that are relevant for this topic and aim at contributing to these with concrete text suggestions based on WATERMINING's research outcomes.

Concerning the suggestion done in the replication study for Israel of introducing guidelines for considering exogenous effects of water use, including the reduction of micro-pollutants, a link could be made with the most recent proposals for the new Urban Wastewater Treatment Directive. It is focussed on monitoring and removing micro-pollutants from urban wastewater, most notably microplastics and pharmaceuticals (European Commission , 2022).

- **Lack of economic feasibility of circular wastewater treatment technologies:** Participants discussed a couple of issues here. First, circular wastewater treatment and products mined from the waste are still relatively expensive, so based on economic grounds, it is also difficult to scale up the solutions in the market. Participants suggested that the above-mentioned recommendation on BREFs could support technology deployment, as it would require Member States to consider circular wastewater treatment rather than conventional technologies as a standard. At the Market and Policy workshop it was suggested to subsidise the production costs / prices of materials (other than water) recovered from urban wastewater treatment plants to level the playing field with conventionally derived materials.

  Second, the recovered products must find their way into the market, which is also related to the above-mentioned issues of quality and legal restrictions. For that, participants recommended a roadmap with consecutive steps on the marketing of recovered products from wastewater treatment, with recommended policy measures for each step. Third, some participants noted that it is often very difficult for public entities to receive income from economic transactions. As their legal task is mostly to clean water, valorising resources from wastewater treatment is often outside their mandate. It is therefore important to include in EU/national regulations that resource recovery is part of the public tasks related to sewage treatment.

[8] At the Market and Policy workshop it was argued, regarding the latter, that establishment of an EU-level unit may not be feasible and it might be more effective to link this measure to an existing unit or an ongoing process of drafting a Directive.

[9] The BREFs are a series of reference documents with descriptions of a range of industrial processes and for example, their respective operating conditions and emission rates (European IPPC Bureau, 2023). Member States are required to take these documents into account when determining best available techniques generally or in specific cases under the Directive.

- **Contamination of the WWTP's wastewater by illegal waste streams:** The main problem identified in this respect is the lack of enforcement of illegal discharge of waste. This barrier is important as the cleanliness of the wastewater has an impact on the eventual quality of the products 'mined' from it. For instance, if wastewater has high contaminant levels, this also effects the nature of the eventual product, such as Kaumera. At the consortium meeting participants recommended improving the monitoring of the sewage collection network to spot illegal discharges, e.g., by online monitoring and analytics to raise alerts/warnings and/or estimate and locate possible illegal discharges. At the Market and Policy workshop in Brussels it was suggested, as a policy instrument, to mandate and support such monitoring improvements, while tightening enforcement. This would also require stronger penalties as participants shared their experience that, while laws and regulations exist to prevent the illegal discharge of waste in sewage systems, the penalties in case of being caught are not strong enough to scare people away from this practice. Finally, participants suggested strengthening the control of sludge quality at a wastewater treatment plant. A potential policy measure is to mandate safety certification requirements for all products mined from urban wastewater streams, to ensure that they do not carry contaminants such as pathogens or metals.

5. Industrial wastewater treatment – barriers and measures

5.1. Case study – Westlake Epoxy, the Netherlands

5.1.1. Introduction

In this chapter, the focus is on industrial wastewater treatment based on the case study of Westlake Epoxy, located at port of Rotterdam, the Netherlands. It contains a pilot plant for testing the removal of organics from industrial wastewater using the technique of high-pressure oxidation, the integration of waste heat and innovative zero liquid discharge desalination. The products generated from this pilot wastewater treatment, *i.e.*, purified brine and recovered salts (e.g., sodium chloride) are potentially supplied to industrial applications. For instance, companies that currently use fresh brine for electrolysis processes could potentially use industrial brine produced through the circular treatment of industrial wastewater.

5.1.2. Barriers and measures to address these

For the case study in the Netherlands, two meetings with project stakeholders were held, one on 19 October 2022 and one on 25 November 2022. The first meeting was organised as a CoP session at which stakeholders were invited to prioritise barriers and suggest measures to address these. These findings were then discussed at the second, policy-focussed meeting to identify specific policy measures. The second meeting was co-organised by the Jerusalem Institute of Policy Research (JIIS), which is responsible for the policy-focused work package of WATERMINING. Industrial wastewater treatment was not on the agenda of the barrier discussion during the project consortium meeting in Palermo (20 September 2022), as the Dutch case study is the only one in WATERMINING on industrial wastewater treatment. As such, a discussion among partners from different case studies within each subsector was not necessary to come to a common understanding of policy measures for addressing subsector barriers. The meeting on 25 November 2022 was used for that. On 7-8 February 2023, at the Market and Policy workshop organised by the WATERMINING project (and held in Brussels), potential policy measures were discussed with stakeholders from outside the project consortium.

The following barriers and measures to address these were highlighted at the meetings:

- **There is no economic feasibility for circular treatment of industrial wastewater based on current market conditions:** It is currently difficult to formulate a business case for this solution, as industrial (waste) brine has a higher cost than conventionally mined salts. There is also uncertainty about the costs of cleaning industrial brine in comparison to the current wastewater treatment process (bio-treater), which takes place externally. Moreover, regular

business model calculations do not consider the environmental value of circularity, *e.g.*, for recovered salts. Participants recommended, next to further investments in R&D to increase the technology readiness level of the solution, establishing a government programme to financially support industrial wastewater plants' development of cutting-edge technology including investments in transportation solutions. At the Market and Policy workshop, a policy measure to encourage and support university programmes to train the next generation of water experts on circular wastewater treatment was suggested for this. In line with this, accelerators or investment hubs could be established for the development and piloting of industrial wastewater technologies and plants.

The existing cost difference between circular and conventional processes could be covered by subsidy or tax benefit schemes. At the Market and Policy workshop participants also discussed the policy instrument of penalties or fines on industrial plants that dispose wastewater into the environmentment without treatment. Participants concluded that such penalties already exist, but they could be made more effective by, e.g., higher fine levels and strengthened controls. Penalty enforcement is mainly the responsibility of the Member States, but in case the impacts of non-compliance are transboundary, it could be linked to an EU-level policy framework.

Another set of suggested policy measures are related to safety standards for recovered water, safety and quality standards for all substances (aside from water) that can be recovered from industrial wastewater treatment processes, or minimum percentages of water use that industries must recover. In terms of setting standards, such as via BREFs, it became clear that this is strongly desired but also relatively difficult for industrial wastewater treatment as there are many different industries each with their own water consumption and treatment processes (in comparison, the processes of seawater desalination and urban wastewater treatment result in a basic defined number of conceivable products).

Participants also pointed out the potential contribution of circular treatment of industrial wastewater to CO_2 emission reductions. However, valorising this impact is difficult, as the wastewater treatment plants are not covered by the EU emissions trading scheme (ETS); only when the end user of the brine is an ETS plant are emission reductions at the user's site accounted for under the scheme. Alternatively, CO_2 emissions originating from all wastewater reclamation processes could be taxed by the government so the costs of conventional processes would increase vis-a-vis those of circular, low-emission processes.

- **Uncertainty about the end-of-waste criteria for recovered solid materials from industrial wastewater processes:** To deal with this uncertainty, a policy measure (preferably at the level of the EU) could be used to classify recovered resources from industrial streams and mandate their quality levels in hazardous or non-hazardous materials. In a similar vein, a mandate was suggested to classify sustainably recovered substances as useable by-products rather than waste. At the Market and Policy workshop, participants discussed on whether such labelling policy instruments should be voluntary ('carrot') or mandatory ('stick'). Participants argued that voluntary labelling systems can be very effective when a market adopts the label as the standard; in that case, industrial plant that do not carry the lable will go out of business.

Participants at the second CoP meeting recommended a gradual ban on landfilling and discharge to surface water of substances resulting from industrial wastewater treatment. Such a measure would create a relative advantage for circular solutions. Similar to urban wastewater treatment solutions, workshop participants recommended BREF documents for circular industrial wastewater treatment so that this becomes the standard for best-available techniques in the sector.

- **Long permission processes for industrial watermining technologies can prevent operators to implement demos and/or full-scale applications:** At the second CoP meeting, stakeholders noted that long and poorly organized permission processes are a barrier to the deployment of the suggested solutions. For example, the Dutch case study owner, Westlake Epoxy, received the environmental permit for its demo installation 1.5 years after submitting the application to the municipality (the building permit granting authority). The permit for building the plant is yet to be received. As a result, the demo site at the plant in Pernis could not be installed yet. Important reasons for the delay, as argued by participants, are the deficits that municipalities face in terms of budget and staff. Participants therefore suggested to create a separate EU unit that aids the industry in receiving permission to install and operate (circular) industrial wastewater treatment technologies. This could be part of a national or EU-wide strategy for circular industrial wastewater treatment support, including RD&D support, levelling the playing field for circular processes and streamlining permitting procedures. At the Market and Policy workhop it was argued though, similar to the discussion under urban wastewater treatment, that establishing a new EU unit may not be feasible and that it would be better to tap into the agenda of an existing unit.

- **Lack of experience in the mutual dependency between market actors:** In some cases, the implementation of circular treatment of wastewater technologies can lead to a change in market actor relationships, from a traditional supplier-customer relation to a circular relationship. For example, in the case of Westlake Epoxy and Nobian, Nobian will substitute parts of its salt supply with Westlake's purified brine. The quality control of the salts will also shift to Westlake. Participants suggested tapping into the experience of the independent parties within the WATERMINING project or external consultants to facilitate the establishment of agreements between companies within the market value chain of circular wastewater treatment. This could be supported by promoting the cooperation among EU member states concerning the production and use of mined products, including the design and promotion of policies. This would include the creation of minimal standards for mined products, as explaine above, so that they can be traded, transported, and used across the EU. Stakeholders highlighted that this solution should be split up into separate activities for governments and NGOs. Specifically, the participants recommended liaising with the Joint Research Centre (JRC), which could play a role in this regard and may already conduct research activities in this regard.

5.2. Replication study – Germany

5.2.1. Introduction

The replication study conducted in Germany for industrial wastewater treatment, carried out by DECHEMA e.V., has a specific focus on using auxiliary tools and technologies such as the integration of digitalization technology into water management processes. The case of digitalisation tools is particularly interesting from a sustainability point of view since such tools provide the opportunity to: 1) enable circular solutions and products in the first place, 2) improve the overall resource efficiency (energy/materials) of industrial water management processes, and 3) enhance sustainability (e.g., via improved Environmental Social Governance (ESG) criteria) across the whole market chain. Further background on the replication study can be found in Gaast & Renz (2022). It is noted that a second replication study in this subsector was planned based on wastewater treatment in a sugar factory in India. The latter case study was planned under the work package six of WATERMINING, but as the implementation of the testing facility has been delayed in the project, the replication study could not be included in this report due to the lack of data.[10]

5.2.2. Barriers and suggested measures to address these

A stakeholder meeting for the replication study was held on 23 February 2022, with an attendance of 11 participants. It was held as part of a project meeting for the project DynaWater4.0, which aims to provide guidance for industrial water managers on how to implement digital tools and systems within their water treatment processes. Part of this guidance will be on coping with barriers and challenges faced by the water managers during implementation processes, as well as identifying areas for action or improvement. Therefore, there is an overlap between the focus of the Roadmap and the focus of the German replication case study, the role of digitalisation as a tool for circular processes in industrial water management.

At the meeting, the following barriers were identified for applying digitalisation tools in industrial water management, including measures to address these:

- **Lack of clarity in the evaluation of investments in digitalisation measures, i.c. capital expenditure, operational expenditure and return on investment**: Participants explained that, for digitalisation, there is a high initial investment requirement and there are not enough examples of implementation, meaning there are limited examples of how to calculate financial costs and benefits. Participants recommended that companies are guided at the beginning stages of implementation by existing consulting firms that offer digitalisation advice and support and who are financed by the state. Solutions were discussed on ways to reduce the costs of applying digitalisation tools, such as leasing systems, outsourcing operational data analysis and considering life-cycle costs so that the true cost of water could be calculated.

[10] This decision has been taken in consultation with the workpackage 9 leaders (e-mail 24 October 2022) and the Executive Board of WATERMINING (meeting of 1 November 2022).

Authorities could implement regulations on emissions or environmental impacts that circular water treatment aims to prevent, which would spur investment in digitalisation in order to adhere to these regulations.

- **Lack of standardisation of protocols, communication and architectures for digital tool application:** Participants explained that manufacturers often use their own protocols and standards, which complicates linking systems from different actors in the water treatment supply chain (*i.e*. linking sensor technology with complex artificial intelligence systems). Potential policy actions to address this barrier are the standardisation of digital tools across different actors in the market value chain and facilitating, e.g., data exchange[11] and machine-to-machine communication for improved monitoring of water quality.

- **Concerns about network (cyber) security:** Participants pointed out that if digitalisation was to be implemented in support of the treatment of industrial wastewater, cyber security and the protection of industry processes (i.e. trade secrets) would have to be addressed. This includes both internal and external data protection and security, as well as the protection of company/employee "know-how" also needs to be considered. Participants were insufficiently familiar with the available company solutions- and value-chain-level data security, which could be considered a token that more information is provided to market actors on cyber risks and ways to protect against these.

- **Silo mindsets:** The meeting discussed the aspect of 'insular' or 'silo' thinking within the water management value chains, which is considered a barrier to collaboration and data exchange on circular wastewater treatment. Government action in this field could be the setting of a specific timeline for publishing data on water quality levels and environmental criteria and establishing online (real-time) systems for tracking compliance with these levels and criteria.

[11] Such data exchange should be vendor independent, i.e. independent of the individuals and companies that develop and sell enterprise or consumer software applications.

6. Conclusions

For this report, six sea- and wastewater treatment case studies and three replication studies have been analysed in terms of existing barriers to deployment of WATERMINING's circular water treatment technologies. This analysis has been conducted with stakeholders in participatory settings, in the framework of WATERMINING's communities of practice (CoP) or dedicated workshops (in case of the replication studies). For each subsector – sea water desalination, urban and industrial wastewater treatment, common barriers have been identified, with potential (policy) measures to clear these. Across the three sectors, the following main barriers have been identified as urgent ones to address:

- **Lack of economic feasibility**: In general, the technology solutions of WATERMINING face the problem that the technology is relatively expensive compared to conventional technologies, while the revenues from the products 'mined' from seawater and wastewater streams are often unclear. Therefore, based on economic grounds it is difficult to scale up the solutions in the market. A generally suggested solution across the case studies is pricing of environmental impacts of conventional water treatment processes, so that costs to the environment are internalised in product prices. An example of a policy measure to be taken is to subsidize the production cost / price of materials (other than water) recovered from wastewater treatment plants to level the playing field with conventionally derived materials (depending on efficiencies and price comparison).

  Moreover, a support policy measure can be to make circular technologies the standard in the market for sea- and wastewater treatment. For that the best available techniques reference documents of the EU (BREFs) could be an effective instrument. In particular when a relevant BREF is being drafted or revised, the WATERMINING team could offer contributions from its case study work to such processes. It has been noted though that while circular economy standards are of crucial importance for industrial wastewater treatment, standardisation is relatively difficult for this sector as, contrary to urban wastewater treatment, there are many industrial sectors which cannot easily be captured by a single or a small set of standards.

- **Legislative barriers for products made from wastewater**: Across the case studies and replication studies it has been mentioned that current legislation in case study countries exclude 'watermined' products from food and/or other applications. For example, there is often uncertainty about the end-of-waste criteria for recovered solid materials from wastewater processes. In this respect, it is at the EU-level where criteria are set for end of waste status of products, but Member States could interpret these more stringently; Member State-level criteria cannot be weaker than the EU-level ones. In this respect has been recommended to enhance knowledge exchange across Member States, e.g., by creating an EU-based unit (or competencies within an existing unit) to promote cooperation among EU Member States and regional authorities concerning the production, sale and use of products recovered from wastewater treatment.

- **Lack of demonstration plants, leading to perceptions about safety and quality**: Case study stakeholders generally pointed out that the water sectors are overall conservative. Water treatment actors traditionally have a main focus on purifying water and supplying this to the market. Generating products from waste streams is, therefore, a new type of business, which stakeholders are often insufficiently familiar with. Obviously, this barrier is related to the above economic feasibility and legal barriers, but it is also related to lack of knowledge and the need to build familiarity with new circular techniques. Disseminating the case study knowledge from the WATERMINING project would be helpful, but also the 'Dutch model' was mentioned as a way to create national centres for the development of knowledge and technology for water management, which would serve as an R&D accelerator.

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