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The Green Collection

Aligning Desalination Proposals to the Green Deal

The Green Collection: A series of short notes providing information to help align selected infrastructure projects to the European Green Deal.

This collection provides basic information on the environmental, climate, biodiversity and disaster risk reduction aspects of selected types of infrastructure projects. It aims at equipping colleagues dealing with such projects in headquarters and European Union Delegations to better address their alignment to the Green Deal.

Desalination fundamentals

Desalination removes salt from water, typically for municipal or industrial/agricultural uses. It is produced from brackish or from seawater. Although desalination of brackish water is cheaper, its total volume is limited. In contrast, the world's oceans with over 97percent of the planet's water resources provide an unlimited supply. Over 150 countries are already using desalination with over 22,000 operational desalination plants, supplying over 300 million people with potable water (*International Desalination Association*). Despite being energy intensive technology, the *IPCC* lists desalination as an "adaptation option".

Desalination includes a wide suite of technologies which can roughly be divided into two main categories:

- **Membrane-based:** pressure-driven processes such as reverse osmosis (RO) and nano filtration (NF) that transfer water at high-pressure through a series of semi-permeable membranes. These represent two-thirds of installed capacity globally. The recovery ratio[1] is 30 to 50 percent. Because membranes can easily get clogged, seawater reverse osmosis (SWRO) plants usually build in pre-treatment facilities to improve raw water quality. The raw water quality and the number of pre-treatment steps have (apart from energy) a major impact on the overall cost. Higher salinity levels, higher suspended solids, higher temperatures (and temperature variations), and higher organic loadings and biological activity lead to increasing costs; SWRO has a competitive edge in less saline, cleaner, cooler waters. Membrane-based desalinated water usually requires more post-treatment because of its lower quality, compared to thermal processes.

[1] Portion of the input water to a desalination plant that is converted to fresh water.

- **Thermal** processes such as vapor compression (VC), multi-stage flash distillation (MSF) and multiple-effect distillation (MED) that use heat from an external source (such as a power plant or refinery) to evaporate and condense water to a purified form. Thermal processes use huge amounts of seawater; their recovery ratio is typically only 10 percent to 20 percent. Thermal technologies are not sensitive to seawater quality and have a competitive edge in more saline and hotter waters with a high risk of biofouling. Because of high temperature, large quantities of polluting anti-scalant[2] chemicals are needed.

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Hybrid desalination plants incorporate a combination of a thermal facility and membrane system. These may be the best option where source water quality is poor and options for cheap energy exist. In particular, they may be competitive when there are large diurnal or seasonal variations in power demand, leaving low-cost power periodically available for desalination.

Benefits of Desalination

Addressing water scarcity. With increasing population, urbanisation, and economic growth, water scarcity is projected to worsen. By 2030 the world could face a 40 percent shortfall in water supply, exacerbated by the consequences of climate change. Already one-third of the world's aquifers are in distress. Even with reuse of treated wastewater and drainage water, only half of the supply-demand gap would be closed.

Tool of risk management. The ocean is practically limitless. Desalination is thus drought proof, and it is a good way to deal with climate change risks. Desalination is becoming increasingly important as a solution to the water challenges and a serious climate change adaptation option. It also provides a response to exogenous risks such as dependency on increasingly expensive imported water. The stable, efficient supplies of urban and industrial water that desalination provides can help governments manage a range of economic, social, and political risks.

High quality, high reliability. Despite significant reduction in cost, desalination can still be expensive, depending on local circumstances. It needs to be used strategically to address a limited range of problems. For example, to serve markets that require high quality and complete reliability of service such as large cities, high-value industry, commerce, and tourism. Desalination is of specific interest in locations where alternatives are high cost or where the risk of supply failure is high. Furthermore, it taps a virtually infinite resource that is more immune to political or social claims than conventional hydraulic works.

Limited but effective locations. Desalination is demanding in terms of location. Water is very expensive to lift or transport. The location of a desalination plant should therefore be near the sea and close to its market. The typical location of a desalination plant is a coastal city or coastal industrial zone. Conveniently, already over one-third of the world's population lives in urban centres bordering the ocean and in many arid parts of the world the population concentration along the coast exceeds 75 percent.

Improving performance on cost and environmental issues. In the past desalination was expensive and with serious environmental impacts. However, new technologies are radically reducing plant construction costs, increase productivity, and reduce the need for chemicals. In addition, renewable energy-powered plants are beginning to become commercially available, scalable, and affordable. Membrane operations driven with renewable energy can make desalination more sustainable and environment friendly. In particular, Reverse Osmosis (RO) desalination technology coupled with solar energy will supply freshwater at a competitive price and reduce the usual greenhouse impacts associated with grid electricity demand for desalination (Kharraz et al., 2023). The World Bank suggests it is not unlikely that cost reductions of 20 percent within 5 years will be developed for SWRO and 60 percent in 20 years.

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[2] Scaling is the formation and precipitation of crystallized mineral salts that form scale. Anti-scalant is added before the feed water enters the facility. "Green" antiscalants claim a faster biodegradation. However, in reverse osmosis membrane systems, quick biodegradation creates a carbon source for bacteria and contributes to biofouling. Avoiding the use of antiscalant as much as possible remains the best option.

Table: Summary of Worldwide Seawater Desalination Costs (*World Bank, 2019*)

Desalination method		Capital costs (million US$/MLD)		O&M costs (US$/m³)		Cost of water production (US$m³)	
		Range	Average	Range	Average	Range	Average
MSF		1.7-3.1	2.1	0.22-0.30	0.26	1.02-1.74	1.44
MED-TVC		1.2-2.3	1.4	0.11-0.25	0.14	1.12-1.50	1.39
SWRO Mediterranean Sea		0.8-2.2	1.2	0.25-0.74	0.35	0.64-1.62	0.98
SWRO Arabian Gulf		1.2-1.8	1.5	0.36-1.01	0.64	0.96-1.92	1.35
SWRO Red Sea		1.2-2.3	1.5	0.41-0.96	0.51	1.14-1.70	1.38
SWRO Atlantic and Pacific oceans		1.3-7.6	4.1	0.17-0.41	0.21	0.88-2.86	1.82
Hybrid	**MSF/MED**	1.5-2.2	1.8	0.14-0.25	0.23	0.95-1.37	1.15
	SWRO	1.2-2.4	1.3	0.29-0.44	0.35	0.85-1.12	1.03

Note: Costs are at 2016 values. MED-TVC = multiple effect distillation with thermal vapor compression; MLD = million liters per day; MSF = multistage flash distillation; O&M = operation and maintenance; SWRO = seawater reverse osmosis.

Environmental concerns related to desalination facilities

Feed water intake: Water intake structures can suck fish and shellfish or their eggs into the system. Larger animals may be killed or injured when they become trapped against screens at the front of an intake structure. An intake velocity of less than 15 cm/second is thought to be slow enough to let aquatic species escape. The structure itself may change local physical conditions of the seabed. Proper site selection for intake reduces the aquatic loss caused due to entrainment.

- **Surface intake** (in open water) is the most popular method used by seawater desalination plants, and typically delivers lower-quality feed water that requires more pre-treatment and is highly affected by seasonal changes. Harmful algal blooms can result in closure of the desalination plant.
- **Subsurface intakes** are located below the ocean floor or in beach wells; water of better quality than sea surface water is pulled through the sand and pumped to a desalination facility (see examples here). They avoid the above problems by using the soil as a natural filter. They require more energy. Bringing deep seawater to the surface may *release greenhouse gases*.

Chemicals[3] are commonly used in the pre-treatment phase to limit algae growth, minimize corrosion, avoid scaling, chlorinate the water, and adjust the pH. These substances are usually discharged with the brine. Because SWRO operates at much lower temperatures than thermal technology, scaling is much less and therefore the required quantity of antiscalant chemicals is considerably lower.

Brine discharge. Brine is the effluent of a desalination facility with double the salinity of seawater. Badly constructed or positioned brine discharge facilities result in increased salinity and temperature of seawater, reportedly causing depletion of fish populations, death of corals and plankton, increased mortality of mangroves and seagrass, and pollution caused by inflated copper and nickel levels. Some of antiscalants bioaccumulate in living organisms.

Even though natural marine ingredients are found in desalination brine, disposing of brine without dilution will cause the brine to descend to the sea floor due to its higher density compared to ambient seawater, forming a stratified system with "**brine underflows**" whose effects can reach hundreds of meters. Furthermore, if the effluent brine is not properly mixed before release, the quantity of dissolved oxygen in the water may change. Moreover, because the toxicity of chemicals and metals increases as the temperature rises, the discharge of brine with a temperature much higher than incoming seawater can have a variety of consequences on marine life. Brine from SWRO is more concentrated and requires more treatment, but the quantities are smaller.

Brine management is both expensive and technically difficult, and hence most desalination plants discharge untreated brine directly into the environment:

[3] Including sodium hypochlorite ($NaOCl$), ferric chloride ($FeCl_3$), aluminium chloride ($AlCl_3$), sulfuric acid (H_2SO_4), hydrochloric acid (HCl), and sodium bisulfate ($NaHSO_3$)

- **Surface discharge** of brine via an outfall structure very near to the coast, results in a build-up of highly concentrated saltwater in that area, including high dissolved solids, with serious consequences on benthic marine life and particularly on sessile (attached, not moving) organisms such as corals and plants.
- **Submerged brine discharge** is used by most large desalination plants. It allows brine to be discharged deeper and further into the mixing zone of the receiving water body via pipes with diffusers or vertical risers embedded at the discharging end. This method allows for better dilution of brine with ambient seawater to reduce salinity, thus reducing the impact on the marine environment compared to surface discharge.

The impact of brine discharge can be partly addressed by blended discharges, i.e. mixing brine with alternative clean water sources of a lower salinity (e.g. treated wastewater, power-plant cooling water). Other mitigation measures include:

- **Minimising process chemicals** allowed in the outfall and enforcement of discharge limits.
- Implementing **new technologies** such as low-pressure membrane pre-treatment, to reduce the chemical load associated with coagulants and polymers in reverse osmosis desalination plants.

Several brine management solutions have been developed lately, with increasing water recovery to eventually achieve zero-liquid discharge being the most promising strategy for reducing the harmful impact on marine ecosystem health.

Energy consumption. Both membrane and thermal technologies consume large amounts of energy. Thermal facilities need heat; membrane technologies need electricity. The energy consumption of the thermal-based processes (MSF, MED and MVC) is much higher than the membrane processes (RO, FO and ED).Recovery of energy from the hot brine stream can reduce thermal energy consumption; technological innovation in reversed osmosis significantly reduces its energy consumption. The energy requirements for the thermal desalination technologies are practically independent of salt concentration, while the energy need for the membrane processes is exceedingly dependent on salt concentration (Anshul et al., 2021). Although a considerable amount of energy is used, it is not excessive compared with other energy uses; it may even be less energy intensive than water transfer. Renewable energy for desalination is set to expand, offering new opportunities for more sustainable desalination options.

However, the expansion of renewables is not without potential issues. Renewables occupy land or ocean space and may have impact on landscapes; it requires raw materials and may contribute to GHG emissions and air pollution (for instance with combustion renewables). Some renewable sources, like bioenergy are also water intensive.

The main challenge of Renewable Energy Desalination is that Desalination technologies generally work in steady-state conditions, but Renewable Energy sources are usually non-stationary. Given the importance to run utility-scale desalination plants at maximum capacity (that is, 24 hours per day, seven days per week), a large energy storage option is required for wind- and solar-based energy sources (also with its problems in terms of raw materials).

How to look at desalination proposals

A strategic approach to the water supply gap. In many countries a systemic approach to water management is largely lacking. The first step is to construct a set of future water use scenarios and identifying the water supply-demand gaps (in agriculture, in industry, in large cities, or in the environment). In a second step, the options to close the different gaps can be identified, combined with a strategic environmental assessment informing the process on boundaries of environmental sustainability and climate neutrality. This integrated planning better informs decision-making on future sources of water, and the strategic position of desalination. In fact, this is what Integrated Water Resources Management (IWRM) is about.

Try water conservation first. Increased water conservation and efficiency remain the most cost-effective approaches in areas with a large potential to improve the efficiency of water use practices. Wastewater reclamation, urban runoff and storm water capture can provide multiple benefits over desalination, also in level of treatment and recharging groundwater. Demand management may provide options for reduced water use.

Select high quality feed water. The need for pre-treatment is highly dependent on the quality of feed water, which has an impact on the quality of brine discharged. Lower-quality feed water with high biological activity necessitates more chemicals such as anti-fouling agents, chlorine, and acids which ultimately end up being discharged.

Apply Environmental and Social Impact Assessment (ESIA). Once the strategic choice for desalination has been made, alternative technologies and locations should be assessed on their environmental, climate and social consequences. Check available *National Biodiversity Strategies and Action Plans* on sensitive areas and try to avoid these.

Information and capacity needs for desalination

Re-use of brine. Studies have demonstrated that there are economic opportunities associated with brine, such as commercial salt and metal recovery and use of brine in micro-algae, fish, and halophyte production systems. There is a need to translate such research to convert an environmental problem into an economic opportunity.

Affordability of desalination. Due primarily to the relatively high economic costs, desalination is currently concentrated in high income and developed countries. There is a need to make desalination technologies more affordable and extend them to low income and lower-middle income countries.

Strengthen institutional context. Desalination requires a strong institutional capacity to implement and operate mega projects and innovative technology. Given the economic, social, and environmental implications of adopting desalination, good practice would be to conduct extensive public consultations before and during the feasibility studies.

Expected near future prospects. Technological refinement for low environmental impacts and economic costs, along with innovative financial mechanisms to support the sustainability of desalination schemes, will likely be required. The expansion pattern and economics of desalination facilities in recent decades suggest a positive and promising outlook for expansion in desalination facilities around the world.

Further information and support

International Desalination Association: *Desalination at a glance.*

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Contact

INTPA and NEAR Environment & Climate Change Mainstreaming Facility:
INTPA-GREENING-FACILITY@ec.europa.eu | *NEAR-GREENING-FACILITY@ec.europa.eu*

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