Policy implications for the EU in balancing technological sovereignty and environmental sustainability in development of water desalination technologies

Master's thesis

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Abstract

Water scarcity is a global challenge that is expected to intensify in the coming decades due to population growth, urbanization, and climate change. Desalination, the process of removing salt from seawater or brackish water, is a potential solution to address this challenge. However, desalination technologies can have significant environmental impacts, such as energy consumption and brine discharge. This research explored the policy implications for the European Union (EU) in balancing technological sovereignty and environmental sustainability in desalination technology development. The study focused on five desalination technologies: Reverse Osmosis (RO), Multi-Stage Flash Distillation (MSF), Multi-Effect Distillation (MED), Nano Filtration (NF), and Electrodialysis (ED). The research aims to answer the main question:

"What are the policy implications for the EU in balancing technological sovereignty and environmental sustainability in desalination technology development?"

To answer these questions, the study employed a mixed-methods approach, including a literature review, patent network analysis, and expert interviews. The literature review investigated the current state of water desalination technologies and their environmental impacts, revealing RO as the predominant technology in the EU. The patent analysis identified key players and trends in desalination technology development. The expert interviews provided insights into the challenges and opportunities associated with balancing technological sovereignty and environmental sustainability in desalination technology development. The experts indicated that economic efficiency often drives company decisions, yet sustainability remains an achievable goal. A critical finding was the potential trade-off where prioritizing technological sovereignty could lead to lock-ins with less environmentally optimal technologies, a relationship previously underexplored in literature. The findings of this research will provide insights for EU policymakers on how to promote the development and deployment of sustainable desalination technologies while ensuring technological sovereignty. This involves fostering domestic Research and Development (R&D), implementing incentives for environmental-friendly technologies, and engaging in strategic international collaborations to navigate the complexities of water security in a changing global landscape.

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ED: Electrodialysis
EI: Environmental Impact
EU: European Union
GHG: Green House Gas emissions
MED: Multi-Effect Distillation
MSF: Multi Stage Flash Distillation
NF: Nano Filtration
RO: Reverse Osmosis
SWED: Seawater Electrodialysis
SWRO: Seawater Reverse Osmosis
WF: Water Footprint

1. Introduction

1.1 Scientific background & problem statement

Water scarcity is a growing global challenge (Shemer et al., 2023), affecting over two billion people worldwide. 70% of the Earth's surface is covered by water but only about 2.5% of all water is considered freshwater (Kaushal et al., 2021). Moreover, approximately 1% of this freshwater is accessible because most of it is stored in glaciers and other inaccessible places (CEA, 2014).
A substantial portion of the globe's population struggles with water scarcity, with over 40% lacking access to clean drinking water (United Nations, 2022). In addition, the world is undergoing rapid urbanization, with the proportion of people living in cities projected to increase from 56.2% in 2020 to 68.4% by 2050 (United Nations, n.d.). Water scarcity, where demand exceeds availability, is a key determinant of water security and has dire consequences for the health and wellbeing of urban residents, urban environmental quality, and socioeconomic development (McDonald et al., 2011). Population growth, urbanization and socioeconomic development are expected to increase water demand by 50 to 80% over the next three decades. (Garrick et al., 2019). Additionally, climate change will affect the spatial distribution. In light of these challenges, the severity of (urban) water scarcity is likely to escalate in the future. (IPCC, 2014; Schewe et al., 2013; Vörösmarty et al., 2000).

Moreover, climate change is wreaking havoc on global weather patterns, leading to more severe droughts (Ashraf et al., 2017), more frequent and intense extreme weather events, and a rising sea level (Werner & Simmons, 2009). This perilous situation poses a significant threat to low-lying delta regions worldwide. Coastal communities are directly at risk of displacement due to rising floodwaters, and their access to both freshwater and food supplies is under severe strain.

Currently, climate change is already impacting the availability of freshwater of adequate quality. This is primarily attributed to altered weather patterns and their associated processes, including increased evaporation, reduced soil water retention capacity, and lower projected precipitation. The ramifications of climate change are evident today and, according to recent studies, are poised to intensify in the near future. By 2050, more than half of the global population will reside in regions experiencing water scarcity (Boretti & Rosa, 2019). Alarmingly, recent research suggests that under current projections for climate, population, and the economy, freshwater demand will outpace supply (Boretti & Rosa, 2019). This is a sobering reality, considering that freshwater is the primary necessity or resource for virtually all lifeforms and products on Earth. As such, effective governance of freshwater resources is of paramount importance.

Desalination, the process of removing salt from seawater or brackish water, presents a potential solution for addressing these water shortages. Several studies (Dhakal et al., 2022; Shah et al., 2022; Shemer et al., 2023) highlight the importance of novel technologies to decrease the worldwide water shortage, but the importance and influence of environmental factors of these water desalination technologies have been under researched. This is an important gap in the current literature.

Cohen et al. (2017) explain that the reverse osmosis (RO) technique is the most promising desalination technique, but it is still very energy intensive. Worldwide, the following five techniques are being used the most (Jones et al., 2019) : Reverse Osmosis (RO) 68.7%, Multi-Stage Flash Distillation (MSF) 17.6%, Multi-Effect Distillation (MED) 6.9%, Nano Filtration (NF) 3.4% and Electrodialysis (ED) 2.4%.
While substantial research has focused on its economic efficiency, the sustainability aspect has been largely neglected. For instance, desalination plants situated within a 1-10 kilometer radius of the coast commonly release discharge brine directly into the ocean, as this is the most economically viable disposal

method (Shemer et al., 2023). Inland desalination plants, on the other hand, utilize alternative approaches, including sewer discharge, deep-well injection, evaporation ponds, and land applications. Nonetheless, these methods are not environmentally sustainable and are burdened by substantial capital expenditures (Panagopoulos et al., 2019). The scarcity of freshwater has made desalination one of the most crucial alternatives to traditional water sources. However, public concern over energy consumption and the environmental impacts of brine discharge are two of the key challenges in implementing desalination.

The choice in technology to address the water shortage issues can therefore not be purely based on technological efficiency. He et al. (2021) highlight the need for a multifaceted approach to address urban water scarcity. According to He et al. (2021): "*Investment in infrastructure, sustainable water management practices, and innovative technologies is essential to ensure the water security of cities and meet the goals of the United Nations Sustainable Development Goals*."

Given the importance to take the environmental impact of these technologies into account, it's vital for nations to support technologies that concur with their core values. The recent years have shown a surge in concerns about technological sovereignty with nations realizing their dependency upon others for key technologies (Edler et al., 2023; Sheikh, 2022). This dependency becomes an issue especially in the context of technologies that are vital to the green transition (Caravella et al., 2021). To ensure a more sustainable world, a nation needs to ensure that it can use implement and develop the technological solutions it values. The ability to achieve this is referred to as Technological Sovereignty by Grant (1983):

"Technological sovereignty is the capability and the freedom to select, to generate or acquire and to apply, build upon and exploit commercially technology needed for industrial innovation."

This definition does not imply strict autonomy over an entire value chain, but rather internal abilities and balanced relations with other countries (Edler et al., 2023). This increases the complexity of the policy decisions that will need to take into account both the environmental impacts of technological solutions as well as potential dependency issues related to these technologies. If sovereignty concerns outweigh environmental concerns a risk of lock-in into sub-optimal technologies might occur. Unruh (2000) analyses a similar issue with carbon technologies, where technologies with a higher carbon footprint thrived because of the co-evolution of technological and institutional frameworks.

The literature on technological sovereignty focuses much of its attention on telecommunications, AI and chip production (Da Ponte et al., 2023; Sheikh, 2022), green technologies have received only limited attention, with the notable exception of Caravella et al. (2021). The link between sovereignty and environmental impact has not yet been addressed. A risk exists that the technological solutions chosen are more influenced by sovereignty than their environmental impact, slowing down the transition.

Taken together, these dimensions (Sustainability and Sovereignty), show that while sovereignty is an important dimension to take into account, it should be considered in symbiosis with the environmental impact of the technologies.

1.2 Research question

As stated in the previous paragraph, the environment has been overlooked in current research on technological sovereignty, and will therefore be the focus point in this study. Given the context of this topic, we will focus on European countries with access to seawater. As these countries are more likely to aim to develop desalination technologies themselves.

Based on the societal problem, scientific background and gap in the literature, the **research question** states as follows:

What are the policy implications for the EU in balancing technological sovereignty and environmental sustainability in desalination technology development?

Sub-questions

To answer the main research question, the following sub-questions have been formulated.

1. *What are the current desalination technologies used in the European Union?*

2. *What are the environmental impacts of desalination technology, both upstream (e.g., resource extraction, manufacturing) and downstream (e.g., brine discharge)?*

3. *Which areas in the world have the most promising knowledge of water desalination technologies?*

4. *What are the experiences of companies in balancing technological sovereignty and environmental sustainability in desalination technology development?*

5. *What are the potential trade-offs between technological sovereignty and environmental sustainability, in the development and deployment of water desalination technologies in the European Union?*

Research Objectives

The aim of this thesis is to assess the extent to which pursuing technological sovereignty in water desalination technologies may compromise environmental sustainability. The purpose is to describe what is missing in the current state and to prevent potential lock-ins from certain countries or areas.
Answering this question requires an assessment of the alternative technologies and their environmental impact (sub-questions 1 and 2). A mapping is then made to identify which areas in Europe have the most advanced desalination technologies and why (sub-question 3). Using this information, companies will be identified to measure their technological dependency (sub-question 4). Based on the results, the tradeoffs between technological sovereignty and the environmental sustainability of the technological alternatives are deduced (sub-question 5).

The answers to these sub-questions form the basis for policy recommendations for EU countries to achieve a balance between the environmental sustainability and technological sovereignty of water desalination technologies.

1.3 Relevance

This study has the potential to contribute to the academic understanding of technological sovereignty in the development of water desalination technologies in particular and green technologies in general. It helps in its exploration of the complex relation between technological sovereignty and environmental sustainability in the context of water desalination technologies.
The world faces multiple, interdependent, crises simultaneously. The environmental crisis creates a need for sustainable solutions to address water demand, while the geo-political crises create risks that technologies that are less beneficial for the environment will emerge as industry standards. This complex interplay has not been studied in the literature and addresses a societal need for sustainable solution for the water crisis.

The research question highlights the potential trade-offs between these two important considerations. For example, pursuing technological sovereignty may require investing in research and development, which could lead to higher initial costs for desalination plants. However, having a strong domestic desalination industry could reduce reliance on foreign imports and improve national security. On the other hand, focusing on economic efficiency may lead to the adoption of less environmentally friendly desalination technologies. This could have negative consequences for water quality and marine ecosystems.

By exploring these trade-offs, the research question can contribute to a more informed and nuanced understanding of the challenges and opportunities associated with water desalination technology. It can also help to identify strategies that can balance technological sovereignty, and environmental sustainability in the development and deployment of this critical technology.

This study has both scientific as societal relevance, as it contribute to filling the gap in literature of the sustainable relevance in developing desalination technologies and it helps tackling the worldwide societal problem of fresh water shortage.

2. Theories

This chapter explains the theoretical foundations that are necessary for understanding the balance between technological sovereignty and environmental sustainability in the development of desalination technology in the European Union. First, necessity of drink water for a nation is highlighted, related to the concept of resource security. Then, the meaning of technological sovereignty is explored. Subsequently, theories of innovation and the crucial roles of knowledge and patents are examined. Ultimately, the new conversation regarding the potential collaboration between technical independence and environmental goals are discussed.

Resource Security Theory and Water Desalination

When it comes to access to water, the need for reliable access to safe water for all individuals, including future generations is vital (Husane & Hikmat, 2023). The concept of water resource accessibility takes spatial factors into account as well as the analysis of the coupling coordination degree between water resource accessibility and eco-socio-economic water demand elements (Aligholi & Hayati, 2022). Resource security theory (RST) addresses these issues by focusing on the access and control over natural resources (Klare, 2007; Klare, 2012). The theory states that nations seek to secure access to resources to maintain economic stability, power dynamics and national security. It can be applied to evaluate the role of water desalination technology in addressing water scarcity challenges and achieving long-term water security for the European Union and connects seamlessly with the concept of technological sovereignty in its focus on securing access and control. In this thesis, RST theory is used as an underlying framework to identify important dimensions to take into account when analyzing water desalination technologies from a technological sovereignty perspective. Mostly the focus lies on the technological dimension.

Strategic Dimensions and Freedom of Technology

Technological sovereignty is a complex topic that needs to be studied from a number of angles, especially for large entities such as countries in the European Union. Here, the framework proposed by Sheikh (2022) will be used to analyze the technology and identify which elements of the technology may cause concerns from a sovereignty perspective. Sheikh divides a technology into different layers, each of which can be confronted with security or resource scarcity issues. The same logic will be applied to water desalination technologies to identify where the security risks may be present (for instance by identifying rare earth materials, specific technologies or tools etc.). Sheikh (2022) asserts that in order to fully comprehend technical sovereignty, we need to look attentively at how technology and its consequences on people are linked. When relying on outside sources in critical technological fields, it's best to be careful to avoid giving outsiders too much influence or limiting access to important technologies that could hurt national or supranational interests.

Theories of Innovation: Patents, technological dependence, and know-how

Technologies are not created ad hoc, they are the result of the recombination of existing knowledge (Schumpeter, 1942). Joseph Schumpeter's groundbreaking work on creative destruction and the role of innovation in economic growth provides a full picture of how new technologies come about and how they change industries. The innovation process relies on the combination of knowledge from different sources. In the light of technological sovereignty this means that to innovate in water desalination, one might require knowledge from other companies, in other regions of the world. The innovation trajectory of the technology is not defined by one country alone, but creates inherent dependencies through its cumulative nature. When a large portion of the knowledge is created by companies in other countries, and this knowledge is protected with Intellectual Property, then sovereignty becomes an issue.

It is important to ask how much a region, like the EU, depends on the knowledge of other countries. Schumpeter says that innovation is based on the way knowledge builds on itself. This shows that new ideas come from old ones. So, if other countries or groups protect their knowledge, it increases dependency. If a country or organization has better knowledge and control, it can have more power and make others more dependent on technology. This control includes the direction of the technology, making patents an important tool in this area because they can effectively block access to important pieces of information.

Many academic works support the idea that patents define and protect information. Patents are also often used as proxies for measuring technological abilities of regions and organisations. Jaffe (1986), used patents to study the idea of technological opportunity and knowledge spillovers. They have shown that proximity affects how knowledge spreads, as seen by patent citations (Jaffe, 1986). Shapiro (2000), Tseng et al. (2011), and Verspagen (1997) have added to this conversation by showing how patents affect innovation systems in a strategic way. A patent protects knowledge that shows the direction of a technical advancement. A citation between patents shows that an inventor has used knowledge created by another. The more citations a patent has, the higher the dependency and economic value of the patent (Trajtenberg, 1990). This shows how patents can protect and guide technological progress, which could lead to areas of leverage or disagreement. This could lead to "some form of disagreement over ideas, principles, or sovereignty in which the opposing forces contend for dominance" (Zeitoun & Warner, 2006). When thinking about technological sovereignty, this idea is especially important.

Finding a balance between ecological sustainability and technical independence

The last theoretical point is the choice organizations must make when making decisions: do they put technological independence or environmental sustainability first? This is an important strategic choice for a company or a group of people in a certain area. This part will focus on the dangers that come with trying to find a balance. It's important to remember that there isn't a lot of research on the complex balance between technological sovereignty and environmental goals. This gap shows that there is a lot of room for more investigation in this thesis.

In addition, the theory on technological lock-in underlies the analysis. Technological lock-ins are well studied phenomena (Arthur, 1989; David, 1985). Within the bounds of this thesis the risk for a technological lock-in resides in a sub-optimal choice in technology as a result of concerns about sovereignty. If a technology that has a bigger impact on the environment has lower security concerns there is a risk that this technology will be supported by government agencies at the cost of more efficient technologies. This is close to the theory described by Unruh (2000), who analyzed carbon lock-ins. The latter refers to a situation in which a less efficient technology becomes widespread at the detriment of more carbon-efficient technologies.

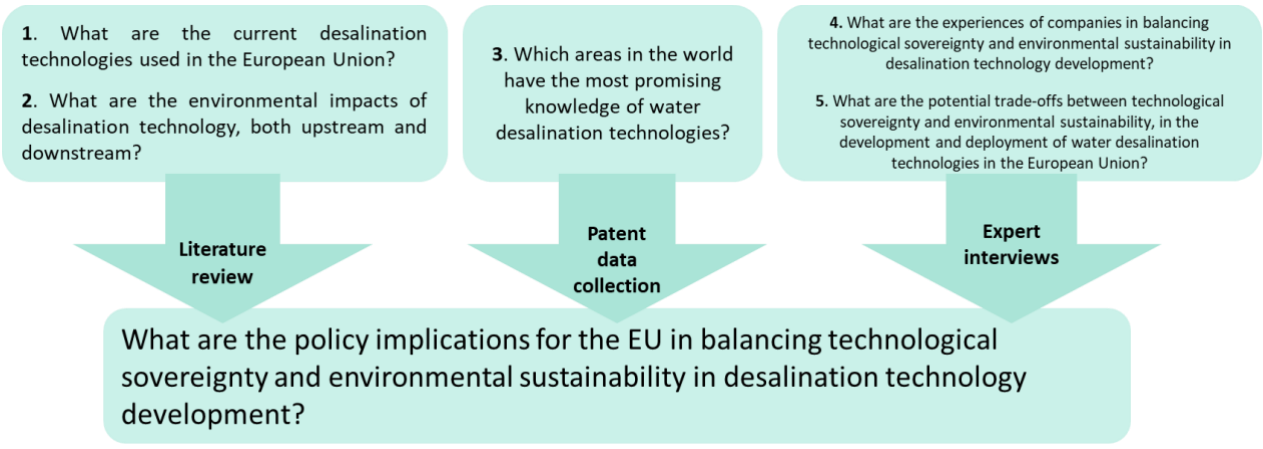
3. Methodology

This study investigated trade-offs between technological sovereignty and environmental sustainability in the development of water desalination technologies to improve innovation policies for European countries.
An explorative literature review was performed to investigate the current state of water desalination technologies, followed by a quantitative study of patents that involves parts of the desalination technologies.
Furthermore, expert interviews were conducted to give insights into innovations and strategies for countries and companies about these technologies and not-yet existing technologies. The interview data was analyzed through a content analysis approach. Finally, quality criteria were formulated to reduce bias.

3.1 Research design

The research used a mixed-methods design, specifically a sequential explanatory design (Clark et al., 2021). This design involves collecting quantitative data first, followed by qualitative data to explain or elaborate on the quantitative findings. A mixed-methods design enhances triangulation, completeness, sampling and enhancement (Clark et al., 2021).
In this case, a literature review was performed, then patent data was collected, followed by qualitative interviews. The technique of Caravella et al. (2021) was used by analyzing patent data, as outlined in chapter 2. This approach enabled the researcher to geographically map the "technological superiority" of water desalination technologies of European countries. The protocols of Jacob and Furgerson (Jacob & Furgerson, 2015) were used when writing and conducting the interviews.
Prior to the quantitative patent data collection, an explorative literature review was performed. An exploratory review is a preliminary exploration of a topic, laying the groundwork for more in-depth research (Frederiksen & Phelps, 2018). This literature review was needed for the researcher to track and compare the sustainable aspects of the four technologies and to research if other technologies have the possibility to compete with the current state-of-the-art technologies.

Figure 1: *Overview Connection Theoretical Framework and Research Questions*



3.2 Explorative literature review

An explorative literature review involves a comprehensive and systematic search of relevant academic literature, industry reports, and other relevant publications (Siddaway et al., 2019). This initial review was necessary for tracking and comparing the sustainable aspects of the five most used technologies and researching the potential competitiveness of other technologies with current state-of-the-art technologies.

The primary search strategy included the keywords: "water desalination technologies", "environmental sustainability", "environmental impact" and "innovation polices". Several criteria were applied to select whether studies were relevant to the research question. Articles related to the sustainable components of the technologies must be published after 2015, because these technologies are heavily evolving, to ensure that they are relevant in present circumstances. The source may be a scientific paper, official government document, official university document, or from known organisations. The literature was obtained using several academic databases such as WebOfScience, Worldcat, Scopus, and Google Scholar. It is acknowledged that Google Scholar has not, per se, peer-reviewed papers. This was taken into account while doing literature research. Papers originating from Google Scholar were included if they have been published in another academic source.

3.3 Patent Research

A patent search was conducted to quantify and analyze data about the five water desalination technologies. The purpose was to create a geographic mapping of “technological superiority” of all countries. Using the assignees on the patents, national innovation activities were measured and quantified. Patent citations were used to mitigate the impact of the patents and identify which organization cites which other organization. This data allowed for the identification of trends for each of the alternative technology and compare countries in their relative technological positioning. Based on this dataset, companies were identified as potential targets for the experts’ interviews.

Patent data was used to measure relatedness between different technologies (captured by patent classes) and the complexity value of technologies (Balland et al., 2018b). This information was used to assess in the assessment of the technological positing of countries.

Lens.org was used to conduct this data collection. Lens.org is a free and open patent search machine. The Lens has been hailed as the “most comprehensive scholarly literature database, that exceeds in its width and depth two leading commercial databases (Web of Science and Scopus) combined” (Penfold, 2020). It also contains a patent dataset that covers all offices in the world, ensuring that we do not have a regional bias in the analysis.

Query input for the five technologies

For each technology, its own query has been used to gather patent data for lens.org. To optimize to come a complete dataset as possible, a combination of IPC classification codes and key words were used.

This study employed network analysis to investigate the technological landscape across five desalination technologies. As mentioned, the data for this analysis was sourced from patent database Lens.org. To ensure comprehensive data retrieval for each technology, a dedicated query was constructed. These queries were formulated through a strategic combination of relevant keywords and International Patent Classification (IPC) codes specific to each technology domain. This dual approach aimed to capture a broad yet targeted set of patent documents. The resulting datasets comprised patent publications, which were subsequently aggregated into 'simple patent families' as defined by Lens.org. This grouping methodology ensured that variations of the same invention filed in different jurisdictions are treated as a single unit of

analysis, thereby mitigating potential biases arising from multiple filings of identical inventions. The subsequent network analysis was performed on these consolidated patent family units, allowing for an examination of the relationships and structures within and across the identified technology areas.

All queries are listed below. An overview of the definition of the used IPC codes, can be found in Appendix A.

Reverse Osmosis (RO):

```
class_ipcr.symbol:B01D61/02
AND
((title:(salt) OR abstract:(salt) OR claim:(salt)) OR (title:(seawater) OR abstract:(seawater) OR claim:(seawater)))
AND
(title:(desalination) OR abstract:(desalination) OR claim:(desalination))
```

Multi-Stage Flash Distillation (MSF):

```
(class_ipcr.symbol:(C02F1/06) AND (title:(multi-stage) OR abstract:(multi-stage) OR claim:(multi-stage)) AND (title:(salt) OR title:(seawater) OR abstract:(salt) OR abstract:(seawater) OR claim:(salt) OR claim:(seawater)))
OR
(class_ipcr.symbol:(C02F9\/*) AND (title:(flash) OR abstract:(flash) OR claim:(flash)) AND (title:(salt) OR title:(seawater) OR abstract:(salt) OR abstract:(seawater) OR claim:(salt) OR claim:(seawater)))
OR
(class_ipcr.symbol:(B01D3/06) AND (title:(multi-stage) OR abstract:(multi-stage) OR claim:(multi-stage)) AND (title:(salt) OR title:(seawater) OR abstract:(salt) OR abstract:(seawater) OR claim:(salt) OR claim:(seawater)))
```

Multi-Effect Distillation (MED):

```
(title:("multi effect distillation") OR abstract:("multi effect distillation") OR claim:("multi effect distillation"))
AND
((title:(salt) OR abstract:(salt) OR claim:(salt)) OR (title:(seawater) OR abstract:(seawater) OR claim:(seawater)))
AND
(title:(desalination) OR abstract:(desalination) OR claim:(desalination))
```

Nano Filtration (NF):

```
(title:(nano) OR abstract:(nano) OR claim:(nano))
AND
(title:(desalination) OR abstract:(desalination) OR claim:(desalination))
AND
(title:(filtration) OR abstract:(filtration) OR claim:(filtration))
AND
((title:(salt) OR abstract:(salt) OR claim:(salt)) OR (title:(seawater) OR abstract:(seawater) OR claim:(seawater)))
```

Electrodialysis (ED):
(class_ipcr.symbol:B01D61/42 AND ((title:(seawater) OR abstract:(seawater) OR claim:(seawater)) OR (title:(salt) OR abstract:(salt) OR claim:(salt))))
OR
(class_ipcr.symbol:B01D61/44 AND ((title:(seawater) OR abstract:(seawater) OR claim:(seawater)) OR (title:(salt) OR abstract:(salt) OR claim:(salt))))
OR
(class_ipcr.symbol:C02F1/469 AND ((title:(seawater) OR abstract:(seawater) OR claim:(seawater)) OR (title:(salt) OR abstract:(salt) OR claim:(salt))))

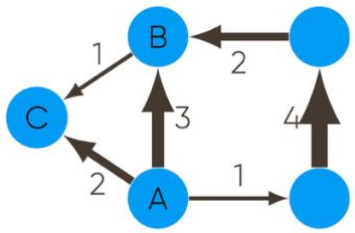
All datasets have been analyzed through a social network analysis (Barabási, 2013), based on **patent citations.** Citations are a well established measure used for the assessment of patent value and knowledge flows. (Jaffe & Trajtenberg, 2002). Patents contain citations, references from one patent to another. Just as scientific publications, a reference shows that the citing patent uses knowledge from the cited patent for its invention. Patent citations can be added by either the author of the patent (the inventor) or the patent office (the examiner). In the patent application process, the role of the examiner is to establish if a patent satisfies the criteria of patentability (novelty, industrial application and inventive step). The examiner uses citations to prove whether or not these conditions are met. If a patent claims that something is new, the examiner can cite patent X to show that this already exists, making the claim false, resulting in its removal from the patent. These citations are therefore quite strong measurements of knowledge dependencies.

For the purpose of this thesis, we looked at citations in a slightly different way following (Van der Pol & Virapin, 2022). When an organisation cites a patent from another, this shows a form of technological dependency. The organisation used knowledge from elsewhere to be able to innovate. This knowledge is also protected by a patent which increases the risk of the invention. The more a company relies on knowledge from others, the more dependent the organisation becomes. Inversely, the more citations an organisation received, the more influential it becomes. From a technological sovereignty perspective this shows that certain organisations have high negotiation power, while other trail and are dependent upon this knowledge for their own innovations.

By representing citations between organisations as a network, we visualized the **dependencies** and influences between organisations in a domain.

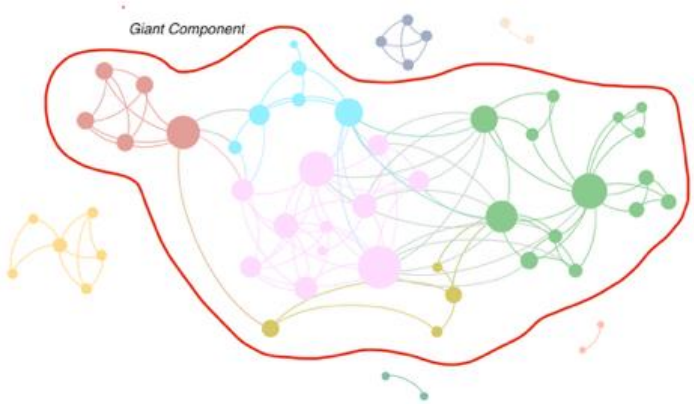
The patent data of this research consists of a directed network. A **directed network** is a pair consisting of a finite set of nodes and a set of directed relationships (called arcs) between distinct nodes. These arcs indicate a one-way connection from one node to another (Jackson, 2008).

Figure 2: *An example of a directed network*



A **'Giant Component'** in a graph refers to the largest connected component that occupies a significant portion of the nodes, where every node can be reached from every other node within this component (Wasserman & Faust, 1994). In this case, the giant component contains the majority of the citations between the companies. Even though other companies are present in the research landscape, they either provide no citations or their patents have not been examined yet. These players were more difficult to analyze since we could not establish a clear link of dependency between the players. The giant component however, contains most of the vital information: showing a clear structure of organisations citing each other. The analysis focuses on the giant component.

Figure 3*: An example of a giant component*



To measure the dependency of a player, we use '**betweenness centrality'**. Betweenness centrality measures the extent to which a particular node lies "between" other pairs of nodes in the network. Nodes with high betweenness centrality act as bridges or brokers in the network, controlling the flow of information or interactions between other nodes because many shortest paths between those nodes must pass through them (Freeman, 1997; Wasserman & Faust, 1994; Brandes, 2001). This indicator was used to find the most central players in the desalination technology. A player that has a high centrality in the network is cited by many players, and these players are closely positioned to it, providing a good measure of influence on the system.

Furthermore, the **weighted in-degree** was analyzed. A weighted in-degree of a node in a directed graph is the sum of the weights of all the incoming edges to that node (Wasserman & Faust, 1994**)**. Indegrees and outdegrees are useful measurements for many different types of networks and relations. A patent with high in-degree often represent fundamental technologies or core inventions upon which many later patents build. Also, the citations act as links of knowledge flow. A high in-degree indicates a significant point of knowledge diffusion within the technological domain. Apart from the most central players, also the players with important patents were highlighted in this research.

The ratio between the weighted in-degree and weighted out-degree was calculated to determine the **sovereignty grade**. The higher the out-degree, the more the entity cites other entities within the database. This indicates a greater reliance on or influence from existing knowledge and technologies. In the context of patents, a high out-degree often suggests that the patent builds upon a substantial body of prior art. The ratio between the weighted in-degree and weighted out-degree was used as a determining factor of sovereignty.

The whole analysis has been performed with open-source program Gephi. Gephi is a known program that can display and analyze large networks.

3.4 Expert interviews

To deepen the understanding of the results from this research, interviews with business professionals were conducted. Expert interviews provide additional insight and perspectives on potential water desalination technologies from individuals that have a deep understanding of the topic. Publicly available data does not always allow for an in-depth vision of value chains and the dependencies between players for specific goods. The interviews were conducted to provide a more in-depth analysis of the dependencies between countries. Patents are a valuable source of information and often used for the analysis of technical expertise in emerging technologies through (OECD, 2018). But, patent data presents some limitations as it only measures the output of the assignees and not the technologies under development. Additionally, not all technological developments yield inventions that are eligible for patent protection, and companies do not seek patents for all of their innovations (OECD, 2018). The expert interviews contribute to reduce this limitation.

For this purpose the thesis focused on companies active in the development of water desalination technologies. Patent data was used to identify these players and interviews were conducted to paint a more in-depth analysis of the value chain in which they operate and to which extend they rely on sources from other countries. This information complements the more technological analysis performed based on the patents.

Initial contact has been established with institutions and practitioners who have made significant contributions to the subject. Snowball sampling was used to involve more interviewees, by asking for relevant contacts in interviews.
A semi-structured interview guide was developed to facilitate the interviews to ensure free answer space for respondents. The semi-structured interview format allowed for a focus on the interviewee's unique perspective and insights into the topic (Clark et al, 2021). The questions were based on insights from the exploratory literature study and aimed to understand new developments within the industry, that may not yet be published.
Before the interview, consent was asked for recording and transcribing for further research to ensure transparency and ethical procedures. This procedure sought to facilitate accurate data gathering while safeguarding the participants' privacy and confidentiality. A transcript of the conversation was sent to the participants via email after the interviews, allowing them a chance to examine it and make any required adjustments or clarifications. Biases during the interviews may occur, as it is a personal activity. Social desirability bias occurs when participants respond to questions in a way that they believe is socially acceptable or desirable, rather than honestly reflecting their true thoughts or feelings. During the interviews, the interviewer minimized social desirability bias by creating an environment of trust and confidentiality. Confirmation bias occurs when researchers focus on evidence that confirms their existing beliefs and ignore or downplay evidence that contradicts them. The interviewer minimized confirmation bias by actively seeking out disconfirming evidence and being open to alternative perspectives.

3.5 Data analysis

The data collected from the explorative literature review, patent research and expert interviews were analyzed separately and then synthesized to answer the research question. The data from the explorative literature review was analyzed using a thematic analysis approach to identify patterns, themes, and insights. This was done through a six-step process by Braun and Clark (2006) which involved systematically organizing the data into relevant categories and identifying, reviewing, and defining themes (Clark et al.,

2021). The literature review revealed the environmental impact of the five desalination technologies.
The patent data was analyzed with the technique of Caravella et al. (2021), measuring Revealed Technological Advantages (RTA) between countries. This technique assessed the relative positions of countries when it comes to water desalination technologies.
The data from the expert interviews were analyzed using a content analysis approach (Neuendorf, 2016) to identify key ideas, themes, and perspectives. Commonalities, divergences, and distinctive perspectives relating to trade-offs of the three factors of water desalination technologies in the European union were revealed through classification and categorization.
The findings from the data sources were synthesized to provide a comprehensive answer to the research question. This data synthesis made it possible to provide well-informed suggestions for creating policies about the multiple factors that belong to policies about the amalgamation of environment aspects and innovative, economically justifiable water desalination technologies.

3.6 Research quality

The quality of the research was measured by four criteria, suitable for inductive qualitative research; reliability, replicability, internal validity, and external validity (Clark et al., 2021; Yin, 2009). These criteria are important because it reduces research bias and improves academic standards. With knowledge of these criteria, measures were taken to reduce bias throughout the process, and readers will better understand inevitable influences on the research itself. Table 1 shows how the four criteria are applied in this research.

Table 1: *Quality Indicators*

Type	Definition	Tactic	Application
Reliability	If the operations of the study were to be performed again, the study would have the same outcome.	Use methodology protocol	The methodology is extensively described in this chapter according to widely accepted literature. Additionally, reliability is improved by comparing literature sources and literature with expert sources.
Replicability	The operations of the study can be replicated.	Use methodology protocol	Undertaken steps in the research are described in the methodology and appendixes. The steps can therefore be replicated.
Internal validity	Establish a causal relationship where certain conditions are believed to lead to other conditions.	Pattern matching	Recurring patterns/themes are identified through thematic analysis. Which will establish a causal relationship between concepts.
		Explanation building	The theoretical framework is used to explain the findings from the thematic and content analysis.
External validity	Defining the domain to which specific findings be generalized across different social settings, beyond the study context.	Use theory	Before analysis, the theoretical framework is formed. Hereafter, the general theories are used in the analysis to be able to generalize results to a broader theory. Furthermore, sources are correctly referenced.

**source: Clark et al., 2021; Yin, 2009*

4. Results

In this section, results are presented from the literature review, the patent analysis and expert interviews. The results are aimed at addressing the main research question. After the literature study, each of the five technologies have been analyzed through an citation network analysis, which will be presented sequential order.
The first section starts with an explanation of each technology, to inform the reader about the core basics of each technology. In addition, the worldwide use and sustainability aspects of each technology will be displayed. Then, the chapter will continue with the patent data results of each technology. Sub-section 3.3 described the different input queries that have been used to perform a network analysis on all five technologies. Subsequently, the results of the expert interviews are presented. These results will complement the literature and patent data results by addressing results and giving extra insights which cannot easily be touched upon with only a quantitative patent data analysis. This chapter ends with a takeaway of the main results that will include all five technologies as well as the interview results.

4.1 Literature review results

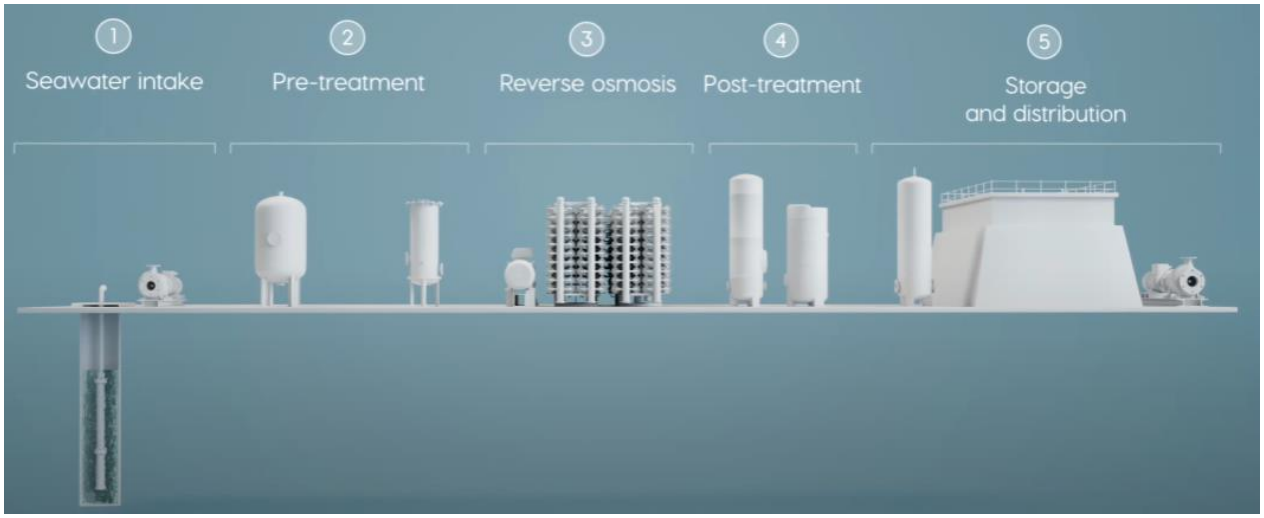
To give the reader a better understanding of the different technologies and its current usage, this chapter has been written. In this section, the key information of each technology will be explained, complemented with an overview of the world's capacity of water desalination.

All desalination processes can be divided into two categories: thermal and membrane based.
Multistage Flash Distillation and Multi-effect Distillation are thermal processes. Reverse Osmosis, Electrodialysis and Nano Filtration are membrane based technologies.

4.1.1 RO

Reverse Osmosis (RO) consists of 5 steps: water intake, pre-treatment, reverse osmosis, post-treatment and storage and distribution.

Figure 4: *RO's Process Steps*



*source: https://www.youtube.com/watch?v=MC6Qrr58SmA&ab_channel=ACIISIGobiernodeCanarias)

Water intake
Water intake happens through open intakes or with wells. Open intakes all for a large water flow to be collected. Wells create a more stable feed as the water input is already been naturally filtered in the ground. The water is then pumped into the pre-treatment stage.

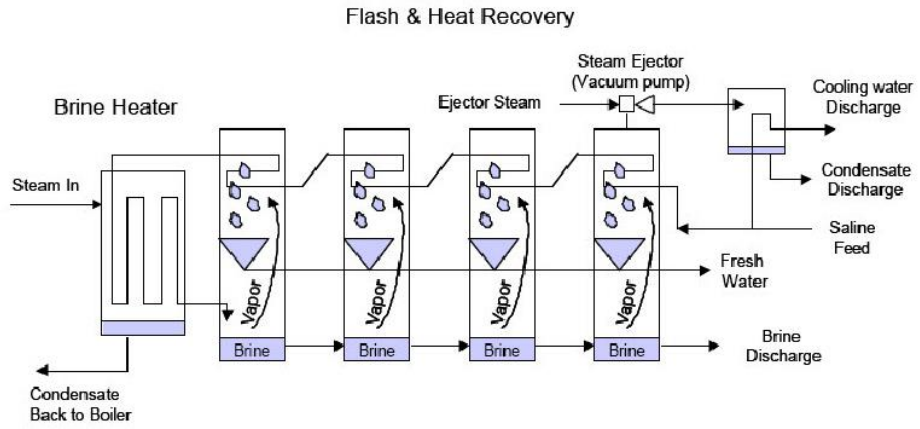
Pre-treatment stage
The water needs to be pre-treated, dependent on the quality of the feed and the physicochemical properties of the water. In most cases, the pre-treatment starts with a filtration using substrates or granulometry. Molecules larger than 20 microns are filtered out. Also, an antiscalant is added to the water to prevent the formation of scale, or crystallized mineral salts. Also, cartridge filters are installed as an additional safety system. These retain particles that have passed the other pre-treatment stages. The filtration size is around 1 to 5 nominal microns. Finally, it is pumped to the membranes, with a pressure between 50 to 60 bar.

Reverse osmosis stage
The membranes consists of racks, composed of a series of pressure vessels. Each vessel contains a number of membranes, in series. The water is pressurized into the vessels, forcing the water molecules into the membranes. Around 40 to 45% of the water passes through the membranes' surface and is directed towards the permeate. Over 99.9% of the salt has been rejected by the membranes. The water that has not passed through the membrane leaves the membranes at high pressure. This water stream is called brine. The pressure of the brine is re-used by an energy recovery system, so that the energy can be used for the next amount of water that needs to be filtered. The efficiency is around 95%. The brine will leave the desalination plant at low pressure. The filtered water goes to the post-treatment stage.

Post-treatment
Desalinated water is corrosive, so it needs to be remineralized to achieve a balance in which the pH, alkalinity and calcium levels become homogeneous. The most common technique for mineralizing is CO_2-injection in combination with calcite beds, that adds calcium carbonate to the water. In some countries, chlorine is also added to the water. Then, water can be distributed through hydraulic networks and pumping systems.

4.1.2 MSF
Multi-Stage Flash Distillation (MSF) is a thermal desalination that mimics the natural water cycle. It works by heating salty water to high temperatures and then sending it through a series of compartments, or "stages," that are kept at lower and lower pressures. As the hot water moves through each stage, the sudden drop in pressure causes a small part of it to "flash" (turn into steam right away). The steam is then condensed on heat exchange tubes, which are cooled by the saline feedwater that comes in. The latent heat that comes out during condensation warms up the feedwater that is coming in, which makes the system more energy-efficient. The clean condensate is collected as desalinated water, while the leftover concentrated brine moves on to the next stage, where it is flashed at a lower temperature and pressure. MSF plants often use waste heat from power plants to cut down on energy use.

***Figure 5**: General Process of MED*



**source: Evans & Miller, 2002*

4.1.3 MED

Multi-Effect Distillation (MED) is a thermal desalination technology that produces fresh water from saline sources like seawater. It mimics the natural water cycle by repeatedly evaporating and condensing water in a series of interconnected chambers called "effects."

Heat Input

Saline water enters the first effect, where it is heated by an external steam source (often low-grade waste heat from power plants or industrial processes).

Evaporation

As the water heats, it evaporates, leaving salts and impurities behind. This evaporation typically occurs under vacuum conditions, allowing water to boil at lower temperatures (usually below 70°C), which reduces scaling and corrosion.

Cascading Effects

The steam generated in the first effect then flows into the heat exchanger tubes of the *next* effect. Here, it condenses, transferring its latent heat to the incoming saline water in that effect. This causes the water in the second effect to evaporate, but at a slightly lower temperature and pressure than the first effect. This process repeats through multiple effects, with each subsequent effect operating at progressively lower temperatures and pressures.

Freshwater Collection

The condensed steam (freshwater) from each effect is collected as distilled water.

Brine Discharge

The concentrated brine, containing the rejected salts, is discharged from the last effect.

4.1.4 NF

Nanofiltration (NF) is a pressure-driven membrane separation process that sits between ultrafiltration (UF) and reverse osmosis (RO) in terms of pore size and rejection capabilities. NF membranes have pore sizes in the range of 1-10 nanometers. Unlike RO membranes, which reject almost all dissolved solutes, NF

membranes are designed to selectively reject multivalent ions (like calcium and magnesium, responsible for hardness) and larger organic molecules, while allowing monovalent ions (like sodium and chloride) and smaller molecules to pass through with varying degrees of rejection. This makes NF particularly suitable for water softening, removal of natural organic matter, and the reduction of specific dissolved solids, often with lower operating pressures and energy consumption compared to RO.

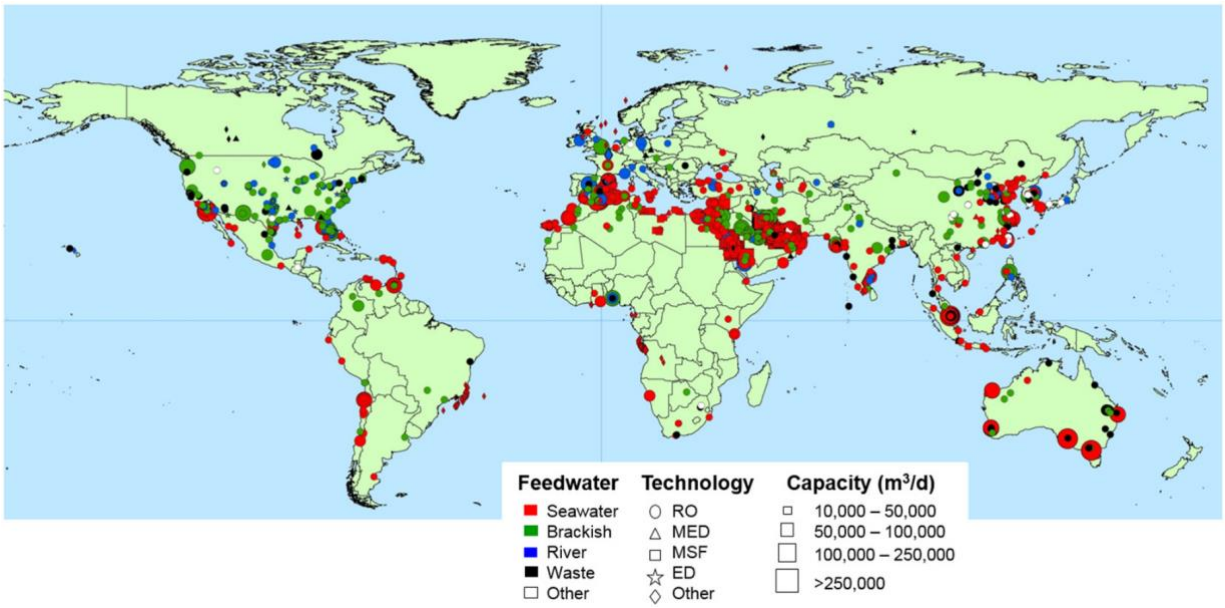
4.1.5 ED

Electrodialysis (ED) is an electrochemical separation process that uses direct electrical current to remove ions from a feed stream. The core of an ED system consists of alternating cation-exchange membranes (which allow positively charged ions, cations, to pass) and anion-exchange membranes (which allow negatively charged ions, anions, to pass), arranged between an anode and a cathode. When an electric potential is applied across these electrodes, the dissolved ions in the feed water are drawn towards the oppositely charged electrodes. Cations pass through cation-exchange membranes into a concentrate stream, while anions pass through anion-exchange membranes into a separate concentrate stream. This leaves a desalinated or "dilute" stream in the compartments between these membranes. ED is particularly effective for desalinating brackish water (water with lower salt concentrations) and can be used for selective ion removal.

4.1.6 The global desalination production

Several researchers have investigated the global desalination production. This paragraph is set out to give an insight of the usage of the different technologies.
Jones et al (2019) demonstrates a distribution as the following: RO: 68.7%, MSF: 17.6%, MED: 6.9%, NF: 3.4% and ED: 2.4%. The next figure shows the global distribution of these numbers.

Figure 6: *Global Distribution of Operational Desalination Facilities and Capacities*

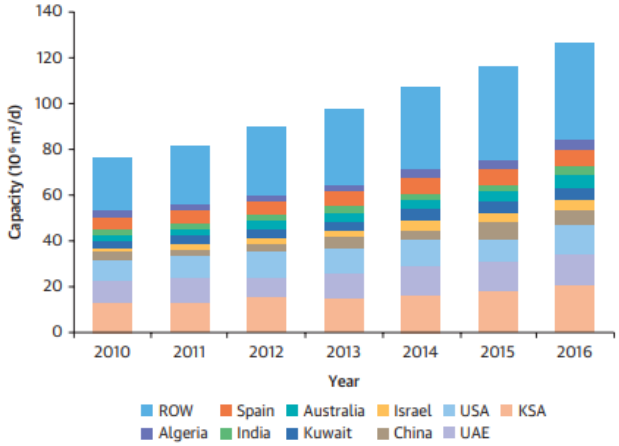


**note: capacity >1000 m3/day by sector user of produced water*
***source: Jones, 2019*

The global desalinated water production is 95.37 million cubic meters per day (Jones et al., 2019). Jones et al. used a global database containing information on approximately 20,000 desalination plants (version of 2018) that is obtained from Global Water Intelligence (GWI) (https://www.desaldata.com).

To confirm the found data by Jones et al, other sources were consulted. World Bank (2019) states a global desalination capacity of more than 120 million cubic meters per day in 2016. See the figure below. It also shows a significant increase in production each year.

Figure 7: *Global Desalination Capacity*



*note: KSA = Kingdom of Saudi Arabia; UAE = United Arab Emirates; ROW = rest of the world; USA = United States of America
** source: World Bank, 2019

Both graphs indicate a very high production facility in the Middle East, Algeria, China and Australia. Also the United States, China, Malaysia, Spain, Peru and India show a strong capacity. Jones et al. divided the capacity in eight geographic regions: 1) East Asia & Pacific; 2) Eastern Europe & Central Asia; 3) Latin America & Caribbean; 4) Middle East & North Africa; 5) North America; 6) Southern Asia; 7) Sub-Saharan Africa; and 8) Western Europe. The total distribution is shown below.

Table 2: *Number, Capacity and Global Share of Operational Desalination Plants by Region, Country Income Level and Sector Use*

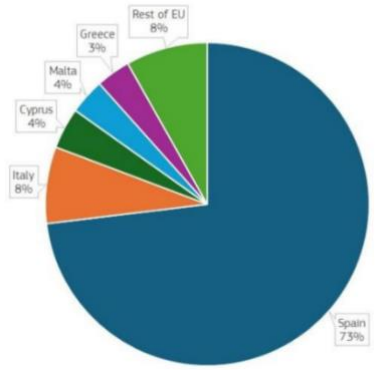
	Number of desalination plants	Desalination capacity	
		(million m^3/day)	(%)
Global	15,906	95.37	100
Geographic region			
Middle East and North Africa	4826	45.32	47.5
East Asia and Pacific	3505	17.52	18.4
North America	2341	11.34	11.9
Western Europe	2337	8.75	9.2
Latin America and Caribbean	1373	5.46	5.7
Southern Asia	655	2.94	3.1
Eastern Europe and Central Asia	566	2.26	2.4
Sub-Saharan Africa	303	1.78	1.9
Income level			
High	10,684	67.24	70.5
Upper middle	3075	19.16	20.1
Lower middle	2056	8.88	9.3
Low	53	0.04	0.0
Sector use			
Municipal	6055	59.39	62.3
Industry	7757	28.80	30.2
Power	1096	4.56	4.8
Irrigation	395	1.69	1.8
Military	412	0.59	0.6
Other	191	0.90	0.4

* source: Jones et al., 2019

The research above shows a general takeaway from the global production and a grasp of the different regions in the world. Next, the desalination capacity of specifically Europe is further elaborated on.
In Europe, the desalination landscape has expanded in recent years. In 2022, the EU has 1901 active desalination facilities, supplying 7,29 million cubic meters of freshwater each day (European Commission, n.d.). 43% used seawater as a source, 47% comes from inland and/or brackish water and 10% comes from treated wastewater.

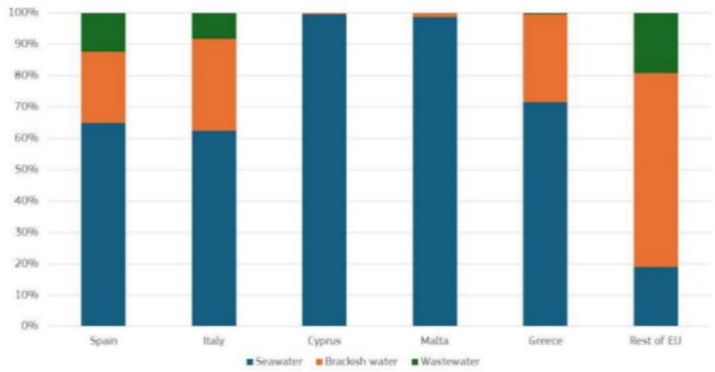
Geographically, the distribution of these plants within the EU is highly concentrated. Spain possesses the most active desalination capacity inside the EU, accounting for 73% of the total. Following Spain, the countries with significant capacities include Italy, Cyprus, Malta, and Greece (figure 8). The installed capacity in the EU has significantly increased over time, particularly during the first decade of the 21st century, when large and extra-large plants were commissioned to serve major coastal cities like Barcelona and Alicante in Spain. Since 2010, the trend has favored the incorporation of small and medium-sized plants. Figure 9 shows the division of type of feed that is being used in Europe.

Figure 8: *Distribution of EU Capacity (2023)*



**note: sea and brackish water*
*** source: DesalData, 2023*

Figure 9: *Feedwater Source for Desalination Plants in the EU*



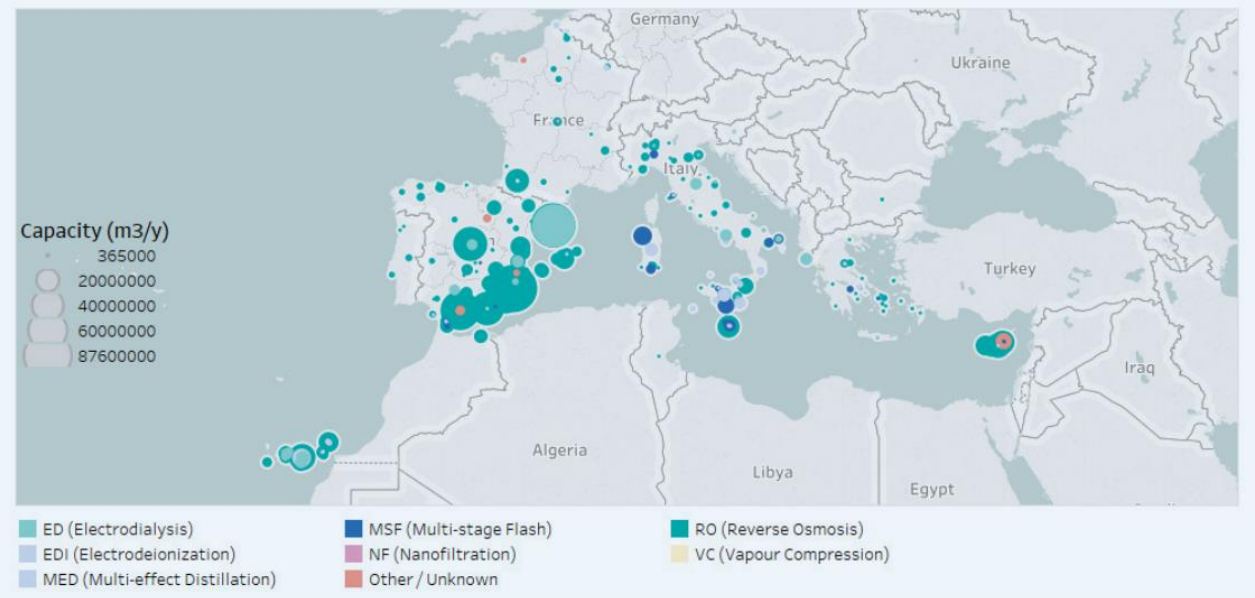
**source: DesalData, 2023*

Figure 8: *Geographical Distribution of Desalination Plants in the EU*

**Source: European Commission, n.d.)*

There aren't any exact numbers to be found on the ratio of the used technologies specifically for the EU. However, a public report by the European Commission shows an overview of the desalination capacity across EU Member States in the Mediterranean region. Below, the geographical overview is shown (Magagna et al., 2019). The Mediterranean desalination capacity accounts for 82% of total EU desalination capacity which gives a good indication of the total usage within the EU.

Figure 9: *Desalination Facilities Across EU Member States in the Mediterranean Region*



**note : freshwater production in m^3/year*
***source : Magagna et al., 2019*

The overview indicates that RO predominates throughout the EU, supplemented by some MSF and MED facilities in Italy and Greece. ED and EDI are less common. Rationally, the majority of facilities are situated in coastal regions.

4.1.7 Sustainability assessment of the technologies

Also, the sustainability part of the technologies have been researched to have good comparison of the different technologies.
There are several research papers in the environmental impact of desalination technologies. Multiple papers have been reviewed and a few of them are used to explain the environmental differences of the technologies.

Several factors can be identified when looking at the environmental impact of desalination. The important factors are: 1) energy-usage and greenhouse gas emissions, 2) brine discharge, 3) chemical use and pollution and 4) intake or marine organisms. The intensity of these aforementioned environmental implications and impacts depends, in their nature and magnitude, on the desalination technology, feedwater type, plant size, energy source, and the local environment (Elsaid et al., 2020). So it is hard to create one fixed overview that shows which technology is the most sustainable.
Looking at the first factor, desalination is inherently an energy-intensive process, which makes it hard to create a sustainable process. The thermal distillation methods typically consume more energy than membrane-based systems like RO. For instance, MSF and MED can utilize 38 kWh/m^3 of thermal input and electrical energy, although RO often exhibits greater energy efficiency (Orfi et al., 2025).

Elsaid et al. (2020) created an overview of the energy requirements.

Table 3: *Specific Energy Requirements of Different Desalination Technologies and Related GHG's*

Technology	Energy, kWh	CO_2, kg	NO_x, g	SO_x, g	PM_{10}, g	Ref.
SWRO	3.7–4.5	3.01	7.20	6.83	0.20	Becker et al. (2010)
	4	1.78	3.87	10.68	2.07	Raluy et al. (2005)
MSF	4 kWh	23.41	28.29	27.92	2.04	
MSF-WH[a]	(+333 MJ)	1.98	4.27	14.79		
MED	2 kWh	18.05	21.41	26.49	1.02	
MED-WH[a]	(+263 MJ)	1.11	2.42	16.12		

[a] WH = waste heat utilized for supply of thermal energy.

**note: based on 1 m^3 of desalinated water*
***source : Elsaid et al., 2020*

Elsaid et al. further describes the environmental impact, based on the composition of the grid energy mix that is being used. Elsaid uses the work of Tarnacki et al. (2012) which focused on comparing different environmental parameters, such as global warming potential GWP as kg-CO2-eq, acidification and more.

Figure 10: *Environmental Parameters Relative to the Grid Energy Mix of Selected European Countries and Renewable Energies*

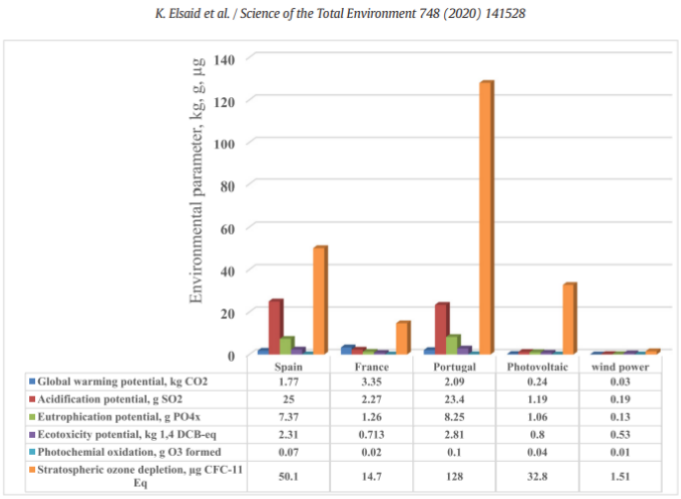


Fig. 4. Environmental parameters relative to the grid energy mix of selected European countries and renewable energies (Tarnacki et al., 2012).

**source: Tarnacki et al., 2012*

A significant environmental issue associated with desalination is the management and disposal of the concentrated waste product known as brine. In 2022, desalination facilities globally produced around 150 million cubic meters of brine daily (European Commission, n.d.). If improperly managed, this highly saline solution, containing dissolved salts and any chemical residues from the pre-treatment process, could be detrimental to the environment. Discharging concentrated salt into natural water bodies can adversely impact marine ecosystems by altering salinity levels, harming aquatic organisms, and potentially resulting in localized environmental degradation (Mohammedi, 2013). In RO systems, diminished water recovery ratios, particularly for seawater, result in substantial quantities of concentrated brine being discharged into the environment.
Jones et al. (2019) provides an overview of the recovery ratio of different feedwater-technology combinations. This gives a reflection on the amount of brine that will be produced with each combination.

Table 4: *Recovery Ratio of Different Feedwater-Technology Combinations Producing Desalinated water*

Feedwater type	Technology							
	RO	MSF	MED	NF	ED	EDI	EDR	Other
Seawater (SW)	0.42	0.22	0.25	0.69	0.86	0.90		0.40
Brackish (BW)	0.65	0.33	0.34	0.83	0.90	0.97	0.90	0.60
River (RW)	0.81		0.35	0.86	0.90	0.97	0.96	0.60
Pure (PW)[a]	0.86	0.35		0.89	0.90	0.97	0.96	0.60
Brine (BR)	0.19	0.09	0.12		0.85			0.40
Wastewater (WW)[b]	0.65	0.33	0.34	0.83	0.90	0.97		0.60

**note I: PW refers to water of a high base quality (low salinity), but that is desalinated primarily for industrial applications requiring very low salinity water (e.g. food processing, pharmaceutical manufacturing).*
**note II: WW refers to reject water from municipal and industrial sources undergoing desalination in specific WW desalination facilities.*
****source: Jones et al., 2019*

In the following section, the patent data results per technology will be displayed.

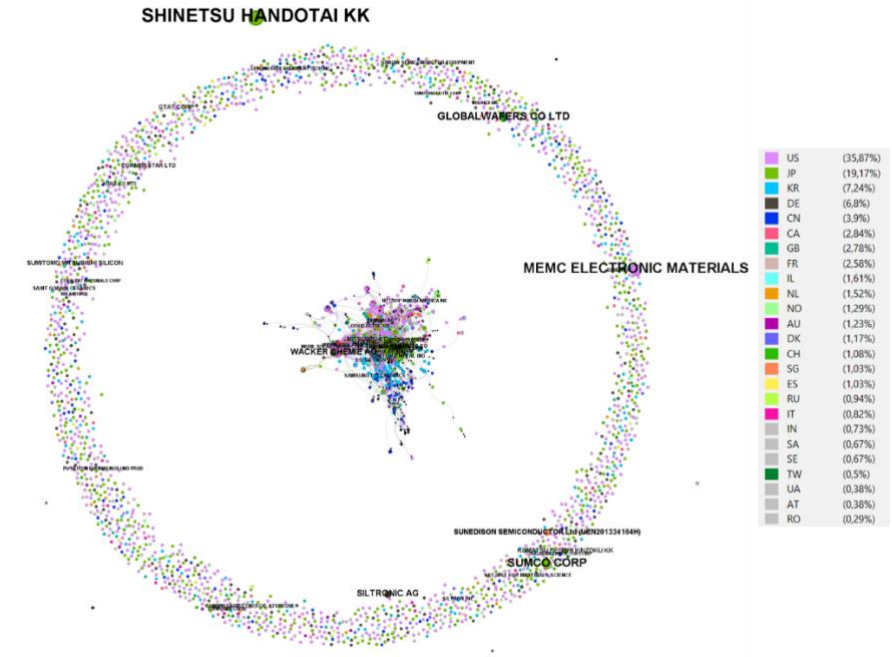
4.1 Patent results of Reverse Osmosis

For Reverse Osmosis, the following query has been used:

class_ipcr.symbol:B01D61/02
AND
((title:(salt) OR abstract:(salt) OR claim:(salt)) OR (title:(seawater) OR abstract:(seawater) OR claim:(seawater)))
AND
(title:(desalination) OR abstract:(desalination) OR claim:(desalination))

This resulted in 1168 patent records and 711 simple families in total. These patent records are used as input for a network analysis. The network analysis has been performed with Gephi. For a full step-by-step analysis overview, see Appendix II.
This network analysis points out the most important players in the RO environment.
Figure 2 shows an overview of all players. The outer circle displays all companies that do not citate other companies. The inner component displays companies that do citate other patents. This inner part is called the 'Giant Component'. A 'Giant Component' in a graph refers to the largest connected component that occupies a significant portion of the nodes, where every node can be reached from every other node within this component (Wasserman & Faust, 1994). In the next steps, the analysis will focus on the giant component. The relationships between the companies in the giant component determine the sovereignty of each company, which is a main focus of this research.
In figure 2, the size of the node shows the amount of patents, found in the used dataset. Shinetsu Handotai, Global Wafers and Memc Electronic Materials are companies with a lot a patents so they might be considered important. However, they have no citations in their patents. This means that, most likely, they tend to not include the needed knowledge of other companies in their patent applications.

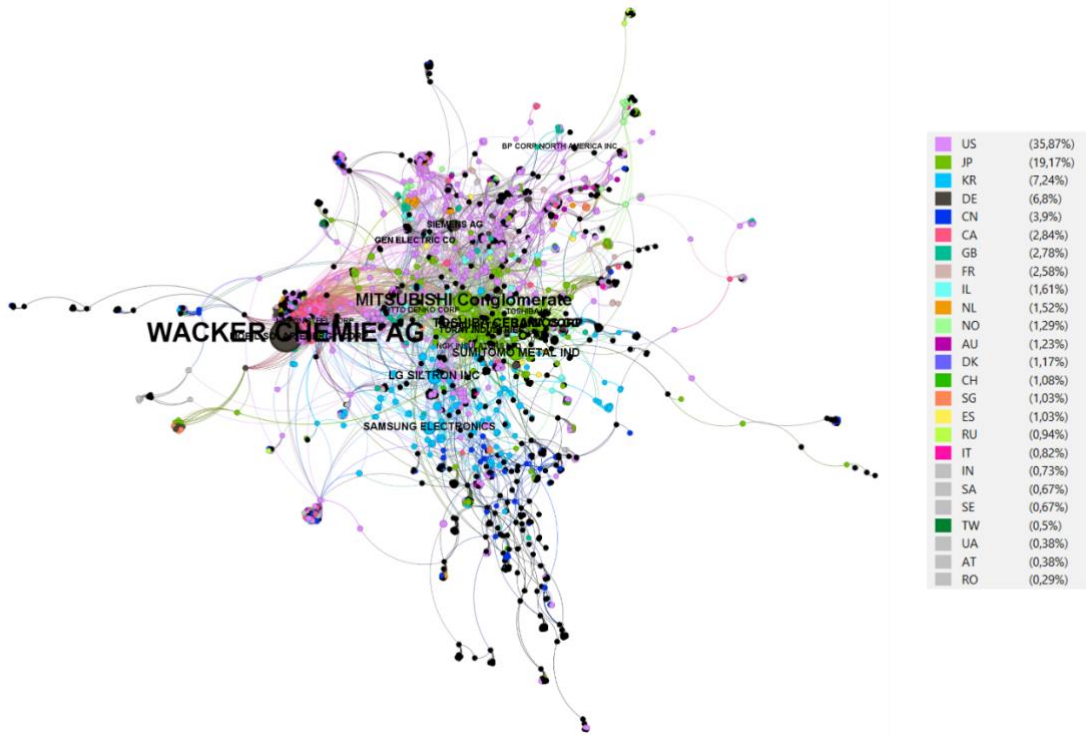
Figure 11: *Reverse Osmosis General Overview*



**Note: company name is shown if amount of patents > 25)*

For a better understanding of the relationships between the companies, the giant component has been analyzed. In figure 14, a full overview of the giant component can be found.

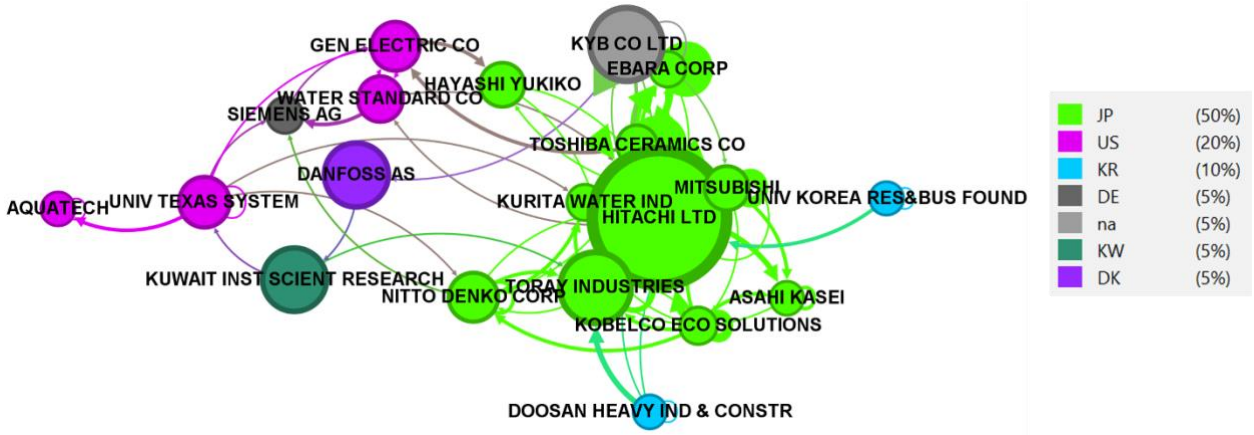
Figure 12: *RO's Giant Component*



**note: node size is based on the amount of patents. Label is shown if a patents > 25*

Within this giant component, several indicators have been calculated to find out the most important players in the field of RO. These indicators are represented in table 5, which will elaborated on further below. The most important indicator is '*betweenness centrality*'. Betweenness centrality is a measure of a company's position within the patent network and its ability to bridge different technological areas. The top 20 have been selected based on this measure. For these players, several indicators have been calculated. These top 20 players have been separately analyzed, to see the dependencies within these players. The overview is shown in figure 15.

Figure 13*: RO's Giant Component Selection*



**note: node size based on betweenness centrality*

The first thing to notice is that Hitachi Ltd exhibits the highest betweenness centrality score. This metric quantifies the frequency with which a node lies on the shortest paths between other pairs of nodes within the network. In the context of patent data, a high betweenness centrality suggests that Hitachi acts as a critical intermediary or bridge, connecting otherwise disparate areas of technological development.
Specifically, this indicates that Hitachi's patents are frequently involved in the pathways linking patents from different companies or technological domains. This positions them as a key player in the flow of information and knowledge across the patent landscape of RO. Furthermore, they hold a degree of control over the diffusion of technological information. Other companies or technologies are more likely to rely on Hitachi's patents to access or connect to other parts of the network. Hitachi may be acting as an 'innovation broker', facilitating the combination of ideas from different technological fields. This suggests a propensity for cross-disciplinary patenting or a role in merging RO technologies. However, Hitachi's central position also implies that it could become a potential bottleneck. Disruptions or changes affecting Hitachi's patent portfolio could have a disproportionate impact on the overall network's connectivity and knowledge flow.
The second thing to notice is that the top 20 players are originating from a select list of countries. Japan, the United States of America and South Korea display as centralized knowledge countries.
Note that KYB CO ltd has no information about its countries and total patents. The information is missing in the database if n/a (not applicable) is noted.

Table 5: *RO's Giant Component Indicators*

Label	All countries	Reference country	Total patents	weighted indegree	weighted outdegree	Sover-eignty grade	Between-ness centrality
HITACHI LTD	JP	JP	50	86	68	1,3	78751,9
TORAY INDUSTRIES	JP;US	JP	42	114	41	2,8	31358,1
WATER STANDARD CO	MH;US	US	9	16	107	0,2	29317,2
KYB CO LTD	n/a	n/a	n/a	4	47	0,1	27826,7
KUWAIT INST FOR SCIENT RES	KW	KW	5	1	18	0,1	23082,7
DANFOSS AS	DK	DK	5	4	2	2,0	22836,5
MITSUBISHI Conglomerate	JP	JP	115	79	68	1,2	22372,0
NITTO DENKO CORP	JP;US	JP	31	57	38	1,5	18075,5
UNIV TEXAS SYSTEM	US	US	11	27	80	0,3	17293,2
TOSHIBA CERAMICS	JP;US	JP	73	44	114	0,4	14516,2
GEN ELECTRIC CO	US	US	42	32	33	1,0	12309,6
EBARA CORP	JP;KR	JP	69	72	85	0,9	12213,0
HAYASHI YUKIKO	JP	JP	1	22	5	4,4	9152,1
SIEMENS AG	DE	DE	46	16	30	0,5	8276,4
UNIV KOREA RES & BUS FOUND	KR	KR	15	10	21	0,5	6611,6
DOOSAN HEAVY IND & CONSTR	KP;KR;US	KR	20	8	26	0,3	6474,1
ASAHI KASEI	JP	JP	6	26	10	2,6	5943,5
KOBELCO ECO SOLUTIONS CO	JP	JP	5	21	36	0,6	5643,1
AQUATECH	US	US	3	6	27	0,2	5491,0
KURITA WATER IND	JP	JP	14	78	17	4,6	4890,7

In table 5 are all indicators displayed of the top 20 players. Besides Hitachi, Toray Industries is also big company with a high betweenness centrality. Next to that are four smaller companies with a high betweenness centrality.

The weighted indegree score is also displayed in the table below. The indegree of a patent is the number of other patents that cite it. A high indegree suggests that the patent is highly influential and widely referenced. The 'weighted indegree' is a more sophisticated measure of patent influence that accounts for the relative importance of citations, providing a more accurate reflection of a patent's impact and significance within a network.
Hayashi Yukiko must be highlighted in this context. This person has a relatively high weighted indegree, even with only 1 patent. This indicates that a lot of companies are referring to his/hers patent. Also, Kurita Water Industries has a high indegree while having the lowest betweenness centrality score. So, although they are not in the center of the network, they still possess relevant knowledge. They also possess the highest sovereignty grade.

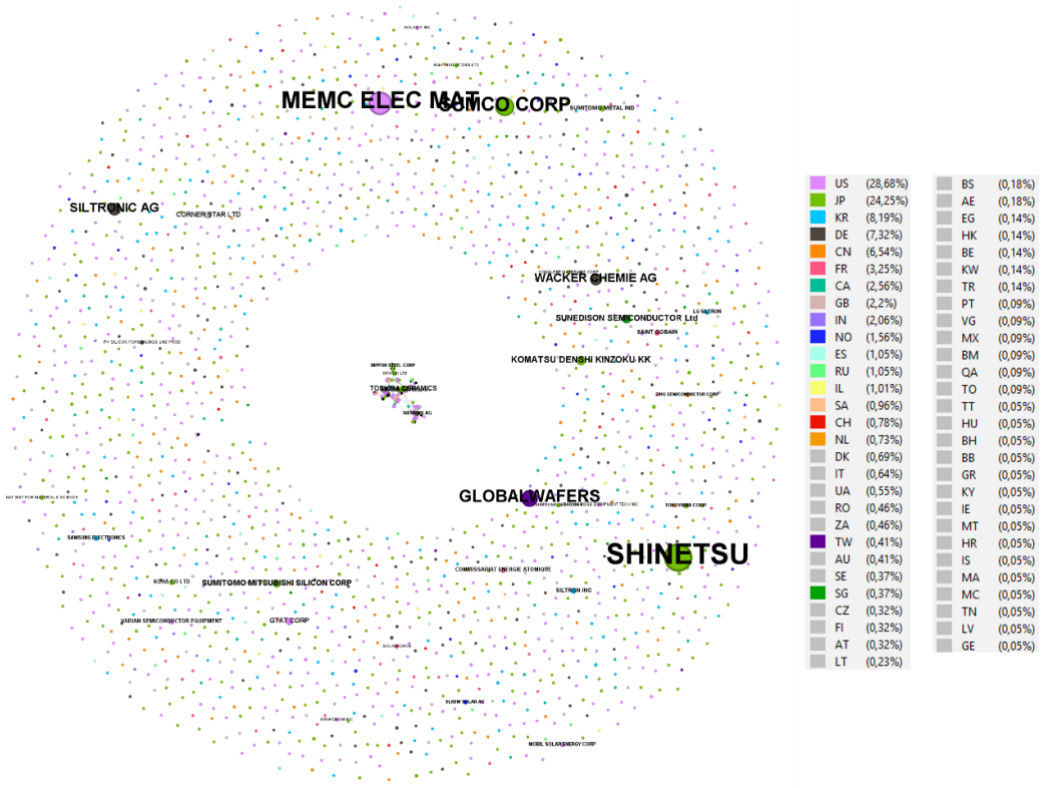
4.2 Patent results of Multistage Flash Distillation

For MSF, the following query has been used:

(class_ipcr.symbol:(C02F1/06) AND (title:(multi-stage) OR abstract:(multi-stage) OR claim:(multi-stage)) AND (title:(salt) OR title:(seawater) OR abstract:(salt) OR abstract:(seawater) OR claim:(salt) OR claim:(seawater)))
OR
(class_ipcr.symbol:(C02F9\/*) AND (title:(flash) OR abstract:(flash) OR claim:(flash)) AND (title:(salt) OR title:(seawater) OR abstract:(salt) OR abstract:(seawater) OR claim:(salt) OR claim:(seawater)))
OR
(class_ipcr.symbol:(B01D3/06) AND (title:(multi-stage) OR abstract:(multi-stage) OR claim:(multi-stage)) AND (title:(salt) OR title:(seawater) OR abstract:(salt) OR abstract:(seawater) OR claim:(salt) OR claim:(seawater)))

This resulted in a total of 390 patent records and 336 patent families in total.

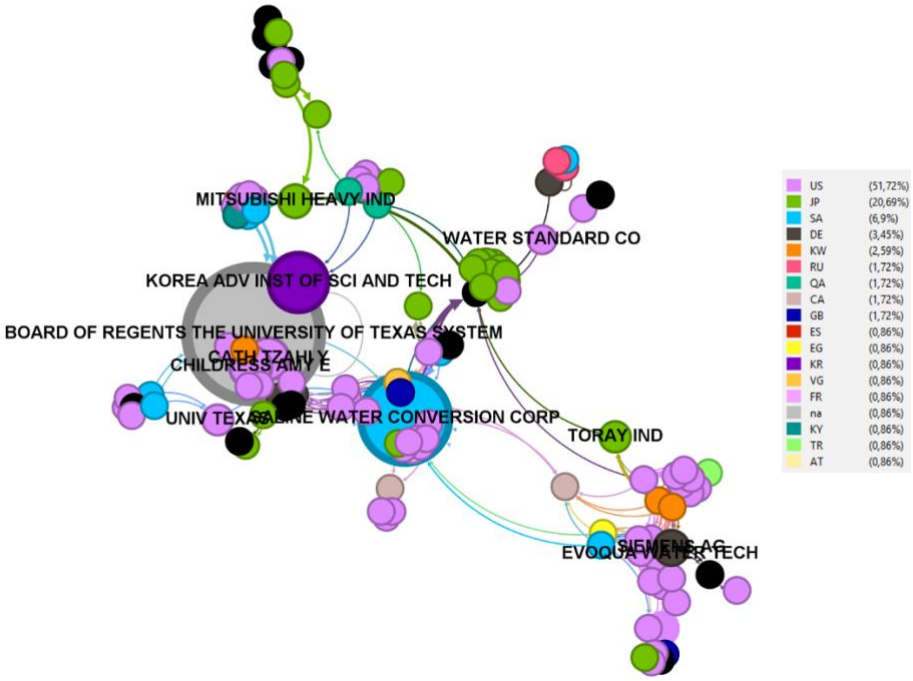
Figure 14: *MSF Total Overview*



**note: node size is based on amount of patents, the label is shown if the player has at least 25 patents*

This resulted in the following 'giant component', see figure 17.

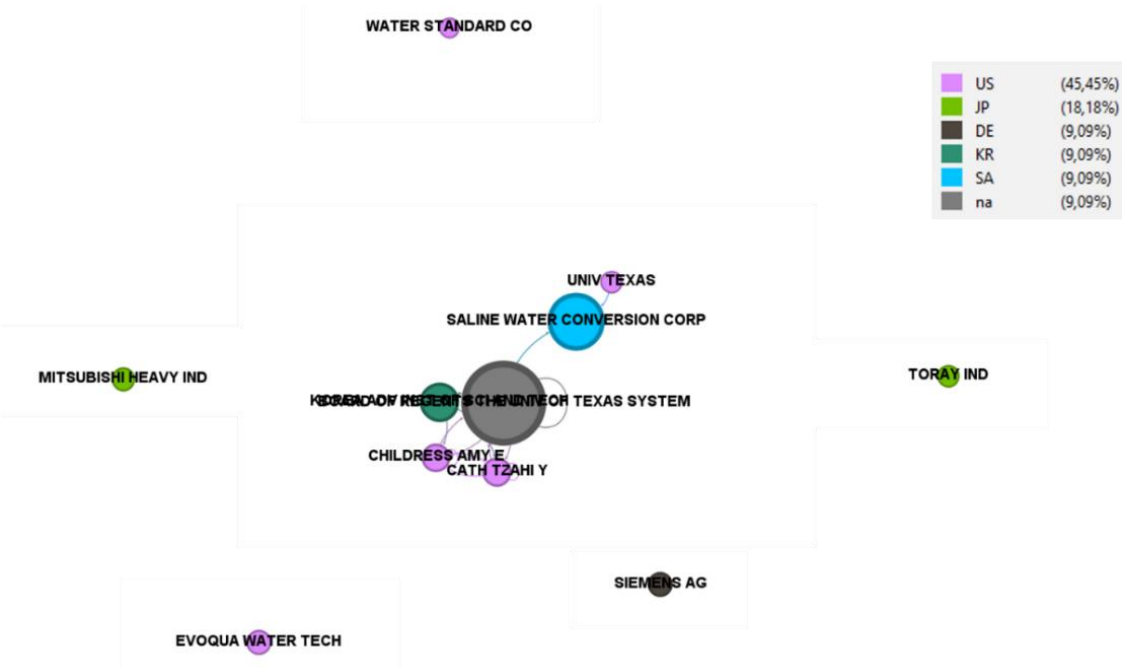
Figure 15: *MSF Giant Component*



**note: node size based on betweenness centrality, label if betweenness centrality > 1*

An selective overview of only the players with a betweenness centrality score is shown below, in figure 18.

Figure 16: *MSF's Main Players of Giant Component*



**note: node size based on betweenness centrality*

The Board of Regents the University of Texas System is the most central player for Multistage Flash Distillation. Also, the University of Texas is one of the other main players in MSF. As seen at RO, the University of Texas System is also an important player there.
Furthermore, almost all players have a similar amount of patents within the MSF environment, with an exception of Siemens, which has far more patents than others.
Besides that is must be noted that Saline Water Conversion Corporation has a very high in/out ratio. This means that they have a very high sovereignty.

Table 6: *MSF's Most Important Players*

Label	all countries	reference country	total patents	weighted indegree	weighted outdegree	Sover-eignty grade	Between-ness centrality
BOARD OF REGENTS THE UNIV OF TEXAS SYSTEM	n/a	n/a	n/a	18	7	2,6	50,0
SALINE WATER CONVERSION CORP	SA	SA	7	23	1	23,0	29,0
KOREA ADV INST OF SCI AND TECH	KR	KR	3	2	3	0,7	15,0
CATH TZAHI Y	US	US	4	12	6	2,0	7,0
CHILDRESS AMY E	US	US	3	12	6	2,0	7,0
EVOQUA WATER TECH	US	US	3	8	1	8,0	4,0
SIEMENS AG	DE	DE	45	8	1	8,0	4,0
MITSUBISHI HEAVY IND	JP	JP	16	10	2	5,0	3,0
TORAY IND	JP;US	JP	10	3	1	3,0	2,0
UNIV TEXAS	US	US	7	2	1	2,0	2,0
WATER STANDARD CO	US	US	3	1	1	1,0	1,0

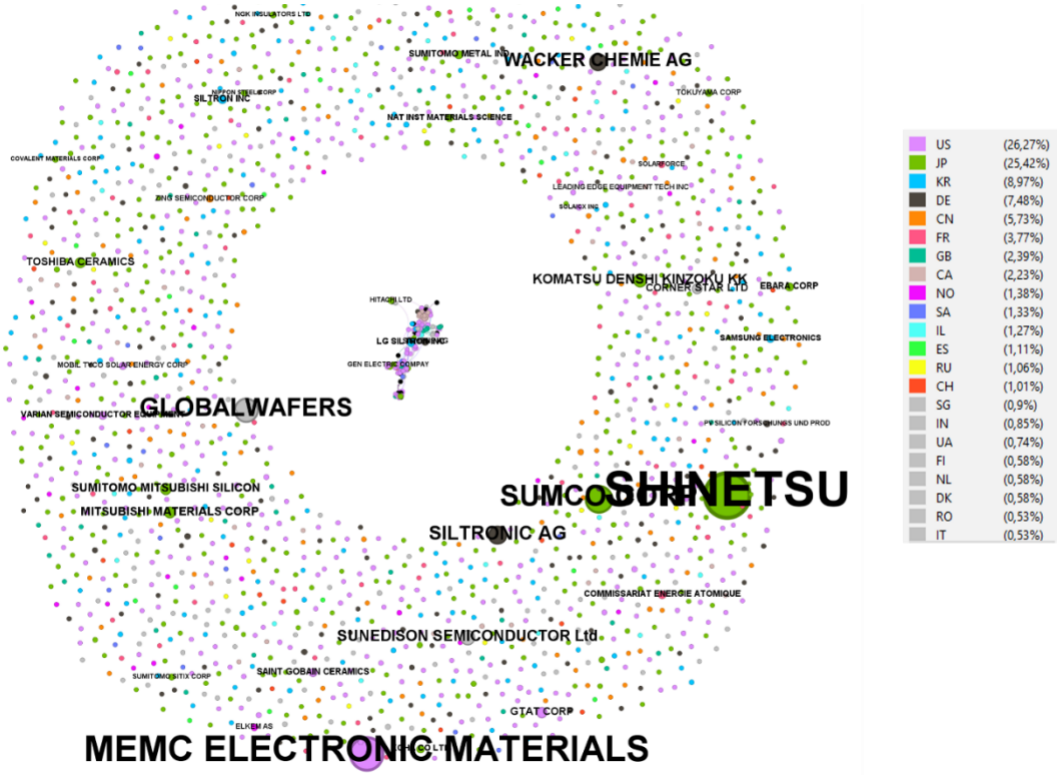
4.3 Patent results of Multi-Effect Distillation

For MED, the following query has been used:

(title:("multi effect distillation") OR abstract:("multi effect distillation") OR claim:("multi effect distillation"))
AND
((title:(salt) OR abstract:(salt) OR claim:(salt)) OR (title:(seawater) OR abstract:(seawater) OR claim:(seawater)))
AND
(title:(desalination) OR abstract:(desalination) OR claim:(desalination))

This resulted in a total of 160 patent records, 132 patent families in total. These patent records are used as input for a network analysis. This network analysis points out the most important players in the MED environment.
Figure 19 shows an overview of all players. Also in this case, the biggest companies are not part of the giant component. It does show that Global Wafers, Wacker Chemie AG, Sumco Corporation, Shinetsu and Memc Electronic Materials possess a lot of patents in the MED development.

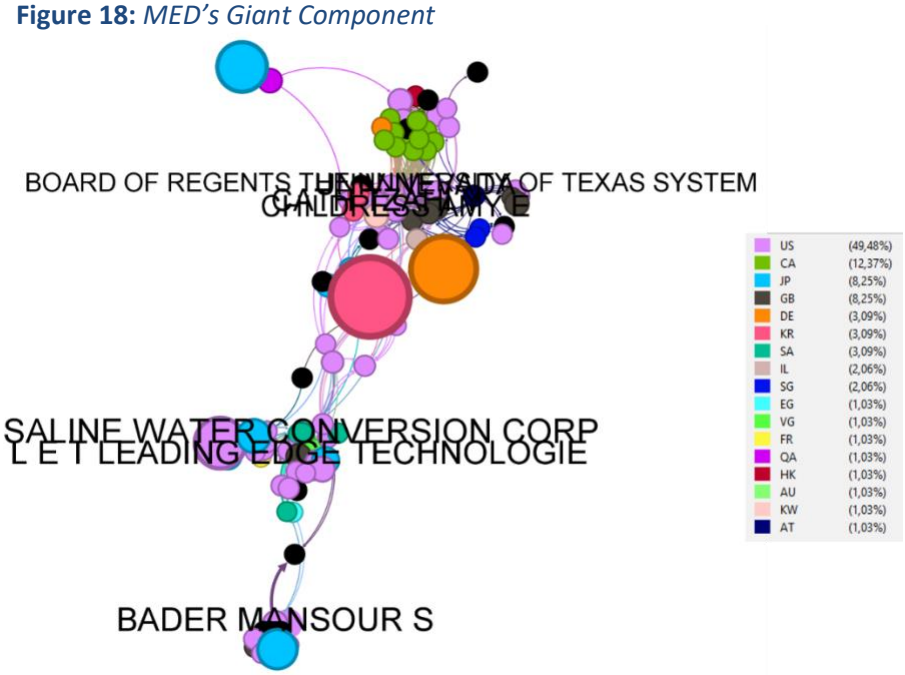
Figure 17: *MED Overview All Patents*



**note: node size based on amount of patents*

Continuing with the giant component only, this results in the following graph.

Figure 18: *MED's Giant Component*



**note: node size based on the amount of patents, label is shown if betweenness centrality > 0*

The node size is based on the amount of patents possessed by the company. Within the giant component, several indicators have been calculated. Betweenness centrality is the focus of the research and only seven players have a betweenness centrality score in the MED database. These players are highlighted in figure 21.

Figure 19: *MED's biggest players in the Giant Component*

**note: node size is based on betweenness centrality*

This figure shows that only a few players are centered in the MED development of water desalination. One of the main differences with the other technologies is that these central players only have a 'handful' of patents in total. It must also be noted that Board of Regents The University of Texas System is also an important player in the RO environment.

Table 7: *MED's Giant Component Overview*

Label	All countries	Reference country	Total patents	weighted indegree	weighted outdegree	Sovereignty grade	Between-ness centrality
UNIVERSITY OF TEXAS SYSTEM	US	US	1	38	17	2,2	206,7
SALINE WATER CONVERSION CORP	SA	SA	7	29	1	29,0	205,0
L E T LEADING EDGE TECHNOLOGIES	GB;IM	GB	6	13	13	1,0	199,0
CATH TZAHI Y	US	US	5	25	16	1,6	42,7
CHILDRESS AMY E	US	US	4	25	16	1,6	42,7
UNIV NEVADA	US	US	4	13	16	0,8	26,0

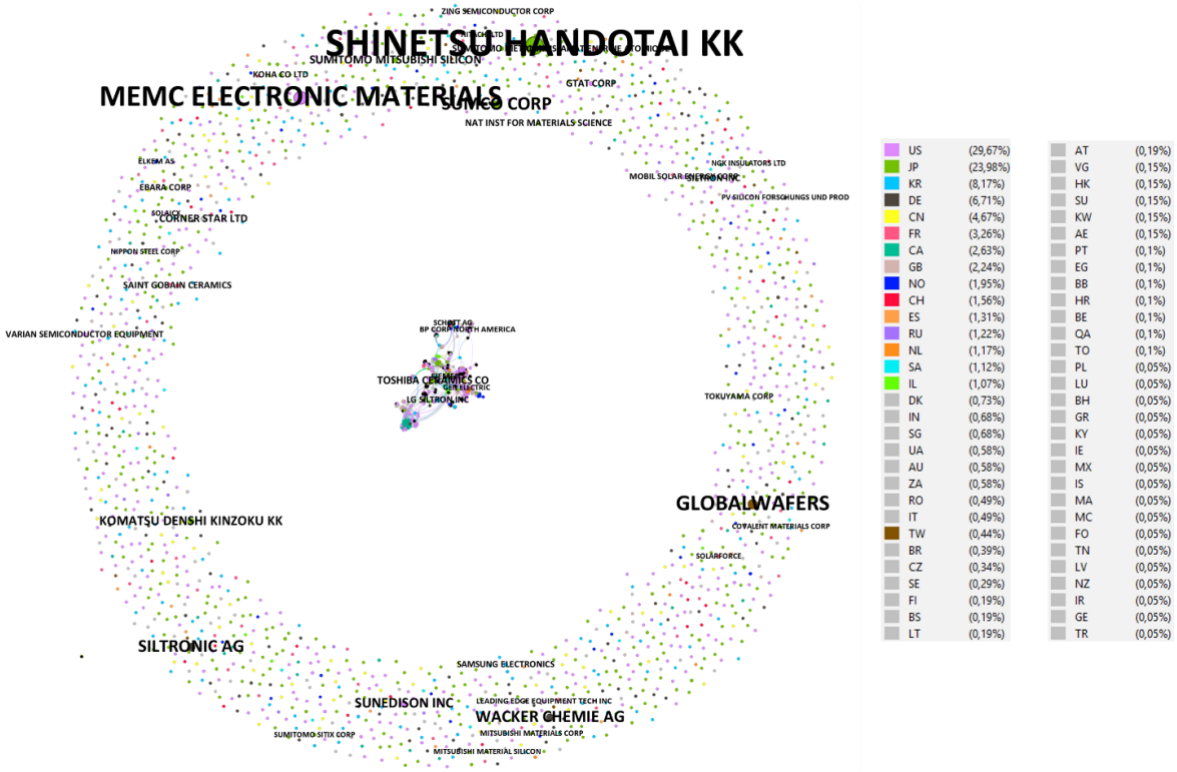
4.4 Patent results of Nano Filtration

For NF, the following query has been used:

(title:(nano) OR abstract:(nano) OR claim:(nano))
AND
(title:(desalination) OR abstract:(desalination) OR claim:(desalination))
AND
(title:(filtration) OR abstract:(filtration) OR claim:(filtration))
AND
((title:(salt) OR abstract:(salt) OR claim:(salt)) OR (title:(seawater) OR abstract:(seawater) OR claim:(seawater)))

This resulted in a total of 136 patent records, 100 patent families in total.
Figure 22 shows an overview of all players. The outer circle displays all companies that do not citate other companies. The inner component displays the 'Giant Component'. In the next steps, the analysis will focus on the giant component. The relationships between the companies in the giant component determine the sovereignty of each company, which is a main focus of this research.
In figure 22, the size of the node shows the amount of patents, found in the used dataset. Shinetsu Handotai, Global Wafers and Memc Electronic Materials are companies with a lot a patents so they might be considered important. However, they have no citations in their patents. This means that, most likely, they tend to not include the needed knowledge of other companies in their patent applications.

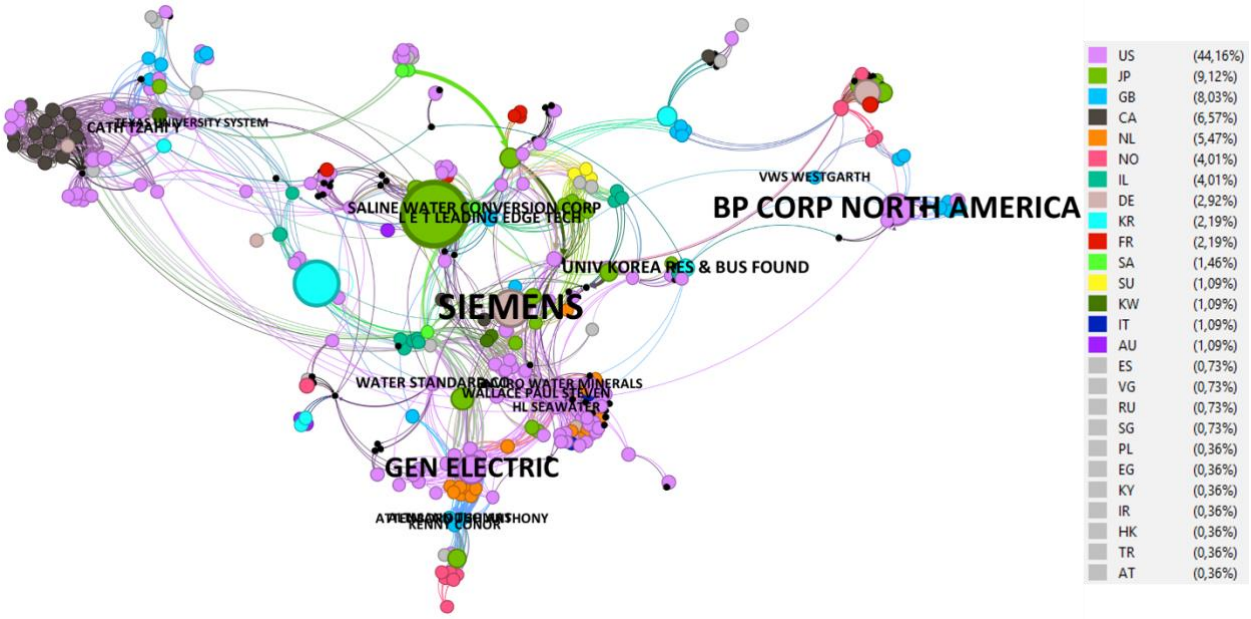
Figure 20: *NF General Overview*



** note: node based based on amount of patents, label if amount of patents >25*

Next, we will dive deeper into the Giant Component. **Figure 23** shows the Giant Component of the Nano-filtration network.

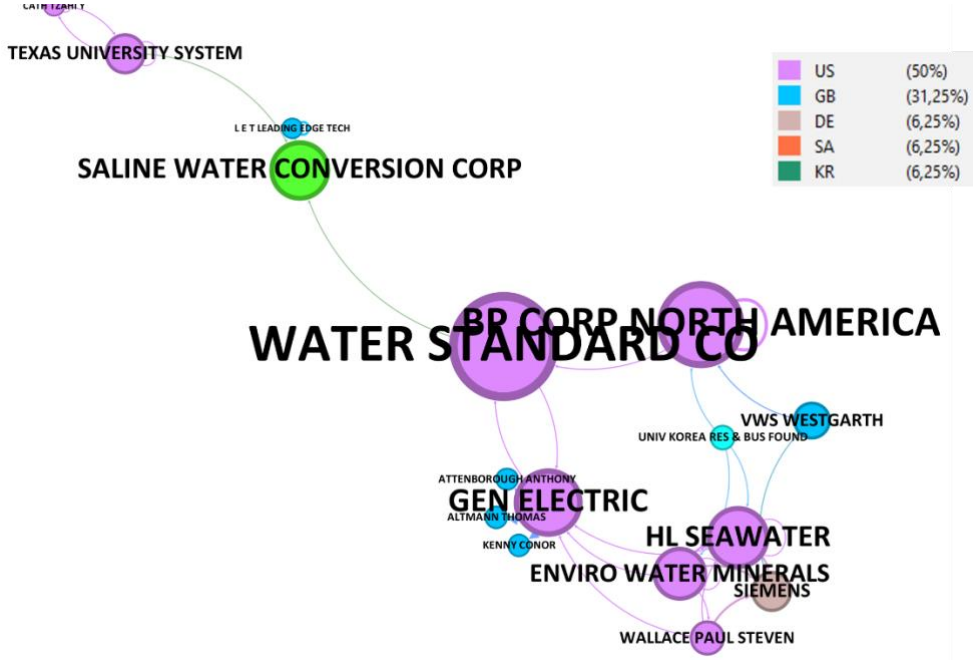
Figure 21: *NF's Giant Component*



**note: node size based on the amount of patents, label shown if betweenness centrality >85*

For all the known actors of figure 23, a more detailed overview is shown below in figure 24. Also, the most relevant indicators are displayed in table 8.

Figure 22: *NF's Biggest Betweenness Centrality Players*



**note: size on betweenness centrality: 10-50)*

These indicators shown that Water Standard Company is the most central player in the field of nano-filtration. Furthermore, it most be noted that BP Corporation is the second most central player. This player does not use the patent to produce drinking water, but it is being used for the production of petroleum.

Table 8: *NF's Most Important Players*

Label	All countries	Reference country	Total patents	weighted in-degree	weighted out-degree	Sovereignty grade	Between-ness centrality
WATER STANDARD CO	MH;US	US	5	8	13	0,6	825,8
BP CORP NORTH AMERICA	GB;US	US	34	16	12	1,3	640
GEN ELECTRIC	US	US	28	7	34	0,2	483,3
HL SEAWATER	US	US	2	13	88	0,1	438,1
SALINE WATER CONVERSION CORP	SA	SA	7	26	5	5,2	417,0
ENVIRO WATER MINERALS	US	US	2	9	92	0,1	361,8
TEXAS UNIVERSITY SYSTEM	US	US	1	28	13	2,2	253,0
SIEMENS	DE	DE	44	13	5	2,6	249,0
VWS WESTGARTH	GB	GB	2	2	3	0,7	225,0
WALLACE PAUL STEVEN	US	US	3	9	88	0,1	202,1
UNIV KOREA RES & BUS FOUND	KR	KR	9	1	4	0,3	119,3
ALTMANN THOMAS	GB	GB	2	15	8	1,9	98,7
ATTENBOROUGH ANTHONY	GB	GB	2	15	8	1,9	98,7
KENNY CONOR	GB	GB	2	15	8	1,9	98,7
CATH TZAHI Y	US	US	4	24	14	1,7	88,0
L E T LEADING EDGE TECH	GB;IM	GB	6	20	10	2,0	85,9

4.5 Patent results of Electrodialysis

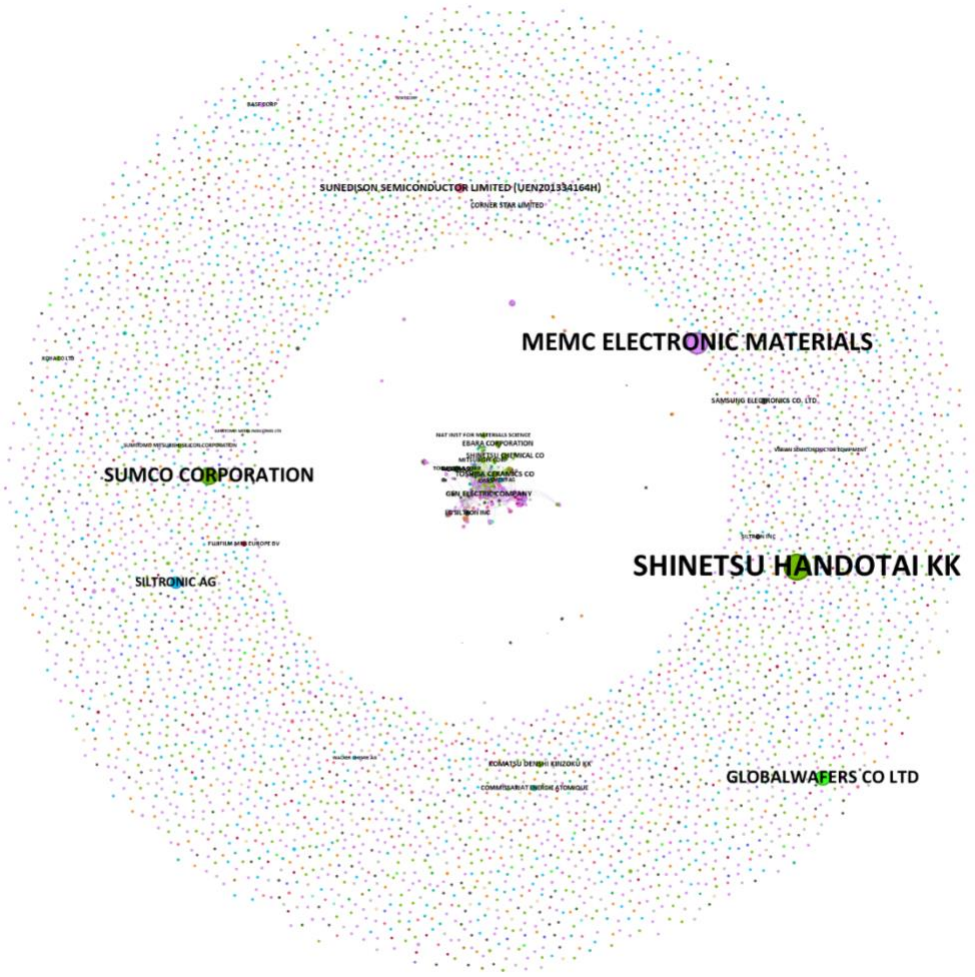
To assess the competitive landscape and technological evolution of electrodialysis, a patent landscape analysis was conducted. The search query, focusing on relevant IPC classes (B01D61/42, B01D61/44, C02F1/469) and keywords related to "seawater" and "salt," yielded 723 patent records. The full query reads as follows:

(class_ipcr.symbol:B01D61/42 AND ((title:(seawater) OR abstract:(seawater) OR claim:(seawater)) OR (title:(salt) OR abstract:(salt) OR claim:(salt))))
OR
(class_ipcr.symbol:B01D61/44 AND ((title:(seawater) OR abstract:(seawater) OR claim:(seawater)) OR (title:(salt) OR abstract:(salt) OR claim:(salt))))
OR
(class_ipcr.symbol:C02F1/469 AND ((title:(seawater) OR abstract:(seawater) OR claim:(seawater)) OR (title:(salt) OR abstract:(salt) OR claim:(salt))))

This query input resulted in 723 patent records in total.
A network analysis on these 723 patent records has been performed to identify key players and their

technological influence within the electrodialysis domain.
Figure 25 is the total network coming out of the data, showing an overview of all players. Also, players who do not citate or are being citated. The node size is related to the amount of patents. The bigger the node, the more patents a company has.
The graph highlights prominent players, with node size indicating the total number of patents held by each company. Companies such as Sumco Corporation, Shinetsu and MEMC Electronic Materials demonstrate a strong patent portfolio in this field, suggesting significant R&D investment and a potential leadership position.

Figure 23: *General Overview of Electrodialysis*

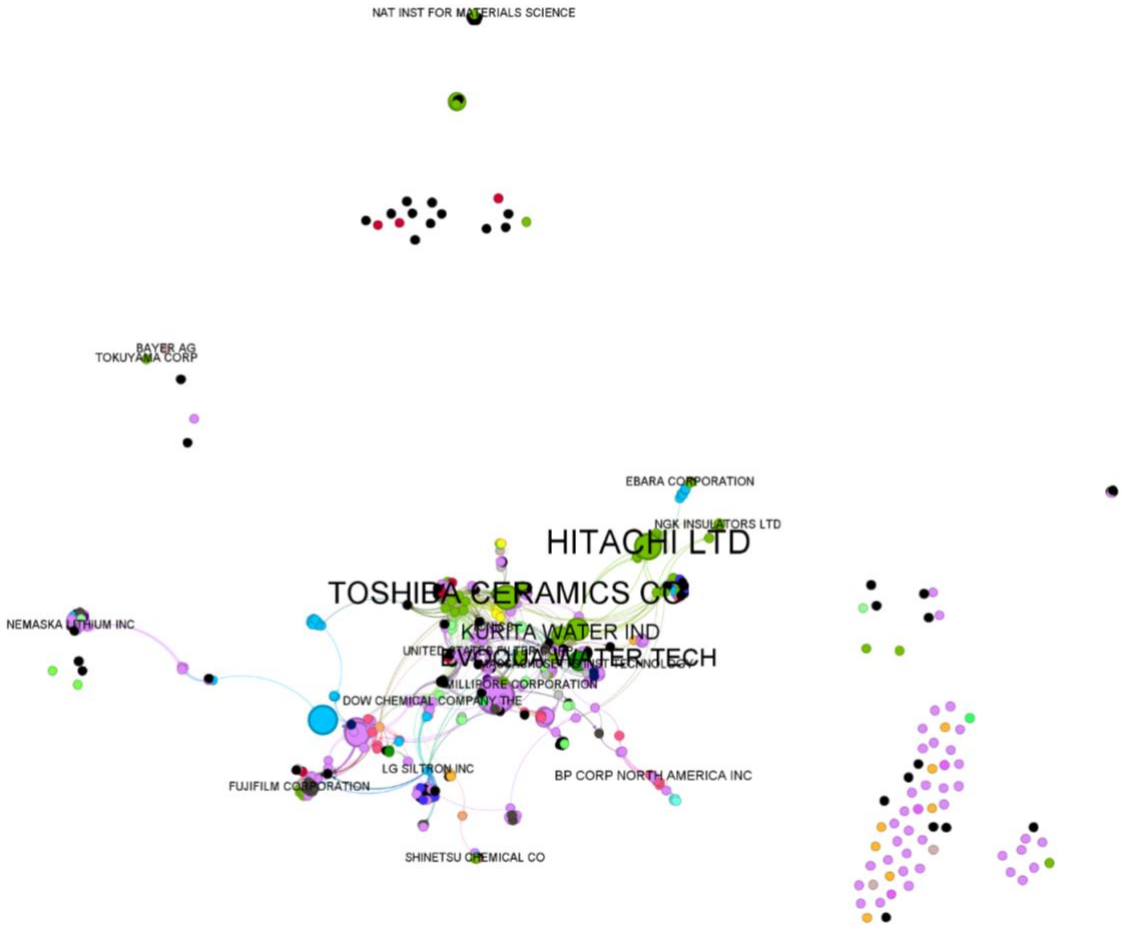


**note: company name is shown if amount of patents > 50*

All companies in the outer circle do not citate other patents so these companies are excluded from the further research. It is not possible to do research about their dependencies on other patents simply because they do not citate others.

Figure 26 highlights the inner component which is called the 'giant component'. These companies citate other patents and so do rely on other companies' expertise to develop their technology.
A 'Giant Component' in a graph refers to the largest component that occupies a significant portion of the nodes, where every node can be reached from every other node within this component.

Figure 24: *The Giant Component of Electrodialysis*



**note: node size based on amount of patents, label is shown if patents > 25*

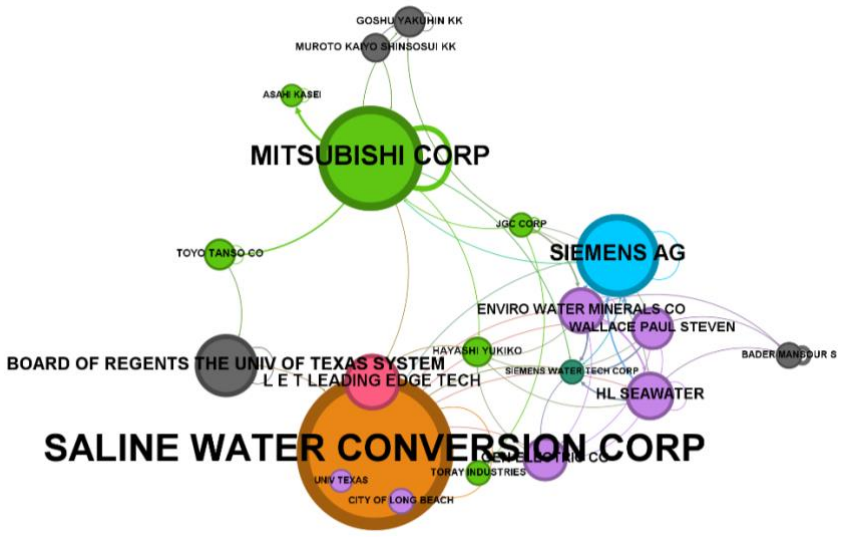
Within the giant component, several indicators have been conducted to find out the key players in this technology. The most important indicator is '*betweenness centrality*'. Betweenness centrality is a measure of a company's position within the patent network and its ability to bridge different technological areas. The top 16 have been selected based on this measure. For these players, several indicators have been calculated. You will see an overview in table 9. Companies with high betweenness centrality, such as Saline Water Conversion Corporation and Mitsubishi Corporation, may play a crucial role in connecting disparate areas of innovation and facilitating knowledge transfer within the electrodialysis field.

Table 9: *ED's Most Important Players*

Label	all countries	reference country	total patents	weighted indegree	weighted outdegree	Sovereignty grade	Between-ness centrality
SALINE WATER CONVERSION CORPORATION	SA	SA	7	22	33	0,7	7929,0
MITSUBISHI CORP	JP;US	JP	199	22	77	0,3	4971,3
SIEMENS AG	DE;US	DE	57	13	23	0,6	3689,2
BOARD OF REGENTS THE UNIVERSITY OF TEXAS SYSTEM	n/a	n/a	n/a	17	15	1,1	2521,6
L E T LEADING EDGE TECHNOLOGIES	GB	GB	4	9	11	0,8	2142,5
HL SEAWATER HOLDINGS LLC	US	US	3	14	90	0,2	1702,9
ENVIRO WATER MINERALS CO	US	US	7	13	95	0,1	1585,7
GEN ELECTRIC COMPANY	US	US	107	16	39	0,4	1450,7
WALLACE PAUL STEVEN	US	US	3	8	90	0,1	1375,6
GOSHU YAKUHIN KK	n/a	n/a	n/a	14	6	2,3	710,0
TOYO TANSO CO	JP	JP	37	4	9	0,4	701,5
HAYASHI YUKIKO	JP	JP	1	20	12	1,7	658,7
MUROTO KAIYO SHINSOSUI KK	n/a	n/a	n/a	1	4	0,3	586,0
CITY OF LONG BEACH	US	US	2	4	15	0,3	421,1
BADER MANSOUR S	n/a	n/a	n/a	12	12	1,0	414,0
TORAY INDUSTRIES	JP;US	JP	16	27	9	3,0	379,3

The visual representation of these players are shown in figure 27.

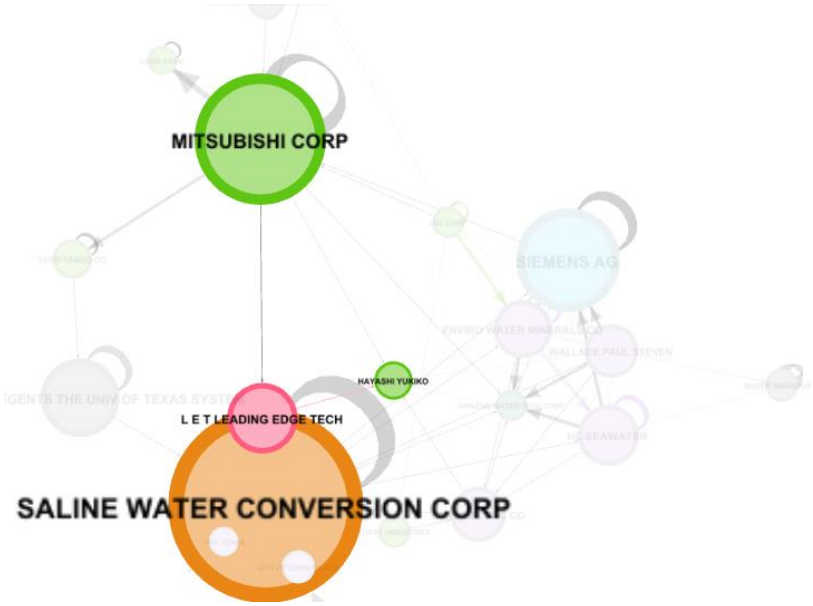
Figure 25: *Electrodialysis Highest Betweenness Centrality*



**note: node size based on betweenness centrality*

As stated before, Saline Water Conversion Corporation and Mitsubishi Corporation have the highest betweenness centrality, meaning they are the most central players in the network.
It must be noted that LET Leading Edge Technologies Inc is interrelated with both Mitsubishi and Saline Water Conversion Corporation, the two companies with the highest betweenness centrality. This indicates that LET has a crucial role in the patent knowledge within the ED environment. Furthermore, Saline Water Conversion Corporation is also an important player in the MED environment, while Mitsubishi holds a significant position in the RO environment.

Figure 26: *Relation Leading Edge Technologies (LET) in ED*



To evaluate the impact and relevance of companies' patent portfolios, an “in-degree” analysis was performed. This metric suggests the degree to which other actors in the field rely upon a company's technology. Companies such as Toray Industries, Saline Water Conversion Technologies and Mitsubishi Corporation emerge as particularly influential, indicating that their innovations have been foundational for subsequent developments in electrodialysis. Also, Hayashi Yukiko only has one patent but still a very high in-degree ratio. This means that a lot of companies rely on her particular patent.

4.6 Overall patent results

The patent analysis has shown that there are a lot of companies involved in water desalination. The analysis shows that each technology is covered with at least 100 patent families, going up to 700. When diving deeper into the data, it shows that some companies are involved in multiple technologies.
One thing that can be concluded is that companies such as Shinetsu Handotai, Global Wafers and Memc Electronic Materials have a lot of patents within the different technological domains. They are the players with the biggest patent portfolios in all five areas. Although, they are not in the giant components of the networks so their patents are not cited by others. This may indicate a certain patent strategy. A company holding a large number of patents that are not being cited by others might be employing several patent strategies, and the lack of citations can be indicative of a few possibilities:

1. Defensive Patenting: Building a "Patent Thicket": The company might be intentionally building a dense portfolio of patents, even on incremental innovations, to create a legal minefield for competitors. The goal

isn't necessarily to have groundbreaking, highly cited inventions, but rather to have enough patents to make it difficult for others to operate without risking infringement. This strategy aims to deter lawsuits and ensure freedom to operate.
2. Blocking Patents: The company might have patents that, while not fundamental or widely adopted, cover specific features or aspects that could be relevant to competitors' future products. By securing these patents, the company can potentially block competitors from incorporating those features or force them into licensing negotiations. These patents might not be cited because the competitors are actively trying to design around them or the technology hasn't become mainstream yet.
The companies Shinetsu, Global Wafers and Memc Electronic Materials are most likely to be building a patent thicket, as they are not being cited by other companies, but do have a dense portfolio of patents. This indicates that these companies are creating a barrier for commercialization for other companies as they must 'hack their way through' by licensing patents.

Another statement that can be concluded is that a few companies and players are central in the network for multiple technologies. For example, L E T Leading Edge Technologies is in the list of most important players for MED, NF and ED. Board of Regents the University of Texas System is in the list for MSF, MED, NF and ED. Toray Industries is in RO, MSF and ED. Water Standard Company is in RO, MSF and NF. Saline Water Conversion Corporation is in MSF, MED, NF and ED. These players most likely possess highly relevant patents which other companies build upon. These companies are originating from the United Kingdom, the United States, Saudi Arabia and Japan, so these countries have a higher sovereignty compared to others. Even though each technology has its own specialties, companies in the central network are involved in multiple technologies. This indicates that these companies have knowledge and know-how about multiple technologies and/or their patents have impact on at least two of the technologies.

4.7 Expert results

The expert interviews are used to triangulate current findings from the patent results, as well an addition and more in-depth analysis of the dependencies between countries.

One of the main takeaways is that the experts point out that Reverse Osmosis and Electrodialysis are the most important and most promising technologies for the future. While RO covers 68.7%, ED only covers 2.4% of world's current water desalination technologies. The experts point out that RO is a more developed and widely used technology and ED is still upcoming. 4 out of 6 experts even state that the most sustainable way would be to use a combination of RO and ED. RO and ED work best on different input. RO has a higher efficiency on salty water, ED has a higher efficiency on less salty or brackish water. RO could be used as a first step in the desalination process, followed by an ED step to further eliminate all salts from the water. A combination of RO and ED can eliminate some posttreatment steps, which makes the total desalination process more sustainable. RO is excellent in removing other components than salt, such as arsenic and ED works better when the amount of salt is getting lower, as RO needs to overcome the osmotic pressure.
So, even though ED is only covering 2,4% of the global production in 2019, it's highly expected that the production of ED will increase in the coming years.
The favored combination of RO and ED is also backed up by academic research. A study investigated the environmental impact (EI) and water footprint (WF) of four seawater (SW) desalination configurations (Alrashidi et al., 2024). Their key findings are as follows: A hybrid SWRO-ED configuration increased water recovery by 18–48 % over standalones. SWRO-ED hybrid configuration has increased membrane replacement by 1.2–3.7 times. Amending SWED with brackish RO reduced CO2 emissions by 41–51 %.

Another takeaway from the interviews is the importance of sustainability while choosing for a certain technology. Most companies try to be sustainable but it is not written down as core principle. Economic efficiency has a higher priority than producing sustainable. This doesn't say that you cannot be doing both. Verweij (2023) shows that electricity cost is the dominant factor in the overall cost, contributing significantly to variations in total water production costs, when looking at SWRO (Verweij, 2023). His insight gives a cost distribution which is as follows: power costs (60%); capital costs (22.7%); chemical costs (10.7%); membrane replacement costs (2,7%) and maintenance costs (4%). The following default operational parameters were used: electricity cost at €0,20/kWh and water temperature at 12,5°C). This shows that 60% of total costs are being used for electricity.

Another takeaway is that experts are convinced that some European countries possess enough technological knowledge to produce drinking water by themselves. But, if a large production facility needs to be build, a company from one of the 'leading' countries will take over. For example, The Netherlands cannot facilitate itself when it wants to build a large seawater desalination site. A company like Suez is suggested as one of the options when a large-scale desalination facility must be build. Suez is a company from French origin.

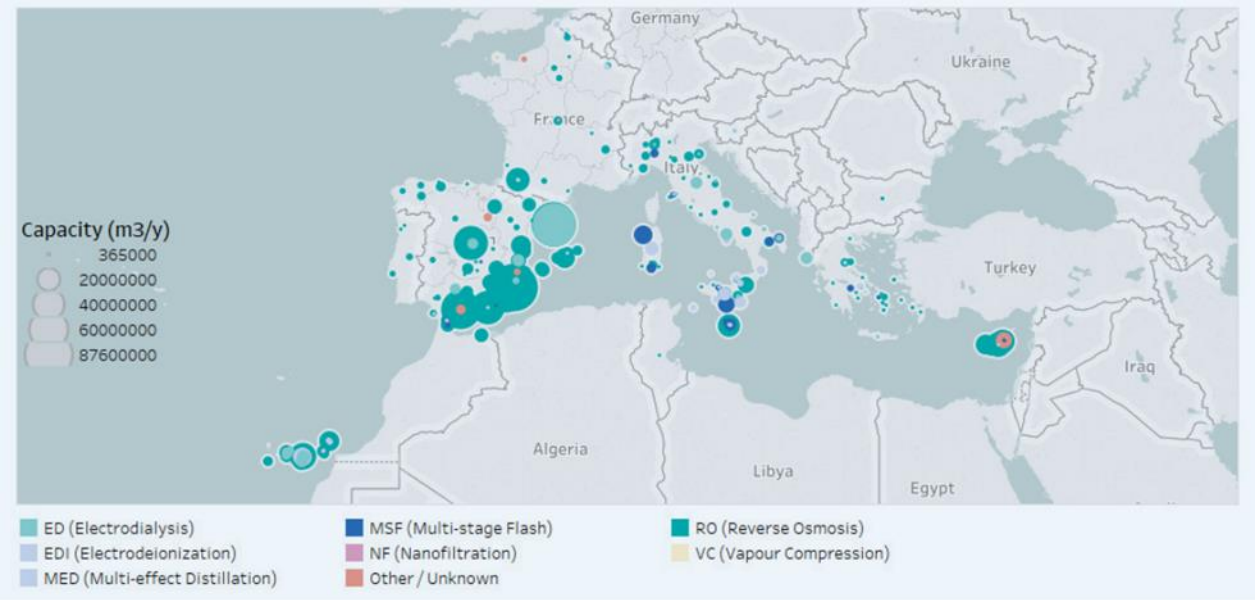
The fourth takeaway from the expert interviews indicates that several interviewees assert Israel should be recognized as a nation with advanced expertise in water desalination. This is primarily due to their historical progress in water desalination. An analysis of the patent database reveals that less than 1% of patents originate from Israeli companies. Experts consistently highlight Israel's advanced expertise in water desalination; however, the country is infrequently represented in patent data. This is highly contradictory. Apart from that, the Middle East is recognized for its implementation of MED and MSF technologies; however, the Government of Israel has initiated a comprehensive, long-term SWRO desalination program (State of Israel: Ministry of Foreign Affairs, 2018). This may shift their focus from MED and MSF towards RO facilities.

5. Conclusion

This thesis is set out to contribute to the current knowledge about water desalination.
The research question for this thesis was: *What are the policy implications for the EU in balancing technological sovereignty and environmental sustainability in desalination technology development?*
The main research question was divided by multiple sub-questions. To answer these sub-questions, a literature review has been performed, a patent network analysis was conducted, complemented with experts interviews to strengthen the found results and to gain additional insights. This chapter combines the results of the different research results to provide an answer to the main research question.

To answer the main research question, the sub-questions needs to be answered. The first sub-question was: *"What are the current desalination technologies used in the European Union?"*
This has been answered by the literature review as well as the network analysis.
Jones (2019) divided the global capacity in eight different regions. During that research, *Western Europe* had 2337 desalination plants, accounting for 9.2% of the global capacity. Region *Eastern Europe and Central Asia* had 566 desalination plants, accounting for 2.4%.
RO is by far the main used technology in the EU. Supplemented by some MSF and MED facilities. ED and NF hold a very low capacity within the EU.

Figure 27: *Desalination Capacity in EU*



**source : Magagna et al., 2019

Answers for sub-question two have been found in the literature review as well. Sub-question two reads as follows: "*What are the environmental impacts of desalination technology, both upstream (e.g., resource extraction, manufacturing) and downstream (e.g., brine discharge)?"* Jones et al (2019), Elsaid et al. (2020), Verweij (2024) and Elsaid et al. (2025) have investigated the different environmental impacts of the technologies. The best overview is given by Elsaid et al., who gives an overview of multiple environmental factors for technologies being used in the EU.

Table 10: *Specific Energy Requirements of Different Desalination Technologies and Related GHG's*

Technology	Energy, kWh	CO_2, kg	NO_x, g	SO_x, g	PM_{10}, g	Ref.
SWRO	3.7–4.5	3.01	7.20	6.83	0.20	Becker et al. (2010)
	4	1.78	3.87	10.68	2.07	Raluy et al. (2005)
MSF	4 kWh	23.41	28.29	27.92	2.04	
MSF-WH[a]	(+333 MJ)	1.98	4.27	14.79		
MED	2 kWh	18.05	21.41	26.49	1.02	
MED-WH[a]	(+263 MJ)	1.11	2.42	16.12		

[a] WH = waste heat utilized for supply of thermal energy.

**note: based on 1 m^3 of desalinated water*
***source:* Elsaid et al., 2020

In addition, both the literature review and the desalination experts clearly stated that the input type of water, how salty your source is, is very indicative for the chosen technology. RO works best for water with higher salt concentration than ED. The breaking point is around 10 to 15 gram salt per liter water. If the concentration is below 10 gram per liter, then ED is preferred. Above 15 gram per liter, RO is preferred. In addition, RO also takes out other elements from the water which skips the need for an extra process step. When using ED, only salt and some elements are taking from the water. So, an extra process step is needed to make the water drinkable. This makes RO a more favorable technique.
They also stated that MSF and MED might work better in regions where a high temperature is 'normal' since a lot of heat is needed for these technologies. So, in colder regions, these technologies are considered less sustainable.
Sub-question three is: "*Which areas in the world have the most promising knowledge of water desalination technologies?"*
When we look at technological leadership in water desalination, Japan, South Korea, and the United States clearly hold a lot of the patent knowledge and know-how.
Some European countries, like France and Germany, are also quite advanced in this area. Interestingly, The Netherlands is recognized for its strong technical capabilities in water desalination, though this isn't currently reflected in their patent data. Drinking water companies are searching for new ways to produce water and seawater as input is being started up at the moment since several companies are now setting up or testing with SWRO pilots.

Sub-question 4 has been mainly answered during the expert interviews. The question is: "*What are the experiences of companies in balancing technological sovereignty and environmental sustainability in desalination technology development?"*
All experts have pointed out that that economic aspects are the most important when deciding and developing which technology suits the best. When looking at membrane-based technologies, experts state that they are not technologically dependent on other companies, since the membranes are already considered as a commodity and can be produced by multiple companies all over the world. The membranes are basically the core of the desalination technology. Experts point out that the installation and infrastructure of a desalination facility is being build by other companies who are not related to the desalination expertise.

Sub-question 5 is *"What are the potential trade-offs between technological sovereignty and environmental sustainability, in the development and deployment of water desalination technologies in the European Union?*

The trade-offs can be differentiated on incentives on the type of organizations. Companies have other

priorities than nations and/or non-profit organizations such as research institutions. Companies are benefitted by an efficient workflow and a high production volume of freshwater. The replacement of membranes is an interesting topic in this case. As Verweij indicated, membrane replacement costs are around 2.7% of the total cost. Economically, it is more convenient for a company to replace the membranes with new membranes, since the costs of membranes have dropped significantly. The old membranes are easily disposed by companies. The common methods are landfilling and incineration.
Apart from that, the EU is only representing around 10% of world's total desalination capacity. The high knowledge areas are mainly outside the EU. So, at the moment, EU countries are dependent on the technological trajectory of the innovations from other countries. In contrast, The Netherlands is indicated as a country with a high research level on desalination. Although, this is not translated into big desalination facilities created by themselves.

To conclude and to give an answer on the main research question: the European Union is in a 'following' position instead of a technological leading position. To raise its technological sovereignty and to become less dependent on other countries, the EU must stimulate its countries to develop their own desalination plants and their innovations. It is important to look specifically for each country where to focus on. To clarify: countries next to a sea have direct access to seawater so they must focus more on RO. Centrally located countries such as Austria and Czech Republic do not have direct access to an ocean so they have to focus more on ED. France and Germany have the highest technological sovereignty within the EU. Other EU countries should opt for an international development program to enhance their desalination knowledge as well. At the moment, they are the only countries who can facilitate a large-scale desalination site. The Mediterranean countries possess the biggest part of EU's production, but they do not display a state-of-the-art knowledge level. They should in-source the latest technological advancements so they will not become dependent on other areas.
Also, governments should help companies by creating incentives to look at the environmental part of production instead of the economic part of production. Only with the correct guidance and regulatory framework created by governments, companies will focus on the sustainable development of drinking water.

6. Discussion

The major goal of this study was to research how European companies and countries copy with sustainability and sovereignty factors related to desalination. Analyzing the worldwide network in this sector, separately for each technology has provided a initial glimpse into the differences between countries and policies in balancing these factors. This study adds to the current literature and theories as the environmental and sovereignty impact has been under researched. A lot of research has been done about the technical advancements and requirements for the different technologies, especially for RO. But never before has the sovereignty question been connected to this desalination topic. This research sheds a new light and gives a new dimension to think about in the desalination world.

The following sections are set out to explain the practical implications of the findings and the limitations of this research. It is of importance to understanding these findings as a foundation for future research on this topic and for the development of desalination.

6.1 Interpretation

This section delves into the practical implications of adopting desalination strategies and outlines key policy recommendations for European governments to effectively balance technological sovereignty with environmental sustainability in this vital domain. The interpretation of the outcomes of this research can vary per EU country.

Practical Implications and Policy Recommendations for European Governments

Desalination technology affords the EU a variety of ways to enhance water security and climate change resilience, while also fostering technological sovereignty. European policymakers should consider the following practical implications and recommendations:

Desalination as a Strategic Tool for Water Security

Desalination offers a solution to the fact that climate change is increasing water scarcity. As highlighted by the World Bank (2019), desalination is immune to fluctuations in rainfall, air temperature, and drought makes it an excellent candidate for climate change adaptation. This is especially essential giving the trends we've seen: less and more erratic rainfall, more droughts, and higher temperatures are all increasing water demand in different places of the world.

Beyond climate resilience, desalination also serves as a great technique to respond to exogenous risks, such as dependency on external water sources. By investing in desalination, nations can secure self-reliance and achieve water supply independence. Examples like Singapore (World Bank, 2019), which opted for large-scale desalination to reduce reliance on increasingly expensive imported water, and Israel, which strategically invested in desalination due to its water scarcity and vulnerable geopolitical environment. In both cases the country raised its technological sovereignty by doing so. These are only a few examples of how desalination can be used strategically. For European countries with limited freshwater resources or significant geopolitical dependencies, desalination can be a vital component of national security. In 2025, this topic is, sadly, highly relevant since the ongoing war between Ukraine and Russia as well as the political discussions and shifts of the NATO. Also, European countries with little surface area, such as Monaco, Liechtenstein and Luxembourg, could copy Singapore by opting for a large-scale desalination plant, since they do not have enough groundwater to supply themselves.

Prioritizing Sustainable and Innovative Technologies
European governments should make the development and deployment of innovative, eco-friendly desalination technologies their primary priority. This means that we should strongly discourage or phase out older, less environmentally friendly behaviors, especially those that use a lot of energy or have a major effect on the environment. Current environmental regulations across different European countries vary widely, which makes it hard to create a unified approach to sustainable innovation. Therefore, there is a clear need for greater focus and alignment on innovation-driven environmental standards at the EU level. This would encourage the development of more energy-efficient and environmental friendly desalination processes. An EU standard would also help the different countries to innovate together.

The Role of Government in Fostering Desalination Development
To facilitate the widespread and effective adoption of advanced desalination technologies, European governments can play a crucial role in creating an enabling environment. This includes:

Financial Mechanisms: Governments can provide guarantees and incentives to private companies involved in desalination projects. The Israeli experience shows how helpful government guarantees can be in making these projects financially viable and appealing to private investors. In Israel, government guarantees contributed to record-low bid costs for desalinated water.
Strategic Planning and Infrastructure Development: European governments should add desalination to their national and regional water management plans, just like Singapore does to become water-independent through desalination and wastewater reclamation. This includes investing in the necessary infrastructure for water intake, treatment, and distribution.
Research and Development Funding: Continued investment in research and development is essential to further reduce the energy consumption and environmental impact of desalination, while also exploring new, cutting-edge technologies.

6.2 Limitations

Several limitations can be noted within this research. The limitations are split into the different phases. While the study included interviewees from different perspectives, not all technologies were represented. All interviewees were linked to RO, ED and/or NF, indicating that MED and MSF are missing. This lack of participation may create a bias on the results of the interviews. Furthermore, multiple Dutch persons have been interviewed, which creates a more Dutch-view perspective instead of an European view. On the other hand, experts from Italy and the United States were included, to retrieve a more balanced overview. The interviews were also used as an extra step within the data collection to confirm findings from the patent data.

The technical limitations of the patent data are notable. To build a robust dataset, IPC codes and keywords are combined to create a query for each technology. This approach, however, means that the dataset might not include all relevant patent records, and conversely, it might contain some irrelevant ones. The impact of this limitation is mitigated by explicitly using a combination of both IPC codes and multiple keywords.

Some patent data presented inconsistencies. Some records lacked crucial information, such as the country of origin. Additionally, a notable challenge in patent datasets is the presence of variant spellings for a single company name, an issue that requires careful standardization. To enhance data quality, a formal standardization and merging process was applied to company names. This involved unifying various spellings into single entities. Due to the large datasets, each containing thousands of distinct company names, a pragmatic threshold was established: only companies with over 10 patent records were

subjected to this merging procedure. Companies with fewer than 10 patents were not merged as their limited portfolios were considered less relevant to the analysis.

6.3 Recommendations for further research

One of the main points of this research was to explore the policies of countries and companies within the EU about sustainable desalination development. This has mainly been addressed during the expert interviews. Respondents repeatedly mentioned that their company is looking at the sustainable factors of desalination production as well, but to produce as sustainable as possible is not the priority. Also, brine discharge is something that has been touched in this research, but has not been elaborated on.
Another example, research has been executed about biopolymeric membranes (Mamba et al., 2021). This could end the high disposal of membranes ending up at landfills. This research has not primarily been investigating this topic, but it could help making the membrane desalination technologies more sustainable.
EU governments must address these unsustainable practices and create a shift towards more sustainable alternatives. The EU and national governments must create a legal framework and incentives for companies to embed these sustainable practices in their production facilities.

Also, almost all interviewees have pointed out that Israel is one of the main knowledge areas that stands out. But, this is not reflected in the patent database. Further research should examine why there is a difference there. Israel might prefer secrecy over patenting. This is a common tactic so that an invention is not revealed. A trade secret can be a more effective long-term strategy than a patent, which has a limited term. This is an assumption and has to be further researched to be clarified. Another explanation could be the capitalist attitude of Western countries compared to Middle East countries. Capitalism mostly common in Western countries and they might use this point of view to innovate and to sell or to lease your innovation to other countries. While Israel is less benefitted by this phenomenon as they are in need of desalinated water since they have no other sources than that.

Furthermore, most Dutch interviewees indicate that Germany and France are "ahead of the game" in Europe, and they also acknowledge the high standard of desalination knowledge in The Netherlands. In contrast, only Germany is well-represented in the patent database, while France and The Netherlands have limited representation. This discrepancy could indicate several things. It might suggest a bias, as these experts are evaluating their own countries. Alternatively, it could imply that while The Netherlands possesses significant desalination knowledge, the technology itself is not being invented there. This latter interpretation would suggest a low level of sovereignty for the Netherlands in this specific domain. This finding can be a starting point for further research.

When looking at patent data to learn about technological progress it's vital to note that it doesn't include all creative work. Companies typically look at various ways to safeguard their ideas, such trade secrets, when they are thinking about whether or not to patent an innovation. As trade secrets, businesses could choose to keep their new technologies, processes, or even some designs hidden. This is especially true if the innovation is hard to reverse-engineer or if the benefits of keeping it secret outweigh the benefits of making it public through the patent system.
Furthermore, new concepts or ideas that evolve quickly, particularly those originating from smaller businesses, might not be ready for patenting just yet. Therefore, patent data is helpful in determining the direction and speed of technological advancements, but it does not encompass all innovations. This could make it more difficult to fully understand the state of innovation overall because some recent advancements in desalination technology might not be covered by the current data collection.

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Appendix I: Input query details

Reverse Osmosis	
Cate-gory	**Description**
B01	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL
B01D	SEPARATION
B01D 61/00	PROCESSES OF SEPARATION USING SEMI-PERMEABLE MEMBRANES, E.G. DIALYSIS, OSMOSIS OR ULTRAFILTRATION; APPARATUS, ACCESSORIES OR AUXILIARY OPERATIONS SPECIALLY ADAPTED THEREFOR
B01D 61/02	REVERSE OSMOSIS

Multistage Flash Distillation					
Cate-gory	**Description**	**Cate-gory**	**Description**	**Cate-gory**	**Description**
C02	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE	C02	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE	B01	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE (processes for making harmful chemical substances harmless, or less harmful, by effecting a chemical change in the substances A62D 3/00; separation, settling tanks or filter devices B01D; special arrangements on waterborne vessels of installations for treating water, waste water or sewage, e.g. for producing fresh water, B63J; adding materials to water to prevent corrosion C23F; treating radioactively-contaminated liquids G21F 9/04) [3]	C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE (processes for making harmful chemical substances harmless, or less harmful, by effecting a chemical change in the substances A62D 3/00; separation, settling tanks or filter devices B01D; special arrangements on waterborne vessels of installations for treating water, waste water or sewage, e.g. for producing fresh water, B63J; adding materials to water to prevent corrosion C23F; treating radioactively-contaminated liquids G21F 9/04)	B01D	SEPARATION (separating solids from solids by wet methods B03B, B03D, by pneumatic jigs or tables B03B, by other dry methods B07; magnetic or electrostatic separation of solid materials from solid materials or fluids, separation by high-voltage electric fields B03C; centrifuges B04B; vortex apparatus B04C; presses per se for squeezing-out liquid from liquid-containing material B30B 9/02) [5]
C02F 9/00	Multistage treatment of water, waste water or sewage	C02F 1/00	Treatment of water, waste water, or sewage	B01D 3/00	Distillation or related exchange processes in which liquids are contacted with gaseous media, e.g. stripping
-	-	C02F 1/06	Flash evaporation	B01D 3/06	Flash distillation

Electrodialysis					
Cate-gory	**Description**	**Cate-gory**	**Description**	**Cate-gory**	**Description**
C02	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE	B01	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL	B01	PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL
C02F	TREATMENT OF WATER, WASTE WATER, SEWAGE, OR SLUDGE (processes for making harmful chemical substances harmless, or less harmful, by effecting a chemical change in the substances A62D 3/00; separation, settling tanks or filter devices B01D; special arrangements on waterborne vessels of installations for treating water, waste water or sewage, e.g. for producing fresh water, B63J; adding materials to water to prevent corrosion C23F; treating radioactively-contaminated liquids G21F 9/04) [3]	B01D	SEPARATION (separating solids from solids by wet methods B03B, B03D, by pneumatic jigs or tables B03B, by other dry methods B07; magnetic or electrostatic separation of solid materials from solid materials or fluids, separation by high-voltage electric fields B03C; centrifuges B04B; vortex apparatus B04C; presses per se for squeezing-out liquid from liquid-containing material B30B 9/02) [5]	B01D	SEPARATION (separating solids from solids by wet methods B03B, B03D, by pneumatic jigs or tables B03B, by other dry methods B07; magnetic or electrostatic separation of solid materials from solid materials or fluids, separation by high-voltage electric fields B03C; centrifuges B04B; vortex apparatus B04C; presses per se for squeezing-out liquid from liquid-containing material B30B 9/02) [5]
C02F 1/00	Treatment of water, waste water, or sewage (C02F 3/00-C02F 9/00 take precedence) [2023.01]	B01D 61/00	Processes of separation using semi-permeable membranes, e.g. dialysis, osmosis or ultrafiltration; Apparatus, accessories or auxiliary operations specially adapted therefor (separation of gases or vapours by diffusion B01D 53/22) [2006.01]	B01D 61/00	Processes of separation using semi-permeable membranes, e.g. dialysis, osmosis or ultrafiltration; Apparatus, accessories or auxiliary operations specially adapted therefor (separation of gases or vapours by diffusion B01D 53/22) [2006.01]
C02F 1/469	by electrochemical separation, e.g. by electro-osmosis, electrodialysis, electrophoresis [2023.01]	B01D 61/42	Electrodialysis; Electro-osmosis [2006.01]	B01D 61/44	Ion-selective electrodialysis

Appendix II: Gephi's steps

RO

-Import Network
-Import Nodes info
-copy ID to label
-Merge same companies as one node

- For max freq: calculate sum
- For total patents: calculate sum

For nodes which have more than 10 patents (otherwise not relevant enough)
-Shorten names ("Corporation"→ "CORP"; "Company"→ "CO"; "Limited"→ "Ltd"; etc)
-Node size based on amount of patents (20 to 100)
-Node color based on reference country
-Run of algorithm ForceAtlas 2
-Created duplicate of workspace
-Labels removed if patents < 25
-*First picture created*
-Duplicate workspace removed
-Giant component filtered to new workspace
-Re-run of algorithm Force Atlas 2
-Node size to 10-60
-Created duplicate of workspace
-*Second picture created*
-Duplicate workspace deleted
-Run of all parameters on Giant component
-Data exported to excel
-Selected top 20 players with highest betweenness centrality.
-Filtered them to new workspace.
-Re-run of all parameters
-Re-run of algorithm Force Atlas 2
-Applied the Expansion lay-out, multiple times
-Labels shortened if needed
-Adjusted legend
-Applied Expansion for better readibility
-*Third picture created*

MSF

-Import network
-Import Nodes info
-copy ID to label
-Merge same companies as one node

- For max freq: calculate sum
- For total patents: calculate sum

-Node size adjusted from 10 to 100, based on the amount of patents
-Run of algorithm ForceAtlas 2
-Labels shortened if needed

-Created duplicate of workspace
-Node color based on Reference country
-*First picture created*
-Giant component filtered to new workspace
-New workspace met new legend (still based on Reference country)
-Run of all indicators
-Node size adjusted betweenness centrality (size 10-50)
-Re-run of algorithm Force Atlas 2
-Applied Expansion for better readibility
-Duplicate gemaakt of workspace
-Labels verwijderd bij betweenness centrality = 0
-*Second picture created*
-Created duplicate of workspace
-All players removed if betweenness centrality
-Adjusted legend
- Re-run of algorithm Force Atlas 2
-Applied Expansion, 8 x
-*Third picture created*

MED

-Import Network
-Import Nodes info
-copy ID to label
-Merge same companies as one node

- For max freq: calculate sum
- For total patents: calculate sum

For nodes which have more than 10 patents (otherwise not relevant enough)
-Node size adjusted from 10 to 100, op basis van aantal patents
-Run of algorithm ForceAtlas 2
-Labels shortened by patents < 25
-Created duplicate of workspace
-Node color based on Reference country
-*First picture created*
-Giant component filtered to new workspace
-Run ForceAtlas 2
-Run of all indicators
-Filtered on companies with highest betweenness centrality
-Filtered them to new workspace.
-Re-run of all parameters
-Re-run of algorithm Force Atlas 2
-Adjusted legend
-*Third picture created*

ED

-Same first steps as other technologies
-top 15 selected with highest betweenness centrality
-Filtered these to a new workspace
-Node size adjusted from 15-100 (based on betweenness centrality)

NF

-Import Network
-Import Nodes info
-copy ID to label
-Merge same companies as one node

- For max freq: calculate sum
- For total patents: calculate sum

For nodes which have more than 10 patents (otherwise not relevant enough)
-Run of algorithm ForceAtlas 2
-Labels shortened
-Node size based on total patents (10 to 60)
-Node color based on reference country
-Duplicate created of workspace
-Labels removed patents < 25
-*First picture created*
-Duplicate workspace removed
-Giant component filtered to new workspace
-Run ForceAtlas 2
-Node size 10-50 (based on amount of patents)
-Run of all indicators
-names removed if betweenness Centrality < 85
-Legenda bijgewerkt (op basis van reference country)
-Run Expansion (3x)
-*Second picture created*
-Duplicate workspace removed
-Duplicate workspace created of GC
-top 16 based on betweenness centrality
-re-run ForceAtlas 2
-Run Expansion
-Node size based on betweenness centrality
-*Third picture created*

Appendix III: Interview guide

English version	
1	Are you familiar with the five most used technologies?
2	Are you familiar with other promising technologies to desalinate water?
3	What, in your opinion, is the most sustainable technology? And why? Rank them from 1 to 5.
4	Which technology is your company using and why?
4a	Follow-up question: If so, why is your company not using the most sustainable technology?
5	Technologically speaking, how dependent is your company on other companies to make this technology?
6	From which countries are you dependent on?
7	Do you see sustainable implications because of these dependencies?
8	What are the experiences of your company in balancing technological sovereignty and environmental sustainability with your desalination technology development?
9	In your opinion, which areas in the world have the most promising knowledge of water desalination technologies?
10	In terms of technological advancement, do you see a difference within the countries of the European countries?
10a	Follow-up: Which countries are ahead and why?
10b	Which countries are behind and why?
11	What would you advise for European policy makers or European companies to work on regarding water desalination development?

Dutch version	
1	Bent u bekend met de vijf meest gebruikte technologieën?
2	Bent u bekend met andere veelbelovende technologieën om water te zuiveren?
3	Wat, in jouw mening, is de meest duurzame technologie? En waarom? Rangschik ze van 1 naar 5.
4	Van welke technologie maakt uw bedrijf gebruik? En waarom?
4a	Doorvraag: waarom maken jullie dan zelf niet gebruik van de meest duurzame technologie?
5	Technologisch gezien, hoe afhankelijk is uw bedrijf van andere bedrijven om deze technologie te maken?
6	Van welke landen bent u afhankelijk?
7	Ziet u duurzame implicaties vanwege deze afhankelijkheden?
8	Wat zijn de ervaringen van uw bedrijf met het in evenwicht brengen van technologische soevereiniteit en ecologische duurzaamheid met uw ontziltingstechnologieontwikkeling?
9	Welke gebieden in de wereld hebben volgens u de meest veelbelovende kennis van waterontziltingstechnologieën?
10	Ziet u een verschil binnen de landen van de Europese landen wat betreft technologische ontwikkeling?
10a	Doorvraag: Welke landen zijn voorlopers en waarom?
10b	Welke landen zijn achterlopers en waarom?
11	Wat zou u Europese beleidsmakers of Europese bedrijven aanraden om aan te werken met betrekking tot de ontwikkeling van waterontzilting?

Appendix IV: Overview interview respondents

No	Name	Organization	Date
1	Abdulsalam Al-Hadidi	Fujifilm	8 January 2025
2	Miriam Balaban	European Desalination Society	10 January 2025
3	Karl Littau	Palo Alto Research Centre (PARC)	27 January 2025
4	Jan Post	Wetsus	28 January 2025
5	Tim van Dijk & Timon Rijnaarts	Brabant Water	14 April 2025
6	Bas Rietman	Vitens	23 April 2025

Appendix V: Interview transcripts

The transcripts are not published. For more information, please contact the author.

Appendix VI: Revived Water factsheet

REvivED water

WWW.REVIVEDWATER.EU

Low Energy Solutions for Drinking Water Production by a REvival of ElectroDialysis Systems

CHALLENGE

The balance between drinking water demand and availability has reached a critical level in many regions of the world. Factors such as climate change and water over-abstraction are currently exacerbating the water stress of almost one billion people worldwide who worry about obtaining enough water daily. With seawater making up 97.5% of the world's water resources, low energy desalination solutions are crucial in providing sufficient levels of good quality drinking water for the growing world population.

PROJECT OBJECTIVES

REvivED water aims to contribute to overcoming the drinking water challenge by establishing ElectroDialysis (ED) as the new standard for desalination of seawater. The goal is to produce safe, affordable and cost-competitive drinking water with significantly reduced energy consumption compared to state-of-the-art Reverse Osmosis (RO) technology. The REvivED water project will focus on developing several new innovative ElectroDialysis systems and assessing them in different real environments, ranging from brackish water desalination to industrial-scale seawater desalination.

AT A GLANCE

PROGRAMME:
H2020 – Nanotechnologies, Advanced Materials and Production (NMP-24-2015)

TYPE OF ACTION:
Innovation Action

DURATION:
48 months (1 May 2016 – 30 April 2020)

CONSORTIUM:
10 partners from six European countries

COORDINATOR:
FUJIFILM Manufacturing Europe B.V. (FUJIFILM), the Netherlands

CONTACT US

COORDINATION & MANAGEMENT:
Natalie Tiggelman
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COMMUNICATION & PRESS:
Alberto Vallejo
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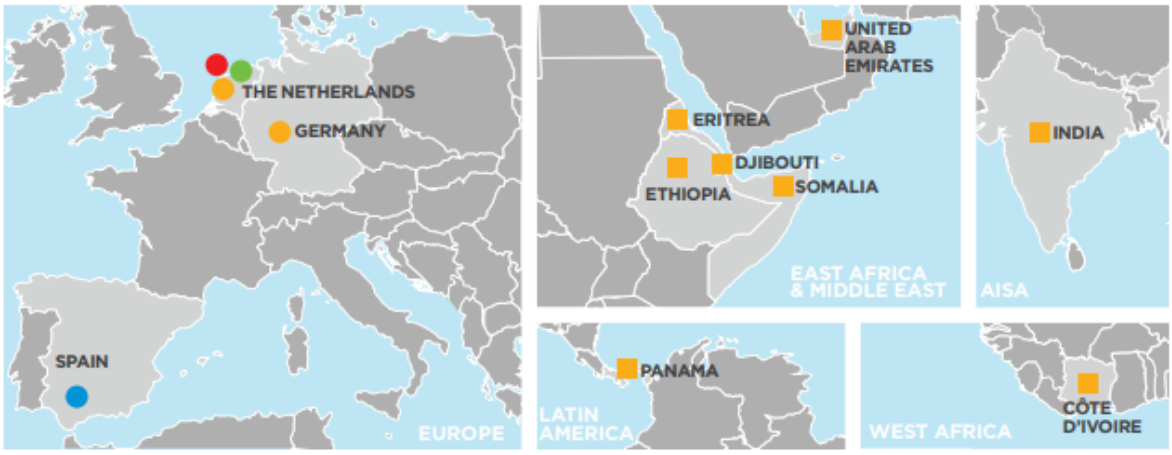
Designed & Developed by **AquaTT** www.aquatt.ie

REVIVED WATER'S ED SYSTEMS AND APPLICATIONS IN DIFFERENT PILOT TESTING LOCATIONS



ED system
Applications:
- Brackish water desalination in developing countries
- Tap-water softening in Europe

Multistage ED system
Application:
- Industrial-scale seawater desalination

Multistage ED system + Reverse ED (RED)
Application:
- Further reduction of energy consumption for seawater desalination

RO systems + RED or ED
Application:
- Market introduction ED-RO without the need to replace the extensive RO infrastructures already developed around the world

EXPECTED RESULTS

- Development of new innovative ED systems based on Reverse ED (RED) and ED components (membrane, electrodes, stacks) for water desalination applications to significantly **reduce their energy consumption** compared to current state-of-the-art energy technologies.
- Assessment of several pilot ED systems in different real environments to discern tangible solutions and **achieve more cost-efficient desalination**, for both seawater and brackish-water, as well as tap-water softening.
- **Sustainable provision of safe and affordable drinking water** all over the world, covering applications ranging from large industrialised plants to small, stand-alone systems for developing countries.

CONSORTIUM

The REvivED water consortium consists of ten partners from six European countries, coordinated by FUJIFILM Manufacturing Europe B.V. The consortium is industry driven, with five innovative SMEs and large industrial partners. It comprises the whole knowledge spectrum required for the success of the REvivED water project.

1. FUJIFILM Manufacturing Europe B.V. (FUJIFILM) (the Netherlands)
2. Abengoa Research (ABENGOA) (Spain)
3. REDstack (REDSTACK) (the Netherlands)
4. Deukum GmbH (DEUKUM) (Germany)
5. Phaesun GmbH (PHAESUN) (Germany)
6. European Desalination Society (EDS) (Italy)
7. University of Palermo (UNIPA) (Italy)
8. Ghent University (UGENT) (Belgium)
9. European Centre of Excellence for Sustainable Water Technology (WETSUS) (the Netherlands)
10. AquaTT UETP CLG (AQUATT) (Ireland)

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WWW.REVIVEDWATER.EU

REvivED water