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# Smart Specialisation in the Context of Blue Economy – Analysis of Desalination Sector

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## Abstract

The smart Specialisation strategy design and implementation offer European territories a solid paradigm for developing effective innovation governance, improving innovation policy capacities, enhancing public-private partnerships, offering common platform for inter-regional cooperation activities, and an operative engagement of stakeholders in the international value chains. The sustainable Smart Specialisation strategies framework can play a key role as an enabler of a sustainable transformation of the European economy towards the Green Deal by streamlining innovation activities around the value chains to reach the competitiveness edge of Europe vis-à-vis the rest of the world. The Blue Economic activities represent an essential component of the European Green Deal activities in the regions and Member States by safeguarding healthy oceans, seas, and waters. One of the emerging blue economy sectors with considerable "greening" potential for a stable water supply in the ever-growing areas with increasing water imbalances is the desalination sector. Besides its essential role in providing water in the areas suffering water shortages, the sector has the potential for creating prosperity and employment in some territories of Europe through a combination of innovation-based sustainable water, energy and chemical technologies, coupled with environmental and societal challenges. This report aims at analysing the sector from the innovation, the EU policy and regional perspectives - in the latter with examples of implementation of desalination technologies in the three types of regions with specific water supply issues across Europe. Examples are provided in the water-scarce regions of the Southern Europe, in European Western and Northern regions, and in the particular case of island regions, where a stable water supply through desalination improves the living conditions and local economy substantially. Overall, the desalination sector provides a sustainable solution for agro-food systems and integrated water provision and management in the water-scarce areas, makes those often vulnerable territories more climate-resilient, efficient, cost-effective, and environmentally and socially sustainable, and contributes to climate adaptation by solving the water scarcity, food security, soil health by enhancing rainwater infiltration and water reuse, nutrition, health and well-being of the population in these areas. Given the increasing climate change pressures, a holistic approach to addressing global freshwater scarcity through sustainable and innovative solutions is needed. The sector of desalination will be granted increasing protagonism in the endeavours to enhance territorial resilience, improve ecosystem services, biodiversity and a more sustainable agricultural production in Europe and beyond.

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**Executive Summary**

The emerging desalination sector is linked to several EU policies and strategies. In the new EU Regulation on minimum requirements for water reuse, the area of desalination has both quantitative and qualitative effects. Desalination should not only save freshwater from the watershed, but it would even become freshwater positive when combined with water reuse. Wastewater originating from desalted water has a lower than average salinity after its first use than conventional wastewater, and hence it will provide a better perspective for wastewater reuse. On the other hand, desalination leads to discharges of concentrated brine streams, which may contradict the EU's Biodiversity Strategy for 2030. The recently adopted Commission's EU Action Plan Towards a Zero Pollution for Air, Water and Soil requires the desalination sector to assess the use of chemicals in their daily operation.

There is also a link between desalination and three of the five Horizon EU innovation missions. It can play an essential role in the mission of Adaptation to Climate Change by increasing water availability for many EU regions and be also a part of the solution to mitigate the risks of water scarcity. Another use of desalinated water is the provision of suitable water and mineral composition for water reuse in agriculture to achieve the mission's goals on Soil Health and Food.

As co-funded by the EU over the past period, the main driver for research and development and resulting innovations is lower desalination energy consumption. A second driver may be to reduce the costs for desalination. It is a challenge indeed and worth the efforts. However, there seems very little room for further energy use and cost reductions. A challenge with more impact would be to turn brine treatment and disposal in the desalination process from a problem into an opportunity.

A relatively modest share characterizes the EU contribution to finance desalination as an emerging blue economy sector over 2014-2019. An EU contribution of €58.2 million from the European Regional Development Fund (ERDF) is dedicated mainly to infrastructural investments. €23.3 million are coming from the EU Research and Innovation programme Horizon 2020 (H2020) to support research and innovation activities.

In the Multi-annual Financial Framework 2021-2027, many programmes can target innovation needs in the desalination sector. PRIMA initiative[1] can take a more holistic approach to address water scarcity by adding fresh water to the cycle using water reuse and desalination. The European partnership Water4All is already addressing sustainable management of residues from desalination plants. Still, it can increase granularity by taking the specific challenges of too much boron and too little magnesium into account. Mission Climate Adaptation could also address the holistic approach of global freshwater scarcity and form the bridge between European RDI efforts and global challenges and regional needs. Mission Healthy Soil and Food could consider the health aspects of desalinated water, boron and magnesium. Mission Starfish2030 could take the challenge to reduce the ecological impact of desalination.

Around 20 European regions are members of the thematic smart specialisation partnership Water Smart Territories, one of the Smart Specialisation Platform for Industrial Modernisation partnerships. There are clear opportunities to engage in strategic interregional cooperation and shared RIS3 priorities to complement each other's competencies, share infrastructure, and develop joint investment projects. Smart specialisation strategies will allow place-based innovation ecosystems to optimize the use of local, regional, national and European funding opportunities and facilitating funding synergies. It would maximise the impact of these various programmes and boost the effectiveness of research, innovation, start-ups and scale-ups in desalination. It can form a foundation for new economic growth, including in Blue Growth in general and desalination in particular.

[1] Partnership for Research and Innovation in the Mediterranean Area (PRIMA)

# 1 Introduction

The desalination capacity of Europe has been recently estimated at 8.7 million m3/day, which is around 9% of the global installed capacity. With an installed capacity of over 4.2 million m3/day, Spain currently has the largest share of the European Union desalination capacity (over 60% of the EU and an estimated 5.7% of the global desalination capacity). Still, remarkably, in the last decade (2010-2019), the newly commissioned capacity was only 0.84 million m3/day with an investment of €630 million, and such moderate growth appears to be sustained during the coming five years. This trend deviates from the sector's global growth in the same period, almost doubling its capacity. Given the age of the reverse osmosis assets, it can be expected that the reinvestment market in the coming five years will be about twice the market for newly developed desalination plants. As a result, the membrane market has become a very competitive replacement market, with low margins and little room for innovation.

The study analyses the primary market for innovative and emerging desalination technologies through a survey showing differences between the emerging technologies and the broader traditional technologies. The survey identified 75 global vendors, of which 25 are based in Europe (share of 33%), which shows that Europe is a central hub for innovation in desalination. However, Europe seems to lag regarding patent activity and licensing opportunities with a share of only 17%. The analysis identified two families of technologies revealed by high patent activity in 2020 compared to the others. The first is electro-chemical processes, which are typically more resistant to fouling than reverse osmosis and can be more selective. The other is membrane distillation processes, which can allow treating water too saline for reverse osmosis. This latter technology can operate at lower temperatures than many other distillation technologies.

Desalination is still considered an emerging sector within the Blue Economy. The EU Blue Economic Report 2020 (European Commission, 2020) states that desalination continues to be a key sector for those regions that are more likely to suffer water shortages, not least due to climate change. According to the report, the EU territory accounts for more than 1,500 desalination plants, mainly spread around the Mediterranean Sea basin, with a production capacity of almost 7 million $m^3$/day and an estimated annual turnover of €2 to 2.3 billion/year[2]. In terms of employment, it was reported that for the operation and maintenance of the desalination plants, the sector represents nearly 4,000 jobs. These numbers show that the desalination sector is still a relatively small economic sector in the Blue Economy in Europe. However, despite the relatively small size of the sector, it significantly impacts associated societal and economic sectors and related jobs (e.g. agriculture, tourism). Climate change leads to dryer summers, not only in the Southern European countries but also across Europe. Summer water deficits are no longer fully replenished in wet winters, and hence all over Europe, water supply companies are looking for water-saving measures and alternative sources. Until recently, desalination of the sea or brackish water was not considered the best water reuse option for the provision of water, mainly due to its energy consumption and particular environmental impact (brine discharges). However, with the rise of integrated renewable energy solutions and emerging environmental remediation solutions, desalination technologies appear increasingly relevant.

This report provides an overview from the technological and policy perspectives. It first describes the EU innovation market, the EU industrial leadership and R&D position, and the associated challenges and opportunities (Chapter 2). It explores how desalination fits in many of the agendas of the European Union (Chapter 3) and how existing financial instruments can support it. The desalination panorama in Europe is complemented by three desalination cases representing a variety of geographical locations (three sea basins), applications (municipal, agricultural, energy sector), and scales (small, medium, large). Chapter 4 provides some insights into the investigation in the opportunities to specialise in innovation-related desalination techniques through smart specialisation strategies related to the three presented cases. The report concludes with a set of policy recommendations (Chapter 5).

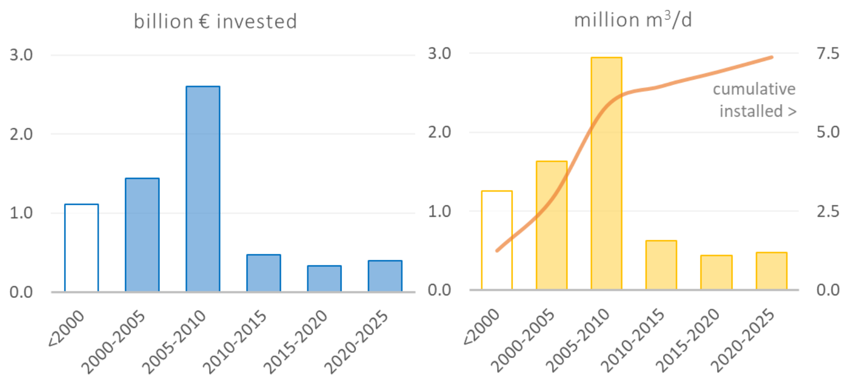
[2] Calculation based on desalination costs for RO, ranging € 0.56-1.43/$m^3$, depending on source water and scale of the plant. Provided that 72.6% is supplied from plants with large capacities (>10,000 $m^3$/day), and the remaining 27.4 % from plants with small capacity, weighed average price of € 0.80-0.90/$m^3$ can be assumed.

# 2 Desalination from the Innovation Perspective

## 2.1 EU Desalination Market

The historical and projected investments in desalination and the installed capacity follow an erratic trend since the introduction before 2000 (Figure 1). In 2019, a total of 1 573 operational desalination plants were located in the Eu Member States, offshore or in coastal areas, producing 6.9 million m3/day (2020 EU Blue Economic Report). For the whole European area, the capacity was recently estimated to be 8.7 million $m^3$ water/day (Jones, Qadir, Van Vliet, Smakhtin, & Kang, 2019), which is around 9% of the global installed capacity. For the period 2019-2024, new desalination projects for a total capacity of 0.5 million $m^3$/day are announced. It will bring the estimated total installed desalination capacity in the EU to around 7.5 million $m^3$ water/day in 2025.

*Figure 1: Investments in new desalination capacity and cumulative installed capacity.*

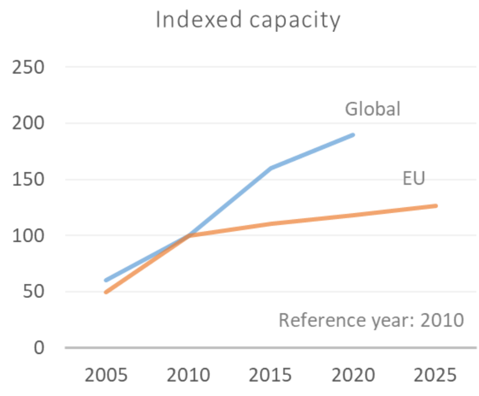



Source: EU Blue Economy Report 2020, open bars are own estimates.

The desalination capacity in the EU has grown significantly over the first decade of this century, with 4.58 million $m^3$/day of new capacity between 2000 and 2009 for a total investment in Engineering, Procurement and Construction (EPC), of €4 billion. Many of the Large (10,000-50,000 $m^3$/day) and Extra Large (over 50,000 $m^3$/day) facilities were commissioned to serve big coastal cities such as Barcelona and Alicante in Spain. Spain currently has the largest share in desalination capacity (over 60% of the European Union) with an installed capacity of over 4.2 million $m^3$/day. It represents approximately 5.7% of the global desalination capacity (Jones, Qadir, Van Vliet, Smakhtin, & Kang, 2019)).

However, the last decade (between 2010 and 2019) has seen a newly commissioned capacity of only 0.84 million $m^3$/day with an investment of €630 million with most of the new capacity installed in the form of Small and Medium size plants (under 10,000 $m^3$/day). This **trend deviates from the global growth** with a doubling of the desalination capacity over the same period (Jones, Qadir, Van Vliet, Smakhtin, & Kang, 2019) (Figure 2). Moreover, the moderate annual growth of the Desalination capacity in the EU appears to be sustained over the coming five years.

*Figure 2 Desalination capacity indexed to reference year 2010*

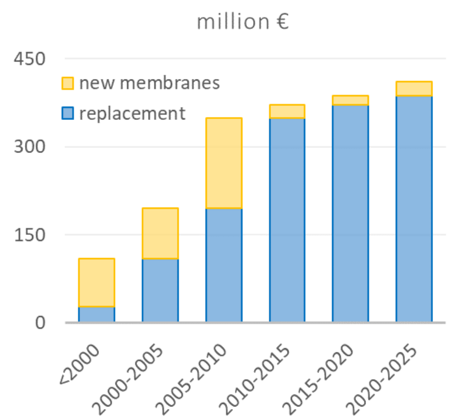



Source: Jones et al., 2019

With desalination plants' lifetimes of 20 to 25 years, it can be expected that in the coming years, increasing investments will be necessary to modernize or replace outdated facilities. Just based on the historical figures, about €1 billion may need to be invested in the period of 2020-2025 for the replacement of outdated plants built before 2000. This reinvestment market is estimated at twice the market for newly developed desalination plants in that same period.

Reverse osmosis (RO) is currently the most widely used desalination technology in Europe, with 85.5 % of total capacity (The EU Blue Economy Report 2020, EC, 2020). Membranes have an estimated lifetime of 5-7 years, meaning that membranes have to be replaced 4 to 5 times in the operational lifetime of a desalination plant when other mechanical components like high-pressure pumps and energy recovery devices typically need to be replaced only once or twice. As a result, the desalination market has turned almost entirely into a replacement market[3] after 2010 (Figure 3). The membrane market for 2020-2025 is equivalent to the contracted construction of new desalination plants in the same period. Hence, the **membrane market is primarily dominated by replacement rather than by investments into new plants**. As a result, this has turned a market into a very competitive commodity, with low margins and little room for innovation.

*Figure 3: Membrane market estimates for new desalination capacity and 5-yearly replacement*




*Source: Own elaboration based on calculation mentioned in the footnote (data for calculation taken from the EU Blue Economy Report 2020)*

[3] By dividing the hourly capacity with an average membrane flux of 20 L/m2.h the installed $m^2$ of membrane can be estimated. Market is estimated with a membrane prize of 25 €/$m^2$ and 5 years lifetime.

## 2.2 Technology & Industrial comparisons

Understanding the landscape of emerging desalination technologies helps provide insights into trends in applying and guidance concerning possible regulatory actions. The **identification of emerging desalination technologies currently in the market, patent activity, and licensing opportunities** coming out of top research universities was performed by an Innovation tracker review designed by Blue tech research based in the US.

### 2.2.1 Technology vendors landscape

Emerging desalination technologies must not only be new but also provide some differentiation from traditional technologies. The emerging technologies are measured by improving efficiency, contaminant concentration achievable, or some innovative business model that the technology may offer. It indicates whether a particular technology will be disruptive enough to find a place in the market to compete with more traditional options. It is important to note that the **emerging technology landscape will likely differ from the conventional technology landscape.** Fourteen technology classes have been identified to provide an analytical framework, ranging from the most mature to the emerging ones (Table 1). Those technologies are not self-standing and do not cover the whole value chain; moreover, they can complement each other. Table 1 also shows that European vendors represent a significant share of the total number of vendors with specific disparities among the technology classes.

*Table 1: Desalination Technology Classifications*

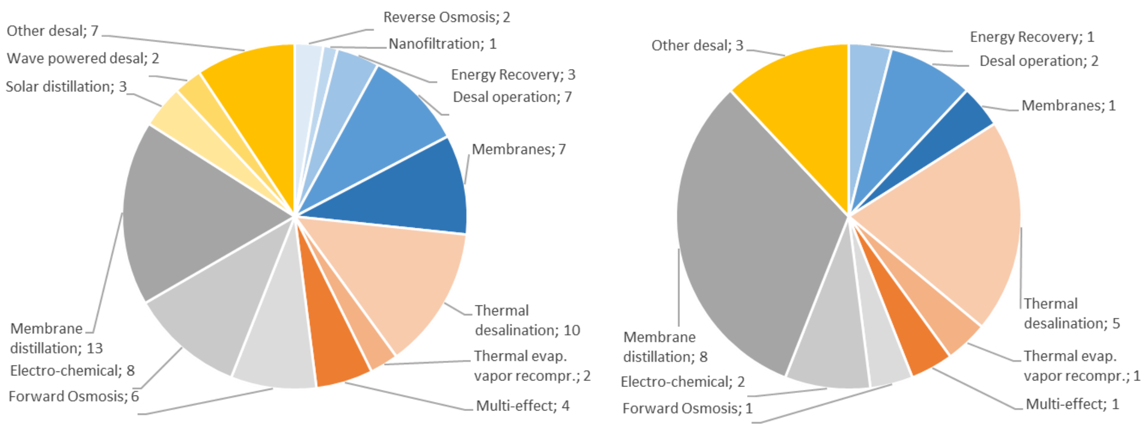
| Technology Class | Vendor Count (Global) | Vendor Count (Europe) |
|---|---|---|
| **Reverse Osmosis Based Technologies** | | |
| Reverse Osmosis | 2 | 0 |
| Nanofiltration | 1 | 0 |
| Energy Recovery Device | 3 | 1 |
| Desal operation[a] | 7 | 2 |
| Membranes | 7 | 1 |
| **Thermal Technologies** | | |
| Thermal desalination | 10 | 5 |
| Thermal evaporation vapor recompression | 2 | 1 |
| Multi-effect | 4 | 1 |
| **Emerging Technologies** | | |
| Forward Osmosis | 6 | 1 |
| Electro-chemical (ED, EDR, EDI) | 8 | 2 |
| Membrane distillation | 13 | 8 |
| **Other Technologies** | | |
| Solar distillation | 3 | 0 |
| Wave powered desalination | 2 | 0 |
| Other desalination | 7 | 3 |
| **Grand Total** | **75** | **25** |

[A] *scaling control, fouling control, pre-treatment, monitoring, etc.*

Source: BlueTech Research, Innovation Tracker, 2020.

When focusing on technology being developed within Europe specifically, the landscape, or distribution of different technology classes, appears similar to that of the broader global landscape. The technology classifications of membrane distillation, thermal desalination, electro-chemical, and operational efficiency offerings being most prominent. The "other" category does make a sizable contribution to the overall landscape, although technologies within this class are primarily early-stage (lab to pilot scale), one-off technologies. Certain technology classes were not observed among European vendors in other regions and included solar distillation, wave-powered desalination, and reverse osmosis. A side-by-side comparison of the technology landscape can be seen in Figure 4.

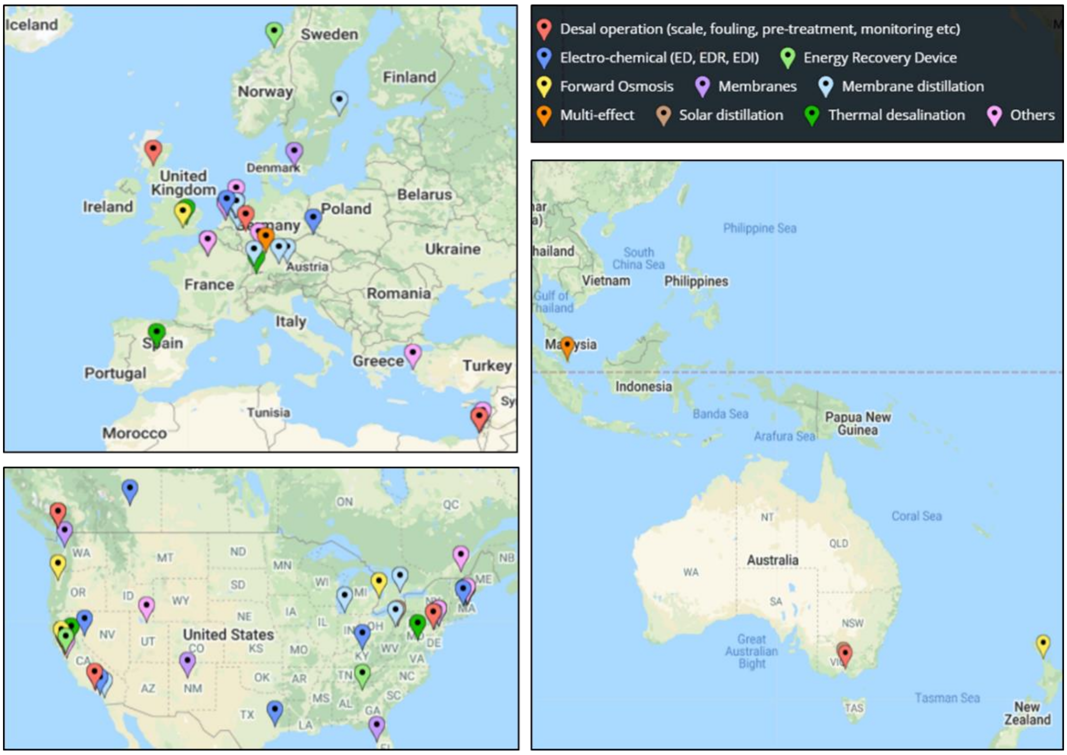
*Figure 4: Comparison of Global vs European Desalination Technology Landscape*




Source: Own elaboration based on the BlueTech Research, Innovation Tracker, 2020

When evaluating the geographic distribution of companies offering these technologies, **North America and Europe are the major hubs of innovation,** with a smaller number located in The Middle East and Asian Pacific regions. Figure 5 shows the locations of technology vendors.

*Figure 5: Location of technology vendors at the major hubs in Europe, North America, and Asian Pacific*



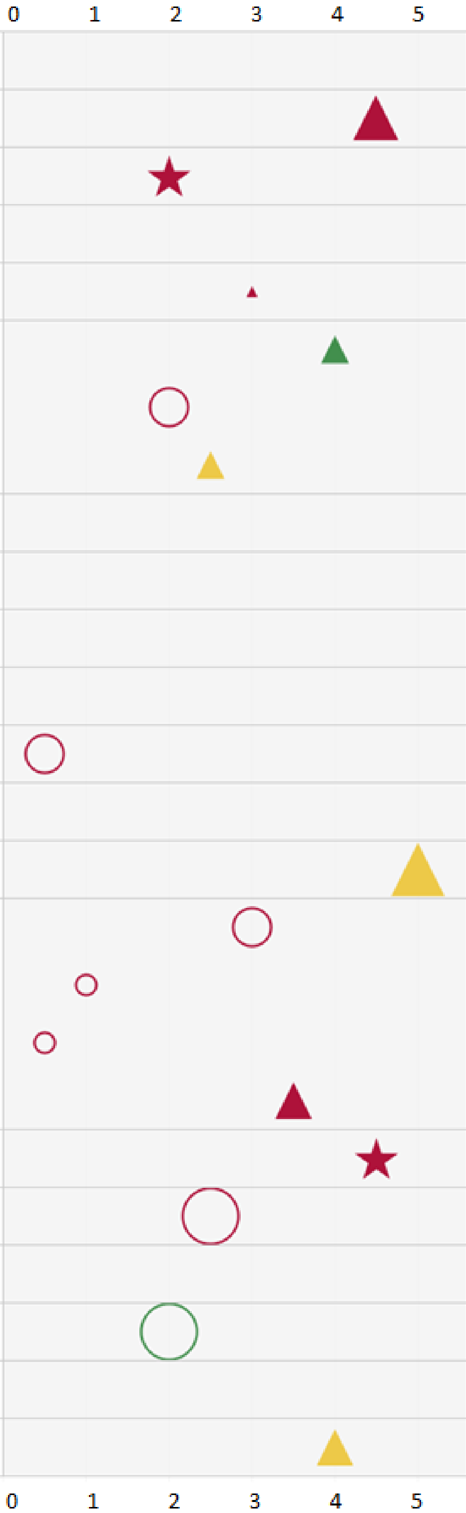

Source: Own elaboration

*European Emerging Technology Companies*

The identification of European desalination technology companies is performed through an analytical framework rating a technology offering based on several criteria to give scores between 0 and 5. These scores are based on the size of the addressable market, strength of the management team, IP protection, differentiated technology/business model, and an overall opinion. Other considerations given to an offering include the growth velocity of a company, the disruption of specific desalination technology in the market (based on efficiency gains over traditional technologies), and the development stage of such technology itself. In Figure 6, the identified innovative companies in Europe are listed with their scores and other variables represented as colours, shapes, and sizes to provide a “desalination technology radar” and help provide a quick view of profiles of these companies. It is important to note that not all companies have received rating up to the date of this publication and are hence shown here as blank.

*Table 2: European Emerging Technology Company Profiles*

| Country | Technology Class | Company |
|---|---|---|
| Czech Republic | Electro-chemical (ED, EDR, EDI) | MEGA a.s. |
| Denmark | Membranes | Aquaporin |
| France | Other desal | Adionics |
| | Thermal desalination | TMW Solutions |
| Germany | Desal operation (scale, fouling, pre-treatment, monitoring etc) | Membran-Filtration-Technik (acquired by Aquarion) |
| | Membrane distillation | EvCon Water |
| | | Memsys (acquired by New Concepts Holdings Ltd) |
| | | SolarSpring |
| | Multi-effect | Qwair Group |
| | Other desal | KSB |
| Norway | Energy Recovery Device | Aqualyng |
| Spain | Thermal desalination | Mora industries water system S.A. |
| Sweden | Membrane distillation | Xzero |
| Switzerland | Thermal desalination | TPTec |
| The Netherlands | Electro-chemical (ED, EDR, EDI) | Voltea B.V. |
| | Membrane distillation | Aquastill |
| | | BLUE-tec |
| | | Memstill and Mempower (WUR) |
| | | SolarDew/ Thermo Dew |
| | Other desal | Cool Separations (previously EFC Separations) |
| | Thermal desalination | Klaren BV |
| | Thermal evaporation vapor recompression | Salttech |
| UK | Desal operation (scale, fouling, pre-treatment, monitoring etc) | Filter Clear (Acquired by Bluewater Bio ) |
| | Forward Osmosis | Modern Water |
| | Thermal desalination | Desolenator |




**Development Stage**
- Early and Late Majority
- Early Adopters
- Pilot Stage
- Demonstration Scale
- Applied Research
- Null

**Disruptivity**
- ★ Highly Disruptive
- ▲ Moderately Disruptive
- O Low Disruptivity
- ! Null

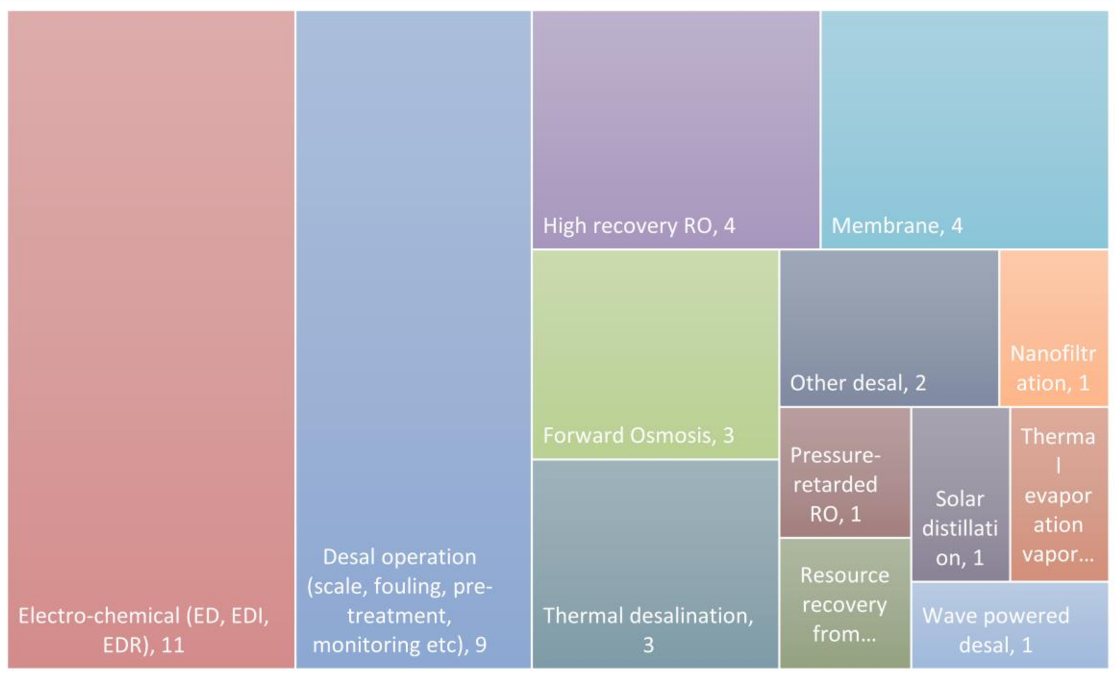
**Velocity**
- Null
- Above Average
- Average
- Below Average

Source: Own elaboration (BlueTech Research, 2021)

### 2.2.2 Emerging technologies

A global patent and licensing review were completed to evaluate if any class of desalination technology can be expected more prominent. Two classes of technology did show high patent activity in 2020 compared to the others. The first is Electro-chemical processes with ten patents filed and operational efficiency offerings with nine patents filed. These two areas displayed more than twice as many patents as the next most active technology class (BlueTech Research, Patent Watch, 2020). A full breakdown of patents filled for each technology class can be seen in Figure 7.

*Figure 6: Desalination Technology Patent Activity in 2020*




Source: Own elaboration - BlueTech Research, Patent Watch, 2020

Only one technology class stands out when evaluating the technology available for license out of the research assessed institutes. Membrane materials, manufacturing, and coatings made up to 33% of the licensing opportunities, while no other technology class considered broke above 11% of the total. Much of the desalination research taking place appears to be focusing on material science and manufacturing practices (BlueTech Research, Licensing Tracker, 2020).

*Key findings were as follows:*

- *Limited patent activity is taking place in Europe compared to the rest of the world*

When comparing patent and licensing activity within Europe to the rest of global patent activity, it is observed that limited patent activity is taking place in Europe compared to the rest of the world. European patents made up only 7 of the 42 total patents uncovered, which account for only about 17% of the total patent activity. European licensing opportunities made up only 3 of the 18 uncovered, also about 17% of the total.

- *The largest share of commercialized emerging technology belongs to membrane distillation, thermal desalination*

Reviewing the technology landscape, patent activity, and licensing opportunities among emerging desalination technology trends present themselves. The review showed that the largest share of commercialized emerging technology belongs to membrane distillation, thermal desalination, electro-chemical, and operational efficiency offerings making up 51% of global and 68% of the European region's innovation landscape. Even though membrane distillation can be considered a thermal desalination process, it is singled out in this review due to many offerings compared to other thermal processes. While membrane distillation and thermal desalination made up the majority within this sub-group, it is essential to note the patent activity occurring within electrochemical processes and operational efficiency offerings, indicating potential advancement in those technologies. When reviewing the licensing opportunities, research is highly focused on materials development and membrane manufacturing improvements to create more robust membranes that are less prone to fouling.

- *Towards zero liquid discharge and improved efficiency*

These technologies connect in a high-level view of a particular application or goal. Further analysis would need to be performed, but based on this review, higher recovery rates, possibly including zero liquid discharge, and improved efficiency appear to be an essential focus of emerging desalination technology. Membrane distillation promises **to treat water that is too saline for reverse osmosis (RO) and can operate at lower temperatures than many distillation technologies** (between 30°C and 90°C), utilizing low-grade heat from sources such as solar, district heating or waste heat. Membrane distillation has struggled to overcome technical limitations that have slowed its commercialization while also occupying a niche with significant and mature competitive technologies such as evaporators. The process could also be used to concentrate water before evaporators further. While missing from the European landscape, those technologies included in the reverse osmosis class consisted of high-recovery reverse osmosis, which attempts to recover more water or act as a concentration step before evaporation. With such a strong performance by membrane distillation and thermal desalination, high water recovery rates, or even zero liquid discharge appear to be the target application.

While recovering more water is expected, the consequences of higher water recovery rates are harsh operating conditions for equipment and management of the resulting concentrated brine produced as a waste product. Installation of a zero liquid discharge treatment train can solve the brine disposal issue, however as salinity concentration increases with recovery rates, conditions would become difficult for any traditional treatment technology to operate. Electrochemical processes and operating efficiency solutions appear increasingly available in the market and improve the problematic operational conditions and brine management.

- *Electro-chemical processes as a promising technology*

**Electrochemical processes such as electrodialysis reversal offer several operational benefits**. The method uses membranes within an electrolytic cell that, when applied, moves dissolved ions across the membrane producing clean water. While these usually imply a more significant capital investment, their operating cost is expected to be lower than those of reverse osmosis. The membranes are typically **more resistant to fouling than reverse osmosis, and the process can be more selective** based on the membranes used within the cell. It gives the ability to control the separation and removal of specific dissolved ions instead of removing all contaminants. It is helpful for resource recovery or altering the chemistry of water to reduce scaling. Operational efficiency solutions attempt to minimise energy input, chemical requirement and monitor water quality to prescribe action to prevent fouling. These are all increasingly important when aiming at achieving higher water recovery rates due to operating conditions present when treating higher salinity waters.

High recovery rates will be desired from water risk regions both from the industrial and municipal sectors. However, the industrial sector will be the one to most likely implement zero liquid discharge. Industries looking to reuse their water will also seek high recovery rate solutions to limit water use and show corporate sustainability goals are being met. **With electro-chemical processes' ability to selectively remove ions, routes to market for recovered resources should be considered as these technologies improve the chance of successful circular economy applications**. With such high interest to control high concentration brines, consideration for brine management would help assist those looking to recover more water or resources from their water without causing a back-end problem of brine disposal.

# 3 Desalination from the EU Policy perspective

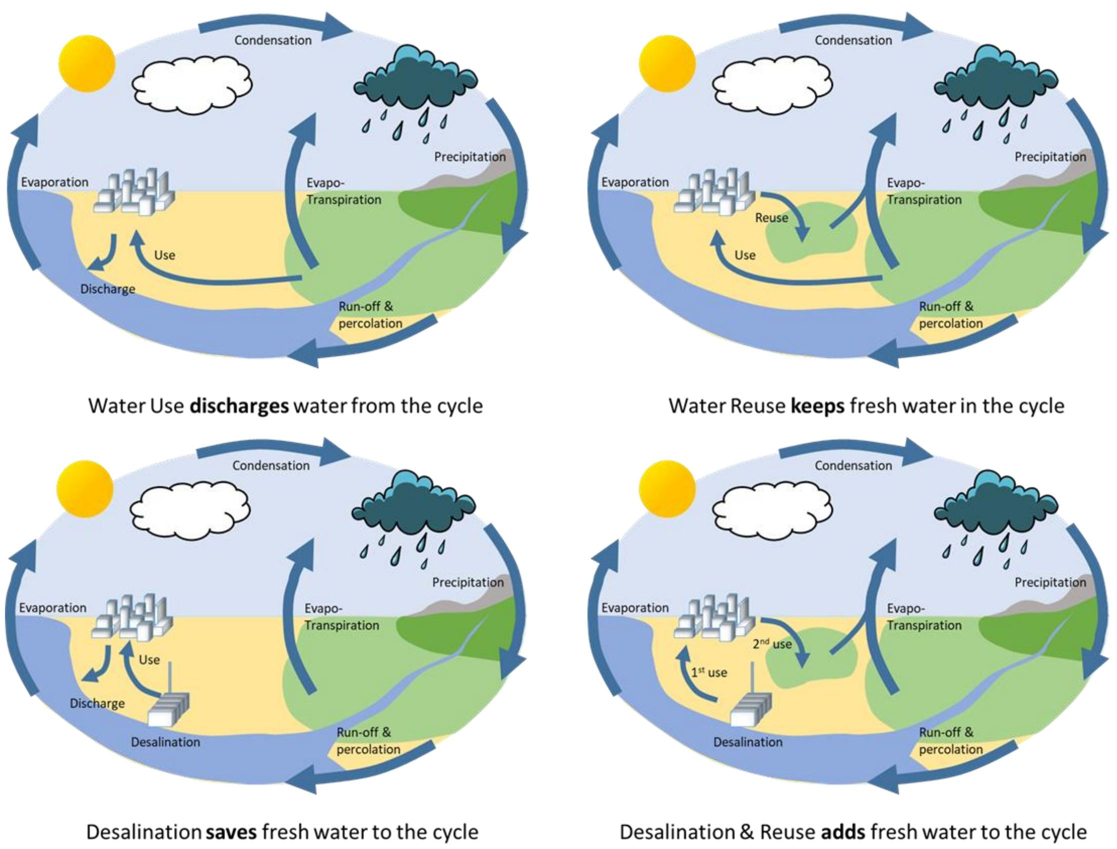
## 3.1 Desalination in the EU policy agendas

The ever increasing demand for water entails the need for alternative water sources for balancing the water supply and demand. Desalination has become a significant alternative water source due to the growing water demand and inadequate conventional water sources in many countries. Desalination removes excess salts and other dissolved solids from water to get clean water for human usage. In many ways, desalination is intrinsically, but often implicitly, part of many of the strategic agendas of the European Union. For illustration, without being exhaustive, the following EU plans, strategies and policies are related to the opportunities and effects resulting from the desalination sector: the EU Regulation on minimum requirements for Water Reuse, the EU's Biodiversity Strategy for 2030, the EU Action Plan Towards a Zero Pollution for Air, Water and Soil, The European Green Deal, The UN Sustainable Development Goals, and also in the Horizon Europe Innovation Missions: Climate Adaptation, StarFish2030, Healthy Soil (see 3.2.).

- *Desalination and Water Reuse Regulation*

The new Regulation on minimum requirements for water reuse for agricultural irrigation has been adopted in 2021. The new rules will apply from 26 June 2023 and are expected to stimulate and facilitate water reuse in the EU. In the EU, one-third of the territories have year-round water stress effects. Climate change increases the frequency and intensity of droughts, and the cost of water shortages in the period 1976-2006 accounted for €100 billion. Figure 8 shows how water reuse and desalination can contribute to freshwater availability.

*Figure 7: How can water reuse and desalination contribute to freshwater availability*

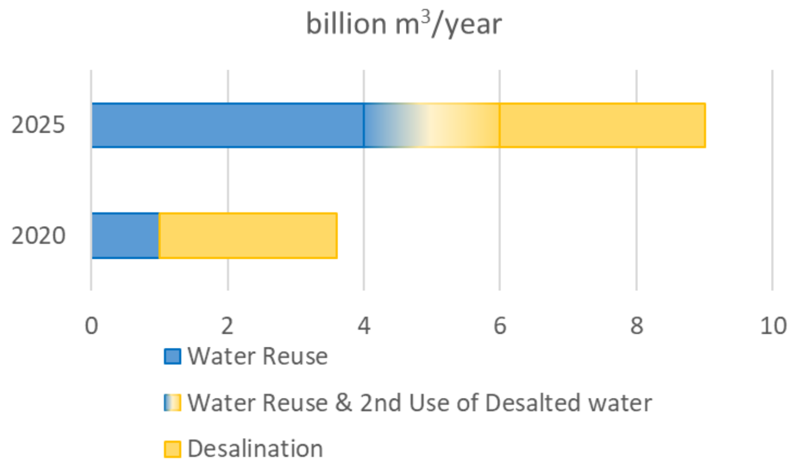



Source: Own elaboration

Water reuse in the EU has largely untapped potential. In 2006, the total amount of reused wastewater in Europe was 1 billion m³/year, mainly in Spain and Italy. Water reuse is a strategic option, beneficial to both the environment and the economy since it keeps fresh water in the water cycle (see Figure 8, top right). The introduction of desalination in the overall water supply schemes will save freshwater from the watershed (Figure 8, bottom left) in the first place. Still, it would become even freshwater positive when combined with water reuse (Figure 8, bottom right). Wastewater originating from desalted water has a lower average salinity after its first use than conventional wastewater and hence will provide a better perspective for wastewater reuse.

Figure 9 places the current European Water Reuse and Desalination capacity in perspective vis-à-vis the envisaged situation for 2025. With 2.6 billion $m^3$ water/year, desalination currently saves more freshwater than water reuse keeps fresh water in the cycle. By 2025, it can be expected that the desalination capacity has grown by a moderate 10-20% to around 3 billion $m^3$/year[4]. The expansion of water reuse may by then even be expansively grown to its achievable potential of 6 billion $m^3$/year (Doeser, 2017). It may well be that the growth of the desalination sector will be boosted as enabling industry to the water reuse sector, as probably also salinity of the wastewater is currently a limiting factor to achieve the more significant reuse potential.

*Figure 8: Current capacity of reuse and desalination, and the perspective for 2025*




Source: Own elaboration (source for an estimate from Doeser, 2017)

- *Desalination and the EU green deal*

The European Green Deal aims to make Europe climate neutral by 2050, boost the economy through green technology, create sustainable industry and transport while cutting pollution. The European Green Deal provides an action plan to increase resource-efficient use by moving to a clean, circular economy and restoring biodiversity and cutting pollution (see below). As been discussed, without doubt, desalination can be regarded as a contributing sector, and in some cases of severe water scarcity even as enabling industry, supplying necessary amounts of water needed to achieve these ambitions.

- *Desalination and the EU Biodiversity Strategy for 2030*

Improved climate and biodiversity tracking methodologies will be implemented to make sure that at least 30% of the total amount of the Union budget and Next Generation EU expenditures will support climate objectives and to ensure 7.5% of annual spending dedicated to biodiversity objectives from 2024 and 10% from 2026 onwards (Wisdorff, 2020). The EU Biodiversity Strategy for 2030 (European Commission, Biodiversity Strategy, 2020) foresees establishing protected areas for at least 30% of land in Europe and 30% of the sea in Europe with strict protection for areas of very high biodiversity and climate value. It also aims to restore degraded ecosystems at land and sea across Europe by planting 3 billion trees by 2030 and restoring at least 25,000 km of EU's rivers to a free-flowing state. Discharges of concentrated brine streams resulting from desalination can have an impact on the surrounding aquatic ecosystems. Studies have been

[4] For estimate of capacity, see chapter 3

performed on the (local) effect on biota changes with particular interest for critical species that are usually ecologically important bio-constructors, such as seagrasses, kelp forests, and corals (Fernández-Torquemadaa, Carratalá, & Lizaso, 2019). Long-term exposure to elevated salt levels from brines can have effects on these critical aquatic ecosystems. Therefore, brine discharge deserves special attention.

- *Desalination and the Zero Pollution Action Plan*

The Zero Pollution Action Plan "Towards a Zero Pollution Ambition for air, water and soil – building a Healthier Planet for Healthier People" is aiming to take actions to secure clean air, water and soil, healthy ecosystems and a healthy living environment for Europeans. The EU needs to prevent, remedy, monitor and report on pollution, mainstream the zero pollution ambition into all its policy developments and decouple economic growth from the increase of pollution, in line with United Nations' efforts. Zero pollution will require the desalination sector to assess the use of chemicals (e.g. pH adjusters, coagulants, flocculants, biocides, anti-fouling agents, reducing chemicals, chlorine and anti-corrosion adhesives) in their daily operation. The EU's chemicals strategy for sustainability is to move towards a toxic-free environment (European Commission, Chemicals Strategy, 2020). The **Chemicals Strategy** is the first step towards Europe's zero pollution ambition. Commissioner for the Environment, Oceans and Fisheries Virginijus Sinkevicius said: "*We owe our wellbeing and high living standards to the many useful chemicals that people have invented over the past 100 years. However, we cannot close our eyes to the harm that hazardous chemicals pose to our environment and health. We have come a long way in regulating chemicals in the EU. With this strategy, we want to build on our achievements and go further to prevent the most dangerous chemicals from entering into the environment and our bodies, and affecting especially the most fragile and vulnerable ones.*" (Loonela, 2020)

- *Desalination and the 2030 Agenda for Sustainable Development as set by the United Nations*

The EU is fully committed to being a frontrunner in implementing the 2030 Agenda for Sustainable Development as set by the United Nations. Through the European Consensus on Development, the EU has aligned its approach to international cooperation and development policy with the 2030 Agenda, placing the SDGs and the Paris Agreement on climate change at the heart of its action, illustrated with previous policy examples. Desalination can be directly linked as enabling for many of the SDGs, here to mention specifically: Clean Water and Sanitation (SDG 6), Sustainable economic growth, employment and work (SDG 8), Innovation and Infrastructure (SDG 9), Sustainable Cities and Communities (SDG 11), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), and Life Below Water (SDG 14).

## 3.2 Desalination in Horizon EU innovation missions

Partly inspired by the Apollo 11 mission to put a man on the moon, the European research and innovation missions aim to deliver solutions to some of the most significant challenges facing our world. They are an integral part of the Horizon Europe framework programme beginning in 2021. Each mission is a mandate to solve a pressing challenge in society within a specific timeframe and budget. Incorporating Missions in Horizon Europe increases the effectiveness of funding by pursuing clearly defined targets. There is a link between desalination and three of the five missions: (1) Adaptation to Climate Change, (2) StarFish2030 and (3) Soil Health.

*Mission on Adaptation to Climate Change*

The mission of Adaptation to Climate Change is that by 2030, 100 pilots of innovative solutions should be in place, thereby increasing the climate resilience of regions and communities. "*Examples include increasing the capacity of our rivers and wetlands that protect us from flooding; more robust buildings, more resilient crops and smarter irrigation; restoring fire-resilient forests, local energy systems, or early warning systems to safeguard our health and wellbeing.*" Availability of sufficient clean water will be a crucial challenge in adaptation to climate change. Desalination can play an essential role in many EU regions to increase water availability.

The Mission Board on Healthy Oceans, Seas, Coastal and Inland Waters has proposed a mission entitled **Starfish 2030**: Restore our Ocean and Waters by 2030. In the coming decade, a crucial challenge will be water security. In addition to global warming, water availability is directly affected by increasing demand for water from industry, agriculture, urbanization and tourism. It escalates global demand for renewable energy, which is strongly water-dependent, saline intrusions, and surface- and groundwater pollution. There are multiple risks associated with water scarcity. To name but a few: loss of livelihood due to increasing water variability, modification of river streams and morphology, and pollution transmission to the entire water system (including the ocean and seas). Desalination can be a part of the solution to mitigate these water scarcity risks and introduce new emissions in coastal areas that have to be managed.

*Mission on Soil Health and Food*

The mission on Soil Health and Food recognizes that land and soils are essential for all life-sustaining processes on our planet. They are the basis for the food we grow and many other products such as feed, textiles, or wood. Soils also provide a range of essential ecosystem services for clean water, supporting biodiversity, cycling nutrients, and regulating climate. Soils are highly dynamic and fragile systems - and they are a finite resource. It can take up to 1,000 years to produce 1cm of soil. Soils are facing pressures from an increasing population with demands on land for production, settlement and industries. Soils are also heavily affected by climate change, erosion and sea level rises. Approximately 33% of our global soils are degraded, and in the EU, erosion is affecting 25% of agricultural land. The second use of desalinated water can provide the suitable water and mineral composition for water reuse in agriculture.

## 3.3 The EU support to Research & Innovation

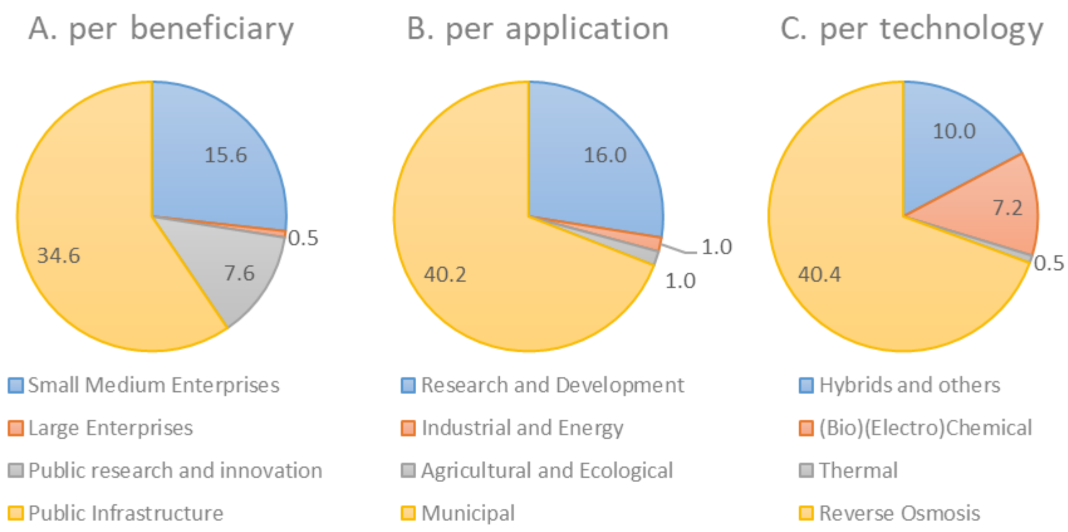
The status of desalination as an emerging sector in EU policy can be measured in terms of the modest share it took from EU contributions over 2014-2019. A contribution of €58.2 million from the European Regional Development Fund (ERDF) was dedicated to mainly infrastructural investments and €23.3 million from the EU Research and Innovation programme Horizon 2020 (H2020) innovation activities. In summary (a detailed analysis below), the contributions to the desalination sector had the following characteristics:

- **Beneficiaries**. ERDF supported €23.7 million to private enterprises, mainly to SMEs all over Europe, to build capacities and equipment for their technology development and production, either directly to the SMEs or via knowledge transfer from knowledge institutions. H2020 supported, with €15.0 million, private enterprises for research and development and with €8.3 million, research organisations.
- **Co-funding purpose.** ERDF co-financed with €34.6 million in investments in desalination infrastructure by public water utilities or companies, mainly around the Mediterranean basin. Besides contributions to existing schemes, at least contributions were made to realize a new desalination capacity of 9,000 $m^3$/d. H2020 supported beneficiaries are spread over the whole European Union, showing that technology providers and knowledge institutes are not only present in the regions with the most severe water stresses.
- **Technology.** ERDF funding went primarily to projects related to reverse osmosis (RO) technology, clearly representing the state-of-the-art of the desalination sector. H2020 funded principally R&D projects related to electro-chemical desalination technology, clearly representing emerging technologies.

### 3.3.1 R&I Projects funded by the European Regional Development Fund (ERDF)

An analysis of projects funded by ERDF in several areas is provided for the period 2014 – 2019 using a dataset designed by the JRC (Bachtrögler et al., 2020). Around €58.2 million was directed to the desalination sector. From Figure 10A, it can be seen that indeed SMEs did receive €15.6 million of this budget mainly for investment in infrastructure, capacities and equipment directly linked to research and innovation activities. Also, a large portion was for the support to environmentally-friendly production processes and resource efficiency, especially investments in energy recovery of desalination plants. Public research organizations received €7.6 million mainly for technology transfer and university-enterprise cooperation, primarily benefiting SMEs.

*Figure 9: Categorization of ERDF funding for desalination over the period 2014-2019 (in Mln €)*




Source: Own elaboration

The largest share of €34.6 million was to co-finance investments in desalination infrastructure by public water utilities or companies a.o. for a total new installed capacity of at least 9,000 m³/day (listed in Table 2, with a total ERDF contribution of €5.7 million) and for some urgent plant extensions (capacity increase not known) or plant optimizations. The total investments in increasing the desalination capacity in the EU is estimated in the order of €200 million for that same period[5].

*Table 3: Investments in desalination capacity co-funded by ERDF*

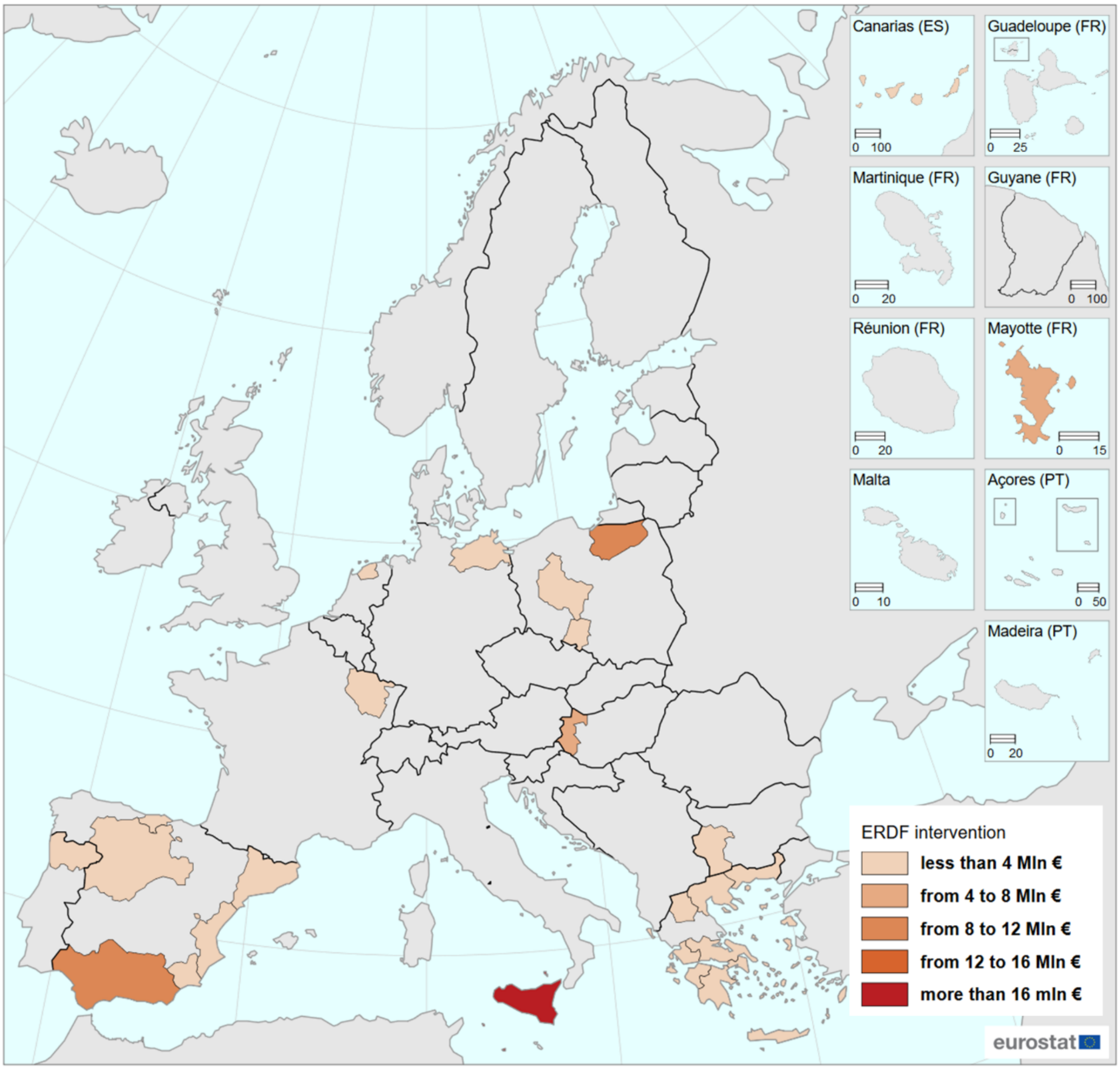
| **Location** | **Capacity (m³/day)** | **ERDF intervention (x €1,000)** |
|---|---|---|
| Hercules (EL) | 300 | 277 |
| Kimo (EL) | 600 | 172 |
| Koufonsia (EL) | 600 | 275 |
| Mykonos (EL) | 1,000 | 650 |
| Karderadou and Bourbulou (EL) | 2,000 | 1,185 |
| Chios (EL) | 2,000 | 2,515 |
| Trojonian (EL) | 2,300 | 642 |

Source: Own elaboration

From Figure 10B, it can be seen that around €16.0 million was directed to research and development, whereas about €40.2 million was attributed to infrastructure related to the municipal water supply. Regarding the breakdown in different technologies (Figure 10C), the contributions mainly were related to reverse osmosis (€40.4 million) and (bio) electrochemical technologies (€7.2 million). Contributions to thermal desalination, globally a relevant class in desalination, were almost absent. The remainder was for hybrid schemes or not classified.

[5] Mainly based on figure 6.17 in The EU Blue Economy Report 2020 (European Commission, 2020) in which investment estimates were based on awards data and derived from Engineering, Procurement and Construction data (Source: Desaldata, JRC analysis).

*Figure 10 Regions with ERDF intervention related to desalination over the period 2014-2019*




Administrative boundaries: © EuroGeographics © UN–FAO © Turkstat
Cartography: Eurostat – IMAGE, 12/2020

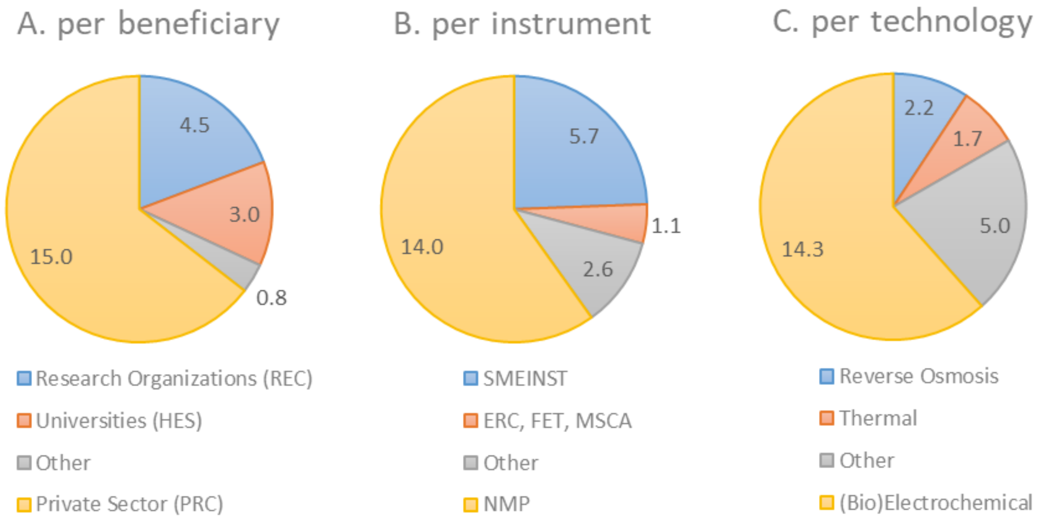
Source: Own elaboration

Regional distribution can be seen based on the location of the beneficiaries, which is provided in more detail per region in Figure 11. The largest share of €35.0 million was for the Mediterranean Sea basin (Spain, Italy, Greece). The most significant ERDF intervention was made in 2018 in Sicily on the Aeolian Islands Lipari and Vulcano (€21.5 million). For the region of Sicily, the situation of the smaller islands (Levanzo, Favignana, Marettimo, Lampedusa, Linosa, Pantelleria, Salina, Lipari, Stromboli, Panarea, Vulcano, Alicudi, Filicudi and Ustica) remains at the top of the priorities to be addressed. These remote islands are still almost entirely dependent on expensive diesel for the electricity supply, and their water supply is another weak point. The region of Sicily has repeatedly submitted a request for recognition of the State of natural disaster to the State, the last time during the severe water crisis of the summer of 2017. Often the water need is overcome by barges, small ships to transport water. The challenging problem of purification also remains pending, which sees the vast majority of small Sicilian islands, with different degrees of non-compliance, outside the legal standards. At the same time, in some realities, there is no type of purification (Battioto, 2018).

### 3.3.2 Projects funded by the Horizon 2020 Programme

A closer examination of projects funded by Horizon 2020 is provided here. The programme aims to achieve breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market. By coupling research and innovation, Horizon 2020 is helping to achieve this with its emphasis on excellent science, industrial leadership and tackling societal challenges. The goal is to ensure Europe produces world-class science, removes barriers to innovation and makes it easier for the public and private sectors to work together in delivering innovation. For the period 2014 – 2019, around €23.3 million were directed to the desalination sector.

*Figure 11 Categorization of H2020's €23.3 million funding for desalination over the period 2014-2019*



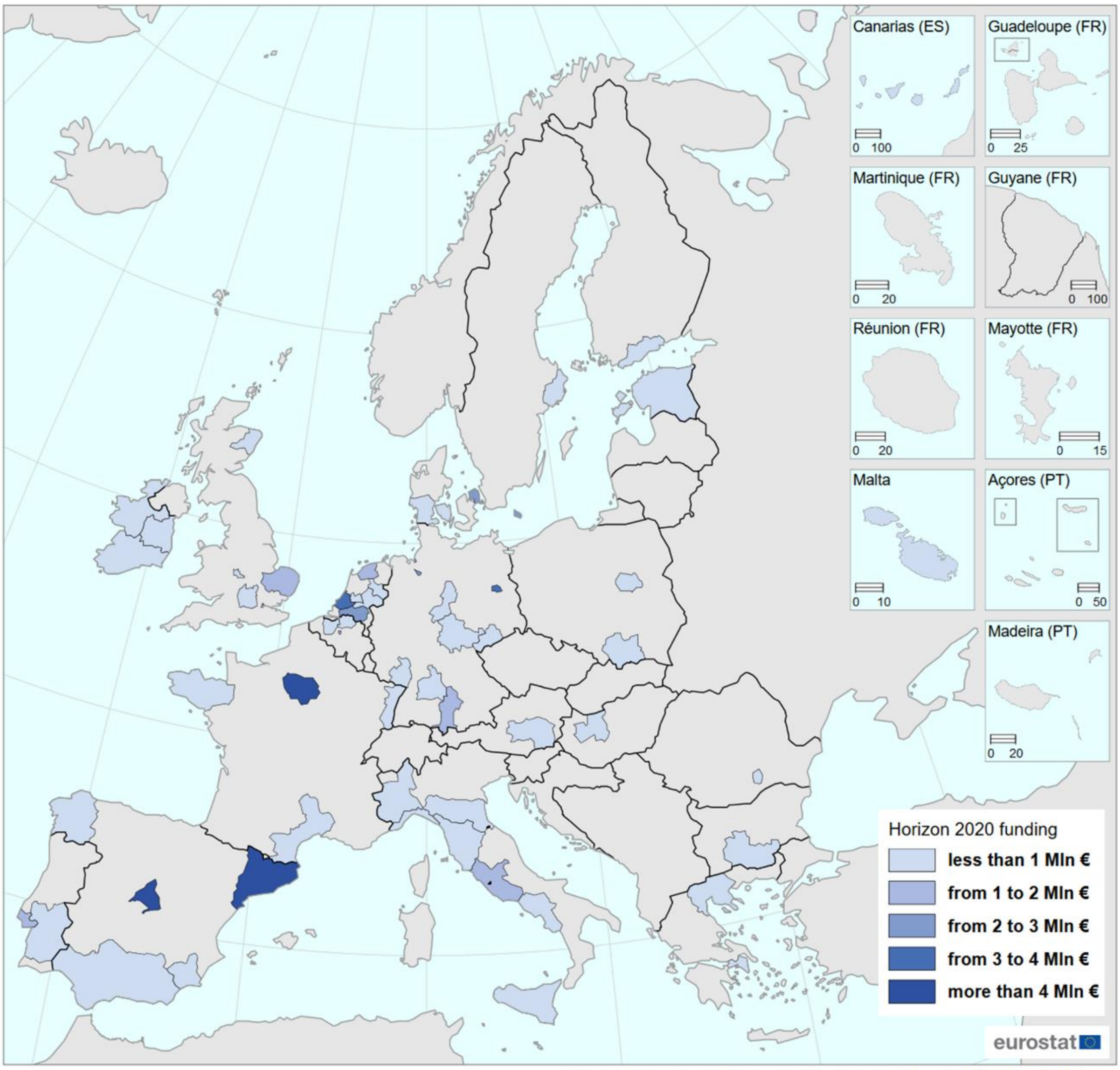

Source: Own elaboration

From Figure 12A, it can be seen that about 2/3 of this budget was directed to the private sector to stimulate research and development (€15.0 million), and most of the other 1/3 to universities and research organizations. From Figure 12B, it can be seen that the SME instrument had a considerable share of €5.7 million in desalination technology-oriented development at SMEs. In contrast, the instruments for foundational academic research had only a small contribution of only €1.1 million. The latter can be explained by the fact that desalination can be seen as an application that the fundamental researcher may not target. The significant contribution came from a dedicated thematic call on desalination in 2015 from the Nanotechnologies, Advanced Materials and Advanced Manufacturing and Processing (NMP), with a total budget of €14.0 million, from which two projects were granted[6]. Regarding the division over the desalination technologies*,* Figure 12*C, the contributions* were mainly related to (bio) electrochemical technologies (€14.3 million), mainly from the two granted projects in the NMP call.

From Figure 13, some regional spreading can be seen based on the location of the beneficiaries. The largest share of €11.7 million was for companies and organizations in the North Sea region (mainly The Netherlands and Germany). In contrast, parties from the Mediterranean Sea basin got €7.4 million (Mainly Spain and Italy).

[6] NMP-24-2015

*Figure 12: regions with H2020 funding related to desalination innovation over the period 2014-2019*




Administrative boundaries: © EuroGeographics © UN–FAO © Turkstat
Cartography: Eurostat – IMAGE, 12/2020

Source: Own elaboration

## 3.4 Desalination innovation drivers for the EU

The main driver for research and development, and resulting innovations as co-funded by the EU over the past period, seems to lower the energy consumption of desalination. A second driver may be to reduce the costs for desalination. In this section, **innovation drivers are revisited**, and it is found that there is not much room for improvements in both aspects. **Essential drivers are d**ecreasing the impact of desalination by reducing brine discharge or **increasing the added value of desalination for the second use**. A **more holistic approach can also be proposed,** which prevents the need for desalination or eventually entails desalination being a temporary addition to the natural water cycle in a watershed.

### 3.4.1 Challenge 1: Make desalination more energy-efficient and cost-effective

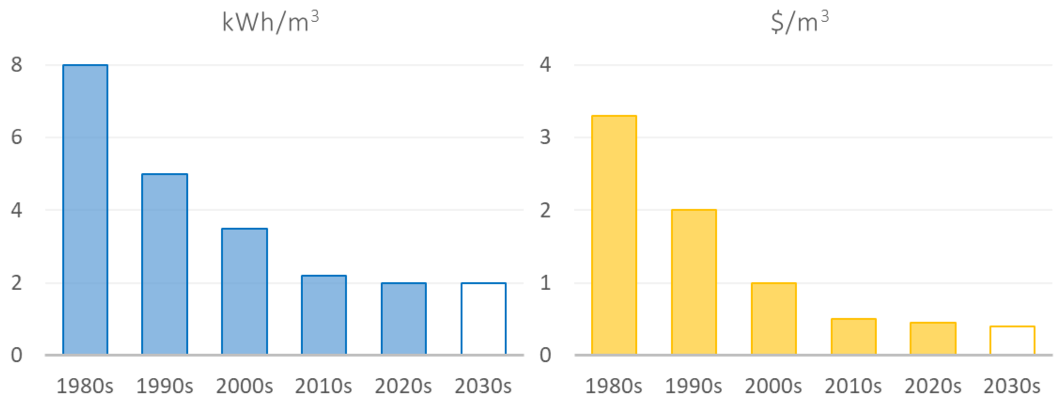
Although it has been proven that reverse osmosis for seawater and brackish water desalination can be regarded as a mature technology, the perception is that it is expensive and energy-intensive.

Regarding energy consumption, over the decades, reverse osmosis technology has become highly optimized in terms of specific energy consumption[7]. State-of-the-art RO systems can operate at a particular energy consumption of near 2 kWh/m$^3$, which may be regarded as close to the practical minimum (McCutcheon, 2019). Also, record after a record is broken by implementing highly efficient hydraulic designs and including energy recovery devices into the scheme.

These reductions in energy consumption also enable the integration of renewable energy sources, particularly solar PV. The new Dubai Reverse Osmosis plant, for example, will be running on PV, and more plants will follow, reducing both environmental impact and costs (Buijs, 2020). As shown in Figure 8, even though it is worth the effort, there seems very little room for further energy-use reductions for seawater desalination and other waters of lower salinity. The energy efficiency of existing plants is close to the best possible. The real point is to make desalination 100% renewables-fed. In this respect, energy storage is the main challenge, and where a grid is unavailable or unfit for buffering power demand and supply, solutions must entail combined water storage and battery storage (Ganora et al., 2019) (Pistochi et al.,2020)

With recent large projects in the Middle East region, records are broken for the lowest desalination costs (see also Figure 8), claiming to achieve even to go as low as $0.31/m3 (Dubai, Jebel Ali desalination plant, 182.000 m$^3$/d, under construction) (Buijs, 2020) (Acciona, 2020). These tariffs may be considered high compared to water treatment schemes for conventional groundwater and surface water. However, especially in coastal areas where advanced treatment is needed to disinfect and remove micro-pollutants, these are already competitive. Hence, also for cost reduction seems very little room for improvement.

*Figure 13: Development of seawater desalination specific energy consumption and costs, indicating the limited room for optimization*




Sources: (Elimelech & Phillip, 2011) and (Shatat, Worall, & Riffat, 2013), 2030 is own projection

### 3.4.2 Challenge 2: Turn brine treatment and disposal from a problem into an opportunity

Desalination of seawater is associated with the production of brine. The term brine for the concentrate coming from a reverse osmosis plant has a negative connotation as if it is of the same class as toxic brines dumped in seas and rivers by chemical industries. However, the concentrate of a seawater reverse osmosis plant neither contains many chemical additives nor hypersaline (only twice the seawater concentration when the plants operate at 50% water recovery). Although this statement is true, sensitive marine ecosystems may require high protection levels, which remains an issue when disposing of the brine (Pistochi et al., 2020). Brines are dispersed into seawater, and chemical additions have been drastically reduced over the years, i.e., minimising the local aquatic ecological impact of brine outfalls (Buijs, 2020). However, it still is a point of attention to reduce chemical use and prevent discharge's local effects. For inland desalination of brackish water, desalination application can become limited by the availability to brine discharge possibilities of the concentrates. High doses of nitrates can be present in the concentrates. Zero Liquid Discharge (ZLD) are considered but often found to become unfeasible because this would include an

[7] i.e., not including site-specific energy consumption for intake, pretreatment, post-treatment, and brine discharge (which will add >1 kWh/m$^3$).

evaporative crystallization process which is energy-intensive and thus costly. It underlines the importance of developments of emerging systems like membrane distillation.

Brines from desalination, however, may allow collecting valuable minerals and metals, mainly when thermal brines are produced that are much more concentrated than with reverse osmosis. In Saudi Arabia, for example, NEOM and the Saline Water Conversion Company have taken up the challenge of making brine mining technically and economically feasible (Buijs, 2020). In practice, this would result in excess amounts of salt deposits, and hence the question is to mine the valuable compounds only selectively. It underlines the importance of developments of emerging systems like electrochemical systems. Brine is also a potential energy source (pressure-retarded). Both minerals and energy recovery have a limited physical and economic scope and can reduce the costs more than representing a profitable investment in the absence of a strong case for alternative brine disposal solutions (Pistochi et al.,2020).

Overall, brine management is a critical issue in desalination, without a single best solution since it is very much case dependent. Local solutions which are available in a place may not work somewhere else.

### 3.4.3 Challenge 3: Enable second use of desalted water in agriculture

In The EU Blue Economy Report 2020 (European Commission, 2020), it was already brought up that desalted water not only would serve the urban or agricultural needs, but it can provide even a net positive water balance to the water cycle (see also Figure 10). After its first use for municipal use, it can be further recycled into the environment, e.g., when treated wastewater effluent provides water for crop irrigation. It was stated that the coupling of desalination for urban demand and water reuse for irrigation could therefore be seen as an adaptation measure and a way to mitigate the increasing water scarcity. Indeed, in Israel, with decades of treated wastewater reuse for irrigation, analyses revealed that the implementation of large-scale desalination considerably reduced the salinity of treated wastewater to levels similar to freshwater. Hence, this enables a larger share of wastewater treatment effluents to become suitable for irrigation (Shtull-Trauring, Cohen, Ben-Hur, Tanny, & Bernstein, 2020).

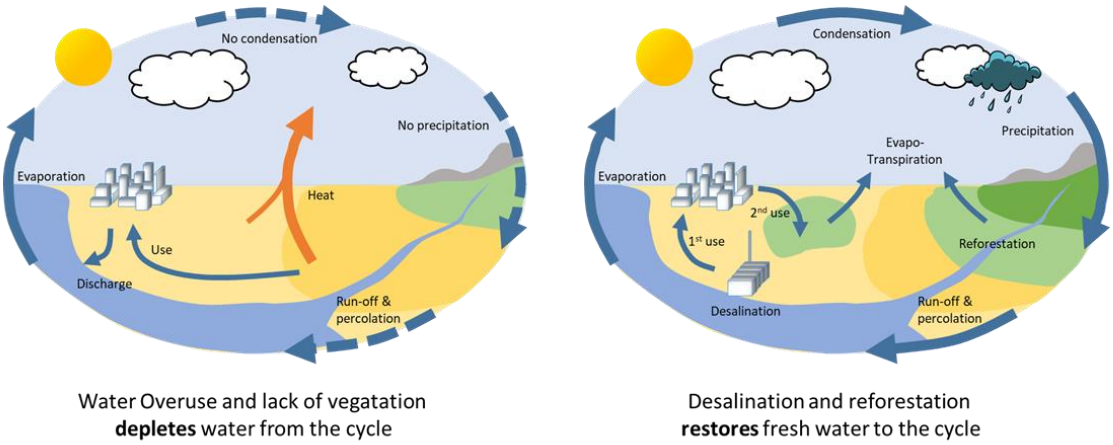
Despite salinity reduction, desalination as an enabler for secondary water use for irrigation needs some reconsideration and hence innovation. Potential negative implications of the reuse of desalted water for agriculture are the reduction in essential nutrients like calcium and magnesium. It leads to deficits for crops, with unfavourable Sodium Absorption Ratios leading to less permeable soils and increasing Boron concentrations, limiting crop growth. Besides the inorganics, traces of organic micro-pollutants (pharmaceutical residues, hormones, microorganisms) will be used for reuse.

### 3.4.4 Challenge 4: Take the holistic approach and look for systemic innovation

There can be a strong case for applying desalination in specific locations of intense water scarcity and high water demand for society and the economy. When zooming out, there are also clear limitations to the use of desalination to alleviate water scarcity. Using desalinated seawater inland, especially on higher altitudes, is economically challenging. Applying desalinated seawater for essential staple foods (maize, rice, cereals, wheat, millet, sorghum, potatoes, cassava, yams and taro) is economically impossible today and unlikely to improve in the future. Producing 1 kg of rice of wheat requires around $1m^3$ of water. Adding 1 euro for the cost price of desalinated water would make these crops too expensive for a large part of humanity.

In the summertime, when vegetation is missing, heat will be building up, but evapotranspiration will be missing, and hence condensation may not happen. This way, lack of vegetation will harm water availability (Figure 9, left). Besides forests also the land use in agriculture is an important driver. Ploughed land hurts summer droughts. In addition, due to water scarcity, the soil is impacted, reducing the chance of rainwater infiltration.

*Figure 14: Desalination placed in a holistic perspective of restoring watersheds*




Source: Own elaboration

Especially in the Mediterranean area, a large part of the annual rainfall arrives after summer in huge cloudbursts, often causing severe flooding of land and cities. Also, here vegetation plays a role; tree roots – and the animals they attract, such as ants, termites and worms – help create holes in the soil for the water to flow through. Plants, bushes and scrubs also help to retain rain and protect the soil.

It is worthwhile to explore desalination in the context of strategies and approaches which enhance the natural sponge effect of soils, use forests to attract rain clouds from sea to land (see Figure 9, right). Vegetation and predominantly deciduous forests help to attract clouds from seas and oceans. In addition, it is shown that these forests emit large amounts of aerosols that contain tiny biological particles – fungal spores, pollen, microorganisms and general biological debris – that are swept up into the atmosphere, which in turn trigger rain. Rain can only fall when atmospheric water condensates into droplets, and these tiny particles make that more accessible by providing surfaces for the water to condense. Some of these plant-based microorganisms even help water molecules freeze at higher temperatures, which is crucial for cloud formation in temperate zones.

Moreover, desalination can be a sustainable way to replenish our water cycle: after primary uses (industrial or domestic), the reuse of desalinated water for irrigation enables agriculture in otherwise unproductive regions and (or) forest growth. The ensuing evapotranspiration feeds the water cycle, further enhancing precipitation while allowing carbon sequestration by plants. In this way, desalination may reduce freshwater abstraction and provide a net water surplus and thus help preserve and restore freshwater-dependent ecosystems (Pistochi et al., 2020).

Increasing water availability, resilience and climate adaptation can be supported by drawing lessons from these recent insights, often missing in models and policies. “Increasing organic farming and biodiversity-rich landscape features on agricultural land”, as mentioned in the European Green Deal, would also support this type of intervention.

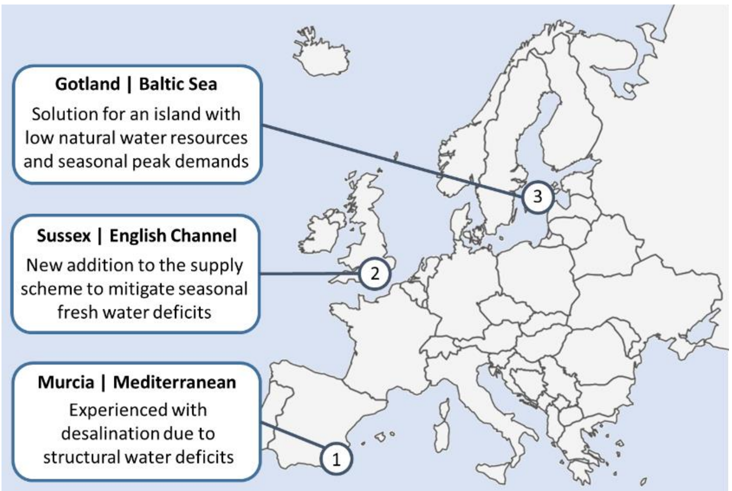
### 3.4.5 Other challenges

Desalination technologies are known for their vulnerability to fouling and their relative low flexibility for peak or intermittent operation. It can be a limitation for the application since desalination plants with relatively high operational expenditures are ideal for standby capacity (e.g., peak season). Areas of innovation in this respect include process engineering (pre-treatment, process conditions) and material science (low fouling materials).

# 4 Desalination from a regional perspective

Three examples of implementation of desalination technologies in Europe are presented in this section. They represent various water source characteristics from the different sea basins, applications and scales, and other needs for research and innovation (Figure 16). Each case starts with describing the specific challenges, how and why desalination is being addressed, and the issues surrounding the (future) implementation. Each case study concludes with the research and innovation needs that were identified.

*Figure 15: Three case studies of desalination, each with specific characteristics*



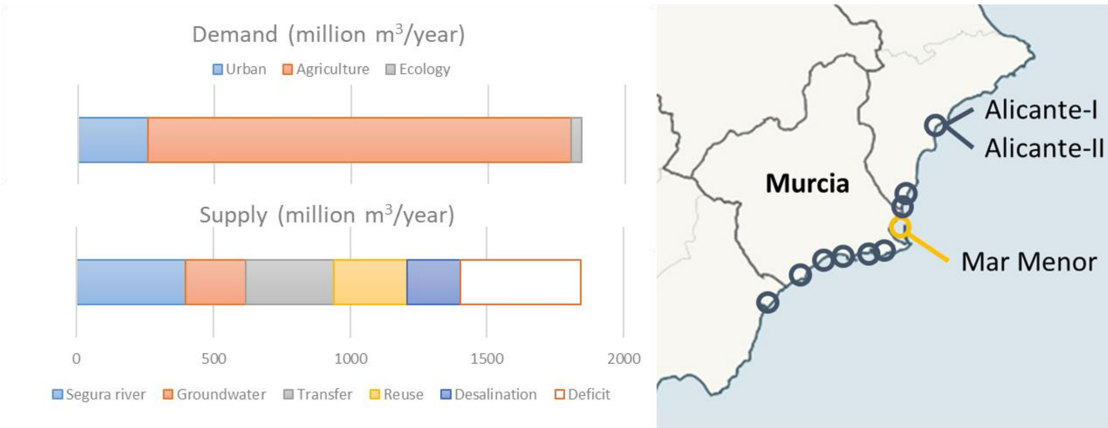

## 4.1 Desalination in the EU Water Scarce regions

### 4.1.1 Integrating water sources: desalination in Murcia

With annual precipitation of only 300-350mm, the Spanish region of Murcia is one of the driest regions in Europe. At the same time, through the years, it has become the fruit and vegetable garden of Europe, primarily due to irrigation and extensive green-house agricultural production. The semi-arid Mediterranean climate of the region makes it ideally suited to produce high-value agricultural products off-season. In the winter months, these fetch premium prices and fruits are supplied to North-Western European markets, such as United Kingdom, Germany, France, The Netherlands and Belgium. Over 2.5 million tons of agricultural products are exported annually, generating over €2.5 billion, representing around 30% of all exports from the region. The sector directly represents 24% of the regional GDP and indirectly 50% (FreshPlaza, 2020). No wonder that water is a critical resource in this region. Murcia region depends on various water sources for its water supply. However, the water demand in the area outpaces the supply and increases the water provision to match the total water demand is not likely to happen in the short term. Hence, not surprisingly, the Eastern coastline of Spain is the epicenter of European desalination capacity. Nevertheless, whether the **desalination can provide sufficient water to address the needs in the Murcia region, how is the integration of different water sources organized?**

Murcia is a Spanish region with 1.5 million inhabitants on a surface area of 11,313 km$^2$, which is 2.2% Spanish. It has 188,000 hectares (1,880 km$^2$) of irrigated land, with highly efficient water use of 3,500 m$^3$/ha/year (i.e., 350mm). The region has a water deficit of around 440 million m$^3$/year (Murcia Today, 2017). Annually the area has a water demand of 1,843 million m$^3$/year and a water supply of around 1,403 million m$^3$/year (Confederación Hidrográfica del Segura, 2020). The water shortage is caused by the low precipitation levels and the growth in surface area of irrigated lands and coastal tourism developments, especially in the ’90s with extensive tourist facilities (Seaview houses and apartments) and golf clubs.

*Figure 16: Annual regional water demand, water supply in million m3/year; Map of Murcia region with indicative locations of desalination plants*




Source: Own elaboration (source for the numbers in the text below).

As can be seen in the breakdown of the regional water demand in Figure 17 (Left), regional water demand consists of 258 million m$^3$/year for households (including industry and golf fields), 39 million m$^3$/year to maintain the aquatic ecology in Segura river, and 1,546 million m$^3$/year for agriculture. It means that every year agriculture receives around 400 million m$^3$ less than requested. As shown in Figure 17 (Right), various water sources are combined to supply water to the region. Approximately 400 million m$^3$/year is available from the Segura river, 218 million m$^3$/year is available from the groundwater, 322 million m$^3$/year is transferred from Tajo and Negratin river basins. Water reuse supplies 270 million m$^3$/year, and desalination accounts for around 193 million m$^3$/year.

The region of Murcia is the European frontrunner in water reuse, with currently already 98% of all the wastewater effluent being reused in agriculture. In the long-term planning of the Segura river basin authority (CHS), there is only little room to increase water reuse with around 20 million m$^3$/year (Confederación Hidrográfica del Segura, 2020).

The maximum water transfer amount through the combined use of aqueducts Tajo-Segura and, to a lesser extent, Negratin-Segura (typically around 17 million m$^3$/year) in the past accounted for the volume of 540 million m$^3$/year. However, in the two most recent hydrological years (2018-2019 and 2019-2020), the transferred water volume was much less abundant and accounted for around 313 and 294 million m$^3$/year, respectively (Confederación Hidrográfica del Segura, 2020). During the period of drought 2015 until 2018, the transfer was substantially lower (142-188 million m$^3$/year). Droughts pose a triple risk. There is less water available for the transfer, but there is also less water available in the Segura catchment area. On top of that, the arable land also received less water directly. **In the years of drought, the only reliable water source for agriculture purposes in the region was desalination**.

Desalinated water is supplied by a whole array of desalination plants (Figure 17, Right). The most extensive facilities are located right above the Murcia region in Alicante (region of Valencia). Alicante-I has 18 million m$^3$/ year, and Alicante-II a 25 million m3/ year capacity and was built with ERDF funding in 2008 (European Commission, EU regional and urban development , 2007). To prevent ecological impact, the desalination plant Alicante-I rejects brines through a pipe at a 1 km distance from the plant and 1.6 km distance from the Posidonia Oceanica meadow (Mancomunidad de los Canales del Taibilla, 2020). Increasing the share of desalination might be limited by the accumulation of boron. In the future, the **desalination capacity in the region is likely going to increase by about 32% from 158 to 209 million m$^3$/year** in the period 2015-2027 (Confederación Hidrográfica del Segura, 2020).

Brackish groundwater is another water source in Campo de Cartagena, where farmers often own Reverse Osmosis desalination installations. The brines of these **brackish water desalination units are rejected into the adjacent Mar Menor** (Figure 17), which would deal with the salt content. The Mar Menor, with 180km$^2$ of surface, is the largest hypersaline lagoon in Europe (Región de Murcia, 2020). **The brines, however, also contain high levels of nitrates, which added to the gradual process of eutrophication**. In 2016, eutrophication started to be visible as a “green soup”. In 2018, the regional government passed a law with urgent measures for Mar Menor intending to reduce nitrates. In August 2019, another phytoplankton bloom was observable. In October 2019, a high impact rainfall event occurred between Murcia and Alicante, and the whole area was flooded. The so-called "cold drop" discharged 60 million m$^3$ of water and 100.000 tons of sediments, including nitrates, phosphates and ammonia, into Mar Menor (We Are Water Foundation, 2019). As a result, anoxia leads to mass death and starvation of fish and crustaceans.

### 4.1.2 Desalination issues

The prevailing water shortages in the region will not be easy to solve with the supply side measures alone, like with increasing the desalination capacity. A combination of the demand and supply-side measures will be needed to optimize the use of available water in the region. Improving water supply is not an easy task, and as can be seen in Table 3, it has many limitations, making supply-side measures alone not feasible. However, there is some **room for new technological development to remove some of the current and future environmental and health concerns related to seawater desalination and brackish groundwater in the region**.

When looking at the demand side, the already initiated improvements in water efficiency in agriculture are essential. The efficiency in urban areas with greywater reuse for domestic purposes would reduce urban water usage and the overall potential of water reuse within the region. Nevertheless, increased water efficiency in urban and industrial areas should be promoted and lower demand in periods of drought. Due to socio-economic and employment reasons, the possible reduction of agricultural surface size is a sensitive issue, although this might become unavoidable to prepare for future climate change scenarios. Converting part of the currently irrigated lands into rewilding areas could increase regional biodiversity, enhance natural vegetation and hence evapotranspiration, act as a water sponge, capture sediments during natural floods, and increase infiltration rainwater to underground aquifers.

Fertilizers used in Campo de Cartagena end up in the superficial Cuaternario aquifer, which in turn is used as a well for irrigation water after the process of desalination. With current membranes, nitrates end up in the brine and are removed from the fields. With **a new generation of selective membranes,** the desalinated water could include the nitrates, which can be reused on the fields, while the brines - without nitrates - could safely be discharged into Mar Menor. This approach would also reduce the groundwater infiltration into Mar Menor, which would minimise nitrate flows.

*Table 4: Available water sources and limitations to increased usage*

| Source | Limitation |
|---|---|
| **Increased precipitation in Segura river basin** | Although this seems the best solution, the increase in annual precipitation often occurs in intense **flash floods**, called "cold drops", and does not increase the available freshwater supply but does cause enormous damage. |
| **Desalination** | Desalination currently forms around 14% of the overall mix. The amount of **boron** in the irrigation and drinking water creates the limiting factor. Desalinated water is mainly used in the adjacent areas, so locally the share of desalinated water is already higher. |
| **Water Reuse** | The region is **already at 98%** water reuse, so at this moment no room for improvement. With additional water supply to urban and industrial in the future (e.g. from desalination), the share of water reuse could increase in parallel. |
| **Water Transfers** | Water transfers have become an increasingly hot **political** topic. The amount of **water available** for transfers depends on rainfall, local use and water needed for the natural flow of the river of origin (e.g. Tajo). Although 550 million m$^3$/ year is the maximum, 200-350 million m$^3$/ year is more likely. Huge increases are not expected. |
| **(Brackish) Groundwater** | Over the past years, more rainfall along the littoral zone of Murcia and Valencia has also increased groundwater availability to some extent. The main issue is the **nitrates** accumulating in the brines after RO treatment of the brackish groundwater. These brines pose a threat to Mar Menor. There is little room to increase groundwater use but an urgency to improve the environmental impact. |

High concentrations of **boron** in the water represent a severe problem for domestic and agriculture utilizations. The recent EU drinking water directive defines an upper limit of 1 mg-B/l. In addition, most crops are sensitive to boron levels >0.75 mg/l in irrigation water. The boron problem is magnified by the partial (~60%) removal of boron in reverse osmosis (RO) desalination due to the poor ionization of boric acid and the accumulation of boron in domestic sewage effluents (Polat, Vengosh, Pankratov, & Polat, 2004). Therefore, the high levels of boron pose a problem when using desalinated water directly as irrigation or drinking water. It now limits irrigation and drinking water from desalination plants in the Murcia region to other water sources.

Groundwater in Murcia, both in littoral and inland aquifers, have relatively high salt contents. Applying **inland RO systems leads to the accumulation of conductivity and salt** in sewage waters and surface waters. Mixing wastewater or surface water with desalinated water could reduce the conductivity (from brines from desalinated groundwater) and the boron concentration (desalinated seawater). How could the mixing of water with higher conductivity and desalinated water with higher boron content be optimized? **Would it be possible to limit boron levels in desalinated seawater through new membrane designs?** Would it be possible to reduce salt content and conductivity of in-land brine discharges by applying technologies that would remove the salt altogether from the brines, using the specific climatological conditions of 300 days of sunshine per year and prevailing dry weather conditions?

Regarding the potential for rewilding Murcia, it would be interesting to see how far some of the biodiversity targets of the EU and the aim to increase protected land and seas to 30% could take place in the region. Preferably, the sponge effect of land-based natural areas would also benefit the absorption and removal of nutrients from surface and ground waters, leading to an improved water quality inflow into the Mar Menor. In addition, measures to remove sediments and nutrients from this coastal saltwater lagoon could be investigated.

### 4.1.3 Regional smart specialisation strategy

The regional innovation smart specialisation strategy of Murcia (RIS3MUR) has selected the following research and innovation priorities (El Instituto de Fomento Murcia, 2020):

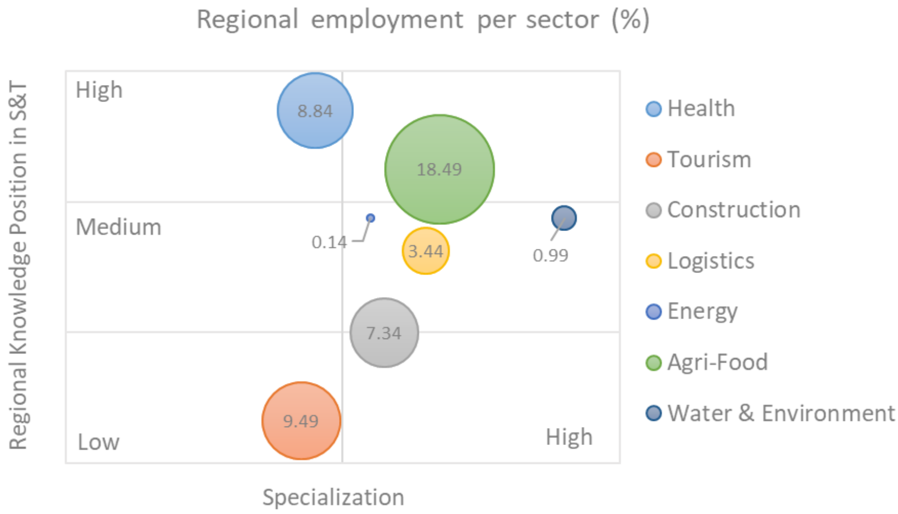
- The food and agricultural innovative activities, including their water/environment and logistics/transport facets.
- Drivers: energy, maritime and marine activities.
- Quality of life: tourism, health and habitat.

In the Eye@RIS3 database, the RIS3 strategy of Murcia highlights, among others topics, the Environment and Water Cycle with the economic domains water supply, sewerage, waste management and remediation activities; water collection, treatment and supply; transportation and storage of water (European Commission, Smart Specialisation Platform, 2020). In addition, among others, the strategy lists KETs in Agrofood Industry, Energy (including Energy Efficiency), Maritime and Marine Industries (including Blue Growth & Blue Renewable Energy).

The RIS3MUR indicates the relative sizes of economic sectors in terms of employment (Figure 18). It clearly shows **a highly specialised water sector**, which might be relatively small compared to other sectors in total economic size. Still, it is **a primary enabler of the most important economic sector of agri-food activities** (agriculture and food processing industries). It includes highly efficient water use (irrigation), water reuse (WWTPs, including tertiary treatment), irrigation canals and running desalination plants.

Concerning water, the autonomous region has exclusive competencies. The strategic importance of water is clearly shown by the "Consejería de Agua, Agricultura, Ganadería, Pesca y Medio Ambiente", the regional ministry of Water, Agriculture, Livestock, Fisheries and Environment, whose name starts with water.

*Figure 17: Regional employment (%), and the level of knowledge and specialisation per sector*




Source: Adapted from the RIS3 of Murcia (Instituto de Fomento Murcia, 2020)

There is also a high degree of water knowledge, expertise and water-related companies. Overall, Murcia is already highly active in tackling the regional water challenges, issues and shortages. At the same time, there is room for research and development of water treatment, desalination and reuse. Participating in interregional collaboration partnerships, such as Water Smart Territories (European Commission, Smart Specialisation Platform, 2020), would be a logical next step to access more knowledge and expertise and share benefit from good practices. Water scarcity is increasing in many EU regions, and the expertise in Murcia could be applied elsewhere and create business opportunities for regional companies, especially in the agri-food sector.

## 4.2 Desalination in the EU Western and Northern regions

### 4.2.1 Adapting to Change: Desalination in Sussex and Hampshire

Desalination can become an unavoidable part of water schemes to obtain a drought-resilient water supply, not only in Southern Europe but also in Western and Northern Europe. For instance, climate change and population growth put increasing pressure on England's water resources: a one out of four chance of a severe drought before 2050. England's National Infrastructure Commission estimates the cost of building resilience to droughts is almost half as expensive as relying on emergency measures in times of drought (saving up to £20 billion over the next 30 years). Despite not being part of the EU, this case can provide information about how desalination is positioned in seasonal droughts and **how the customer would receive desalination in Western and Northern Europe.**

As an example, the regional water distribution service company "Southern Water" supplies 5.3 million $m^3$/day to 2.5 million customers (1.1 million households) in West Sussex and Hampshire, as well as it treats 7.2 million $m^3$/day of wastewater from 4.6 million customers (2 million households) for these regions and East Sussex and Kent (Figure 20). Southern Water has identified the most significant challenge in its Water Resource Management Plan: the loss of available water during droughts. A regional deficit of 294,000 $m^3$/day is predicted by 2030, with a shortage of 188,000 $m^3$/day in Hampshire alone. The trigger for this deficit is a significant reduction in the amount of water Southern Water has available not only for the customers of the Hampshire South but also for the Isle of Wight, due to the implementation of sustainability reductions on sensitive rivers like the Test and Itchen during periods of drought. Proactive investment in water resources can avoid disproportionate recovery costs and economic damage. The National Infrastructure Commission estimates the cost of building resilience to droughts being £21 billion over the next 30 years – while the emergency costs could be £40 billion

*Figure 18: Southern Water's area of operation for water supply and wastewater treatment with locations of planned desalination plants in Fawley and Shoreham*


Southern Water plans to prevent deterioration in service by reducing leakage from the transport and distribution network, constructing a regional grid that enables water trades crossing service borders, and protecting and enhancing flows and natural habitats of their watercourses to improve resilience to drought. Despite extensive water reuse and water trading schemes into the plan, a significant supply and demand deficit will remain in Hampshire and Sussex regions. Therefore, Southern Water is proposing the construction of two desalination facilities at Fawley and Shoreham**.** The proposed desalination scheme at Fawley includes constructing a desalination plant to provide the capacity of 75,000 $m^3$/day of treated, desalinated water, which probably initially will be run at only 1/3 of this capacity under non-drought conditions. The Fawley desalination plant will be based on seawater reverse osmosis (SWRO) technology and would cost £255 million to construct (Southern Water, 2019).

### 4.2.2 Desalination issues

In the business plan 2020-2025, Southern Water states: "*In response to customer and stakeholder feedback, we have sought to maximise the use of more environmentally-sensitive solutions such as water reuse schemes and demand management options. However, the scale of the deficit we are facing has resulted in less-preferred schemes, such as desalination, is required to ensure a resilient service.*" (Southern Water, 2019). Remarkably, desalination here is classified as less-preferred based on a survey. Customers were asked to rank their preferences for supply-side solutions as reservoirs, water reuse, water trading and desalination. *"**Our customers told us that they consider desalination to be the last resort – it was ranked 10th out of 10 options, although they also recognised that it might be needed.***

In general, water supply and seawater desalination require further **investigation of public knowledge and perception of processes and impacts**. Future research will help clarify the public attitude toward seawater desalination and influence public policy processes to approve and set operating conditions for new facilities.

Future research will help integrate seawater desalination plants in sensitive habitats and eventually even be coupled with restoration processes like in this case.

### 4.2.3 Regional smart specialisation strategy

Brighton is part of the Local Enterprise Partnership Coast to Capital, situated in the South East region in the United Kingdom. The Coast to Capital growth hub encompasses the economic hubs of Greater Brighton, West Sussex and East Surrey.

In the 2014-2020 Coast to Capital European Structural and Investment Funds (ESIF) Strategy, the area of Brighton and Hove is described as an internationally recognised university city, with clusters of creative and digital businesses, financial services and a significant visitor economy. Brighton lies at the heart of a new City Region comprising port and market towns, including Lewes, Newhaven and Shoreham.

Important regional sectors and strengths are Creative Digital and IT (CDIT), Financial & Business Services and construction. It also lists essential sectors for business development but outside the priority areas: land-based, food and drink manufacturing and tourism.

Despite direct access to the sea and port facilities, there is **no reference to the Blue Economy**. The only reference is the EON Rampion Wind Farm, which was in the planning phase and was realised in 2018. It has 400 MW of installed capacity, 40% lower than initially planned, mainly because of installing smaller turbines to address regional concerns over visual impact. The Port of Newhaven houses the administration and maintenance offices of the wind park.

The **environmental concerns were also a critical point in the lower level of public support** for desalination. Part of the city of Brighton is called Kemptown, clearly referring to the aquatic ecosystem, which used to be widespread along the coastline. A strategy to revive the kemp fields combined with the sustainable use of desalination might gain popular support.

The RIS3 strategy of Brighton and Coast to Capital does not include a Blue Growth strategy. There are regional needs for solutions, including ocean energy and desalination, supplied from other UK or EU regions. Water provided by desalination could become more critical in the future to support sectors of economic importance for the area, such as land-based, food and drink manufacturing.

## 4.3 Desalination in the EU Island regions

### 4.3.1 Solution for scarce water islands: desalination in Gotland

Water supply on islands is often very vulnerable due to limited natural resources of fresh water and large seasonal fluctuations in demand associated with tourism. Water shortages may ultimately lead to rationing or cutting off supplies on a "pro-rata" basis. In some case, even freshwater is shipped to the islands. Desalination would be the "irresistible solution" as it unlocks the abundant surrounding seawater as a water resource and solves the dependency on climatic conditions and aquifer replenishment. It provides the flexibility to cope with peak season demands.

On the other hand, however, desalination makes the water supply on islands dependent on energy supply, pricing and variability. Hence, desalination on islands may be seen as a shifting problem from one scarcity (freshwater) to another (energy) (Speckhahn & Isgren, 2019), thus not providing a sustainable solution. **What are the drivers for islands to install desalination, and how do they cope with drawbacks?**

An example of an island that has implemented desalination recently is the island of Gotland, Sweden. Located at around 90 km from the mainland, it has about 3,140 $km^2$ (Figure 21), and its population is approximately 58,000. The island is a popular holiday destination. During the summer holiday season, tourism drastically increases the number of water users, e.g., in July 2016, 520,000 incoming visitors were recorded (2016: 2.2 million visitors spending 1 million guest nights) (Florin, 2017). It means that the population on a peak day to be served with water can be estimated to over 83,000 persons. Gotland is very dependent on groundwater for its water supply. It is also true for all of the properties that have individual water sources. Over the past few years, groundwater reservoirs have not filled to the same high degree as previously, and the levels are increasingly becoming very low.

*Figure 19: Map of Gotland (Sweden) showing locations of desalination plants*


In 2019 a broad stakeholder survey was performed (Speckhahn & Isgren, 2019), which suggested four main drivers install desalination capacity: First, not surprisingly, desalination holds the promise of quick and stable access to an infinite water resource; second, desalination enables the protection of groundwater resources and the prevention saltwater intrusion by reducing the extraction of groundwater needed for supply; third, desalination provides clean water whereas in the past quality issues were reported for the supply from groundwater (among others, hardness); fourth, desalination removes the barrier of water limitations for the economic development of the agricultural and tourism sectors.

### 4.3.2 Desalination issues

The survey through the stakeholders' interviews also offered specific concerns that facilitated a broad societal consultation of desalination solutions in the island, which may be helpful in other similar water-scarce islands. ***Despite all the benefits, desalination should still complement other solutions*** (Speckhahn & Isgren, 2019). The concerns mentioned about these shortcomings were related mainly to the higher water costs from desalination than what the citizens used to pay for groundwater. However, the high energy input typically necessary for the desalination process has a leverage of typically 3 to 4 times lower salinity of the Baltic Sea around Gotland than global average seawater. Hence, the energy consumption is much lower. 150 wind turbines supply a large portion of the island's energy island with an installed capacity of 185MW (2018), delivering 432 GWh annually, which is about 45% of the island's energy consumption (2016) (Nilsson, 2019). To put this in perspective, 5.6 GWh would be used for desalination when operating at total capacity year-round (3 million $m^3$/y with an estimated energy consumption of 2 kWh/$m^3$). In the island's capital Herrvik, solar panels have been installed to produce electricity for the desalination plant. In summer, peak water demand coincides with the highest energy production by these solar panels (Swedish Portal for Climate Change Adaptation, 2018). Furthermore, the desalination plants would be considered to operate for peak shaving of water demand instead of baseload water supply.

Another concern mentioned by the stakeholders was that the desalted water could not be sufficiently mixed with groundwater at the desalination plants to obtain the desired mineral content (Speckhahn & Isgren, 2019). However, this was mitigated by adding calcium and sodium carbonates, resulting in a composition which fulfils the requirements placed on drinking water by the National Food Agency (Swedish Portal for Climate Change Adaptation, 2018).

Finally, some concerns were probably not caused by desalination itself. The citizens were worried that desalination might reduce the pressure on different industrial actors (among others, the mining industry) to decrease their consumption or provide legitimacy for their potential water misuse. Some fears were also displayed that by more abundant water availability, careful attention to the quality of the island's scarce water resources might get lost, e.g. concentration for the ongoing problem of high rainwater runoff into the sea due to wetland loss. “The politician argued that there is a **risk that water-related ecosystem services are forgotten if desalination gets framed as the ultimate solution**” (Speckhahn & Isgren, 2019).

It should be noted that Gotland is a frontrunner in the implementation of renewable energy, especially when also the surrounding offshore wind parks are counted, and its biomass plant for combined heat and power (CHP). However, there can be a tradeoff between water scarcity and energy scarcity for other islands, which requires **innovations in integrating renewable energy and desalination technologies**. For example, the smaller Isles of Scilly are still almost entirely dependent on expensive diesel electricity supply. For these islands, the challenge is to implement a smart energy management system together with the desalination plant to produce the desalted water with the smallest possible amount of diesel energy and with the most significant possible amount of PV excess energy (Ciriminna, Pagliaro, Meneguzzo, & Pecoraino, 2016).

Re-mineralization of desalted water by adding chemicals indeed may lead to an acceptable composition for first use. Still, it would not allow for a second use for agriculture or restoring wetlands due to a lack of magnesium. Note that nor for first use and probably neither for second use are sufficient amounts of groundwater available. **Innovations to recover magnesium from seawater are needed** to enable the opportunity for second use. Lastly, Gotland advocates taking the **holistic approach in which desalination is integrated as enabling technology** to restore the natural water system.

### 4.3.3 Regional smart specialisation strategy

Gotland lists two priorities in the regional growth program: Tourism and Food. Eye@RIS3 also highlights these priorities and further specifies under food: the scientific domains Industrial production and technology, Manufacture and food products and Manufacture and beverages. For tourism: the economic domains are accommodation, food and beverage services activities.

All the concerned sectors: tourism, hospitality, agricultural food production and industrial food-processing require water as an enabling resource. The RIS3 does **not specify any economic of a scientific domain to solve the regional imbalance in water** use or develop water solutions, such as desalination.

## 4.4 Opportunities for the next generation of Smart Specialisation Strategies

The design of ERDF 2021-2027 seems to offer better opportunities for interregional collaboration than during the past Multi-Annual Financial Framework (MFF).

Murcia could benefit from this by including interregional collaboration into the ERDF Operational Programme. The initiative of the Interregional Innovation Investments (I3) could also offer exciting opportunities for **Murcia as a living lab for testing new solutions for optimizing water efficiency in water-scarce regions**. In addition, it could provide opportunities for regional solutions and expertise to be applied abroad. With substantial post-pandemic financial support for green recovery starting in 2021, the Recovery and Resilience Facility also offers the opportunity to introduce even more ecological and sustainable solutions in the region. Combined with the enhanced focus on biodiversity in the Common Agricultural Policy (CAP), the region could intensify efforts to make the agricultural sector more sustainable, resilient and biodiverse. Maintaining cover crops reduce the rainwater run-off and soil erosion during intensive precipitations and floods (DANA, “gota fría”), which are often affecting the region (La Verdad, 2019) and might even intensify with climate change.

Water supplied by desalination could also become more critical in supporting sectors of economic importance for the UK and EU regions in Western and Northern Europe. With the UK's departure from the EU, regional smart specialization strategies within the UK are uncertain. The UK might apply for membership of Horizon Europe, which is widely expected. Like the South-East region in the UK, however, many European regions have not included water in their regional smart specialisation strategies. Therefore, they will depend on other regions to develop their solutions or use living labs in the different areas to test technological solutions that their regional universities and companies might grow. A good region for testing new water technologies would be Friesland, located in The Northern Netherlands. The **Region of Friesland has included water technology in its development strategy already in 2003. The topic was later included**

**in its RIS3 and has since developed several demonstration sites and** a whole innovation ecosystem called WaterCampus Leeuwarden. There is a specific demonstration site for desalination, wastewater treatment, drinking water treatment and even renewable energy production by mixing salt water and fresh water (salinity gradient energy). The Campus, city and the region act as **a living lab for water technology, support European start-ups in the field and are also a meeting point for Dutch, European and global water technology companies**. With over 200 European and international company members and collaboration with 25 European universities, it provides a unique insight into existing solutions and scientific developments worldwide. Water conditions in South-East England are comparable to the Netherlands, as both are located at the North-Sea shores. Friesland also borders the Wadden Sea, a "Natura 2000" protected area, requiring specific solutions that address this aquatic ecosystem's needs.

Gotland is a region that acquires the water solution from other areas. Hence, Gotland could be an excellent living lab for testing the holistic approach in which desalination is integrated as enabling technology to restore the natural water system a societal as from a hydrogeological perspective. It would be in line with the more comprehensive proactive implementation of sustainable energy solutions, such as solar, wind and biomass energy and a holistic, sustainable approach to the water scarcity problems. It would thus enable more sustainable, resilient and ecological management of the islands' hydrology.

Around 20 European regions have already become members of the **thematic S3 partnership on Water Smart Territories**, supported by the Smart Specialisation Platform for Industrial Modernisation. Industrial modernisation requires significant investment efforts. The Regional Smart Specialisation Strategies (RIS3) help prioritising and aligning the efforts between public and private stakeholders in EU regions and allocate EU, regional and national funds in a focused and efficient way. At the same time, there are clear opportunities to engage in strategic interregional cooperation along with shared RIS3 priorities to complement each other's competencies, share infrastructure, and develop joint investment projects.

The new programming period foresees a budget of around 500 M EUR to be invested through a specific Interregional Innovation Investment (I3) instrument where specific innovative solutions developed in one region shall be demonstrated at an end-user located in another EU regions. It will probably be the most "close to market instrument" available for financing innovative solutions by the European Commission. Besides this specific instrument, regions can also use their regional ERDF funding to support interregional collaboration and use ERDF for funding synergies with other EU programmes such as Horizon Europe. With the exceptional situation of COVID-19, the European Commission has launched specific funding through Next Generation EU. Depending on regional needs and strategic choices, two of the three funding pillars: **Recovery and Resilience Facility and the React-EU, could be used to install new or improve existing desalination plants**. In either case, the funding will need to be allocated by December 31st 2023. In some regions, climate adaptation increased freshwater availability, and ecological investments have been mentioned as possible intervention areas, for instance, in Spain.

With 1,800 Billion EUR available for the next seven years, the most significant European budget is to be spent through the alignment with the objectives of the European Green Deal. These investments will transform the European economy, industries, and society into a more climate-resilient economy. Innovative specialisation strategies will allow place-based innovation ecosystems to optimize the use of local, regional, national and European funding opportunities and facilitating funding synergies. It will maximise the impact of these various programmes and boost research, innovation, start-ups and scale-ups. It can form a foundation for new economic growth, including in Blue Growth in general and desalination in particular.

# 5 Conclusion and Policy Recommendations

## 5.1 Conclusion

In many ways, opportunities and effects are resulting from the emerging desalination sector for European Union's agendas (section 3.1) like The Water Reuse Regulation, European Biodiversity Strategy, Zero Pollution Action Plan, The European Green Deal, The UN Sustainable Development Goals, and the HEU Innovation Missions (section 3.2): Climate Adaptation, StarFish2030, Healthy Soil. Its status as an emerging sector in the EU policy can be measured in terms of the modest share of EU contributions over 2014-2019 (section 3.3).

For the coming period 2020-2025, it is estimated that investments for new capacity will be €400 million. Still, reinvestments in outdated plants may count to €1 billion and membrane replacements to another €380 million (section 2.1). Analysis of vendors of desalination technologies currently in the market shows that Europe is a central hub for innovation. Regarding patent activity and licensing opportunities, however, Europe seems lagging (section 2.2). Desalination challenges that need to be addressed by innovation include: (1) Make desalination more energy-efficient and cost-effective, (2) Turn brine treatment and disposal from a problem into an opportunity, (3) Enable second use of desalted water in agriculture, and (4) Take the holistic approach and look for systemic innovation (section 2.3).

These challenges are supported by the case study of the Murcia Region (section 4.1). In contrast, the other case studies of the South-East UK Region (section 4.2) and Gotland Region (section 4.3) also revealed societal acceptance and awareness related to impacts of desalination as a solution for water scarcity. Also, the design of ERDF 2021-2027 seems to offer good opportunities for interregional collaboration on desalination issues (section 4.4).

## 5.2 Recommendations

The **challenges mentioned above could be linked to specific programmes and interventions from the following European programming period**. If these are applied in a concerted effort, a considerable improvement of the current status quo related to desalination and blue growth can be obtained. In the Multi-annual Financial Framework 2021-2027, many programmes in which some of the innovation needs - described above- can be addressed.

**PRIMA**, the Partnership for Research and Innovation in the Mediterranean Area, is the most ambitious joint programme in Euro-Mediterranean cooperation. It is paid by participating countries and co-funded by Horizon Europe. PRIMA aims to build research and innovation capacities and to develop knowledge and standard innovative solutions for agro-food systems, to make them sustainable, and for integrated water provision and management in the Mediterranean area, to make those systems and that provision and management more climate-resilient, efficient, cost-effective and environmentally and socially sustainable, and to contribute to solving water scarcity, food security, nutrition, health, well-being and migration problems upstream. Therefore, proactive interventions that would increase soil health, climate resilience, enhance rainwater infiltration and water reuse, and prevent land degradation are paramount. The PRIMA area comprises the entire Mediterranean basin. **It would be advisable to include a more holistic approach to addressing water scarcity and desertification by adding fresh water to the water cycle using water reuse and desalination**. In combination with a change in agriculture and adding more stable organics to the soil to enhance the sponge effect for water and nutrient retention, the area could locally improve the resilience of the catchment area and be better prepared to combat climate change. Specific local actions can further support this holistic effort in improved wastewater treatment and WWTP effluent reuse.

The Strategic Research and Innovation Agenda (SRIA) of European Partnership Water4All, mentions explicitly "sustainable management of residues from desalination plants to protect land, water and sea ecosystems altogether", as well as "efficient citizen engagement in responses to perceptions of risk, and particularly health risk, associated with the use of water from unconventional sources". The SRIA of the European Partnership Blue Economy mentions desalination as a potential interface with the Partnership Water4All. In contrast, no further reference to desalination is mentioned in the SRIA. **To increase the level of granularity of the SRIA for Water4All, it might take the specific health risks of too much boron and too**

**little magnesium into account** for drinking water and irrigation water, respectively. It would require an adaptation of the desalination process and, more precisely, an improvement of the relative selectivity of the membranes used in desalination.

**Mission Climate Adaptation could also address the holistic approach of the global freshwater scarcity** and suggest measures for improvement at the catchment level to enhance resilience, improve ecosystem services, biodiversity and a more sustainable agricultural production. These would make regions less vulnerable to climate change and reduce the need for migration. These measures could improve the EU and the Mediterranean, Middle-East, Sub-Saharan regions, or even the Sahara itself, especially when the increased freshwater availability coincides with regional initiatives, such as the Great Green Wall. Noteworthy are local success stories, such as the interplanting of crops and trees, referred to as farmer-managed natural regeneration, or FMNR, developed by Burkinabe farmer Yacouba Sawadogo (Vizcarra, 2019). Before Sawadogo's successes, on-farm trees were primarily regarded as a nuisance in the Sahel. It is in part due to the belief that trees divert water away from crops. While in fact, trees in African drylands can promote deep soil and groundwater recharge in a future climate with more intense rainfall (Bargués-Tobella, et al., 2020). Yacouba's impact on restoration in the Sahel has been more significant than that of all national and international experts taken together, which is why he was awarded a special reward (The Right Livelihood Foundation, 2018).

**Mission Climate Adaptation can form the bridge between European RDI efforts and global challenges and regional needs**. European and African catchment areas can act as living labs where improvements are shown in practice. These can be wildly successful when also local knowledge is valued and included, as can be observed by the Sawadogo example.

**Mission Healthy Soil and Food could consider the health aspects of desalinated water, boron and magnesium**. It could also improve the soil's organic fraction and the soil's sponge effect and fertility.

**Mission Starfish2030 could take the challenge to reduce the ecological impact of desalination**. Especially brine treatment and use of chemicals are essential to improve or maintain healthy aquatic ecosystems. Mission Starfish could support innovation which can make valuable contributions in this domain. Also, with the European Green Deal in place and the North-Sea, especially Dogger Bank and coastal areas aiming for Green Hydrogen production, there will be a need to sound desalination plants ecologically. Doggerbank is a "Natura 2000" reserve. The cost of desalination compared to the overall cost of hydrogen production is negligible. Therefore improvements in the environmental performance of desalination to increase the overall sustainability of green hydrogen can be developed and included. Specific membrane designs could significantly alter chemical use and brine treatment.

## Table of Figures



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