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On- and Offshore Solutions for Large-Scale Seawater Desalination at the Mediterranean Coast

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KEY FINDINGS

Additional large-scale seawater desalination plants at the Mediterranean coastline are essential to overcome water scarcity in Israel, Palestine, and Jordan.

Seawater desalination plants on offshore structures such as artificial islands are economically viable and have ecological advantages concerning the intake and outfall compared to onshore solutions.

The integration of renewable energy sources can reduce water production costs. In addition, offshore generation of renewable energy could reduce the amount of energy to be stored.

MOTIVATION

Water scarcity in regions where groundwater sources are mostly depleted can only be reduced by bringing new freshwater sources into the water balance. In this respect, building large-scale seawater desalination plants at the Mediterranean coastline could be the only economically viable option to cover parts of the projected freshwater deficits in Jordan and Palestine. Since the late 90s, Israel is investing in large-scale seawater desalination, producing today around 600 million cubic meters per year (Mio. m^3/a) of freshwater, using membrane-based technologies. Process innovations led to significant reductions in energy demand from 20 kWh/m^3 in 1970 to 2.5 kWh/m^3 in 2010 (Fritzmann et al., 2007). Therefore, the water production costs of reverse osmosis seawater desalination plants also significantly decreased to around 0.5 $\$/m^3$. However, implementing large-scale seawater desalination plants is still a major challenge. Population growth and urbanization lead to significant shortages in available land, which can trigger public resistance. This effect is likely to increase in the future, driving up land prices and resulting in land use conflicts at the coastline. Offshore structures such as artificial islands or land reclamation can be a viable option to create new land for desalination purposes. Large projects as the Kansai Airport in Osaka or the artificial islands at the Upper Zakum Field offshore Abu Dhabi show the feasibility of the approach for decades. Creating new land for desalination purposes on artificial islands or land-reclamation is a new approach, only desalination concepts implemented on ships, drilling rigs, or small-scale floats have been discussed so far. Within the SALAM Initiative, the economic feasibility of different desalination concepts was investigated to determine the offshore effect on the specific water production costs.

METHODOLOGY

First, the existing desalination infrastructure in Israel was analyzed, and important trends in the desalination market were identified. This approach enabled the identification of the most appropriate technologies for large-scale seawater desalination. The desalination sites were determined according to the developed water production and transfer strategies and underlying conceptual approach [Water Production and Transfer Strategies, p. 22], selecting the most suitable feeding points to potential water transfer pathways to the regional water demand centers as shown in Figure 1. In addition to the plants on the Israeli coast, a desalination plant in Gaza was considered. In addition to onshore desalination solutions, alternative offshore concepts were developed based on rubble mound breakwaters at various water depths. Figure 1 shows two alternatives that were created for the so-called „Haifa option". Depending on the distance from the coast and location, different

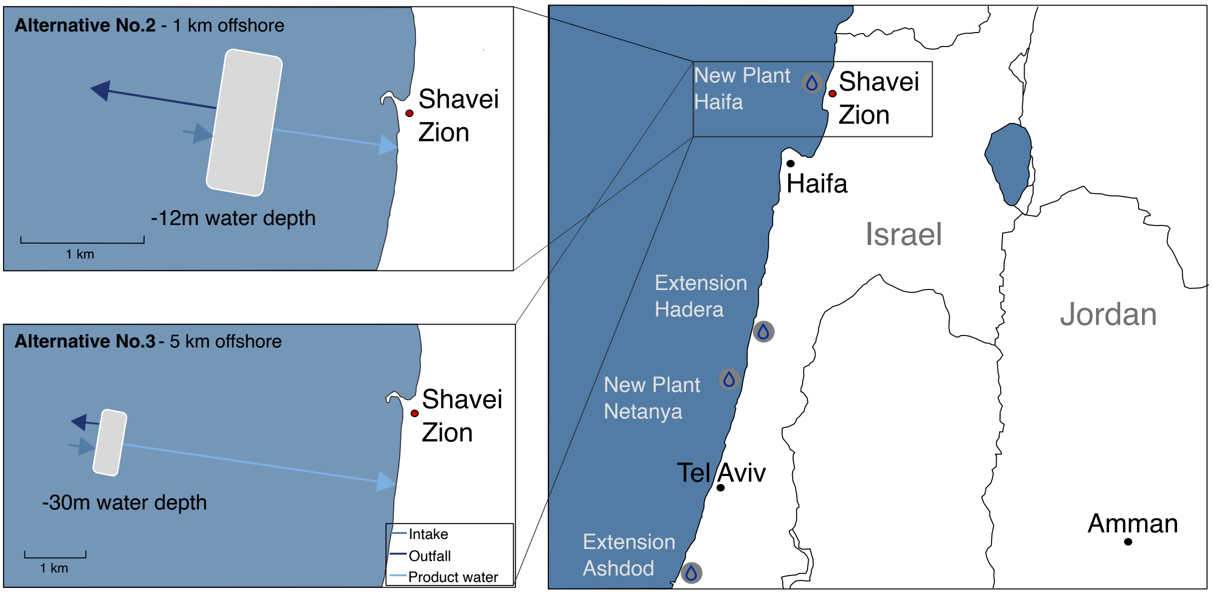

Figure 1: Considered locations for new desalination plants and plant extensions and a zoom-in on the offshore alternatives in the North of Haifa

water depths must be taken into account (Table 1). The preliminary design of the offshore structures was based on the analysis of historical wind data, taking the expected wave heights at the study locations into consideration Based on the water depth at the alternatives locations, an armour layer was designed to protect the structure from erosion by currents and waves. In addition, filter layers were considered to prevent the washing out of the core fill and cover the sub-layers from erosion. The resulting quantities of components and unit prices determined the construction costs of the alternatives. A more detailed description of the methodology for the design of the artificial structures and their cost calculation can be found in Janowitz et al. (2022). All alternative onshore and offshore solutions were evaluated based on a multi-criteria assessment, taking technical, economic, social, and ecological decision criteria into account [Multi-Criteria Analysis of Water Resources Planning Options, p. 80].

RESULTS

The economic analysis conducted within the SALAM Initiative indicates that large-scale seawater desalination plants on offshore structures like artificial islands are economically viable [Techno-Economic Assessment of Integrated Water Resources Management Infrastructure Projects, p. 72] and present ecological advantages concerning the intake and outfall compared to onshore solutions. Figure 2 shows the pre-design of the desalination plant on the artificial island. The entire plant technology must be constructed on the artificial island, as for an onshore plant, and transmission lines and pipelines must be routed to the coastline. In the case of the „Haifa option“, the difference in specific water production cost between the „land reclamation“ alternative No.1 (directly at the coast) and the most distant alternative No.3 from the shoreline (5 km offshore) is only 0.03 US$/m^3. The specific water production costs for alternatives 1 and 3 are 0.63 and 0.66 US$/m^3, respectively (Table 1). For a desalination facility with a capacity of 200 Mio. m^3/a , the cost difference is 6 Mio. US$/y during the plant‘s lifespan. Accepting the increased investment costs of offshore alternatives enables a significant reduction of the environmental impact of the intake and outfall. In addition, artificial islands' influence on the hydrodynamic currents can even be reduced with increasing distance to the shoreline, so beach erosion is prevented (Janowitz et

Table 1: Alternatives for large-scale offshore desalination within the "Haifa option" (Janowitz et al., 2022)

ALTERNATIVES	WATER DEPTH	CREST HEIGHT OF THE STRUCTURE ABOVE CHART DATUM	WATER PRODUCTION COST
No. 1 – Artificial Island Land reclamation	- 5 meter	+ 8 meter	0.63 $/m^3
No. 2 – Artificial Island 1 km offshore	- 12 meter	+ 14 meter	0.64 $/m^3
No. 3 – Artificial Island 5 km offshore	- 30 meter	+ 14.4 meter	0.66 $/m^3

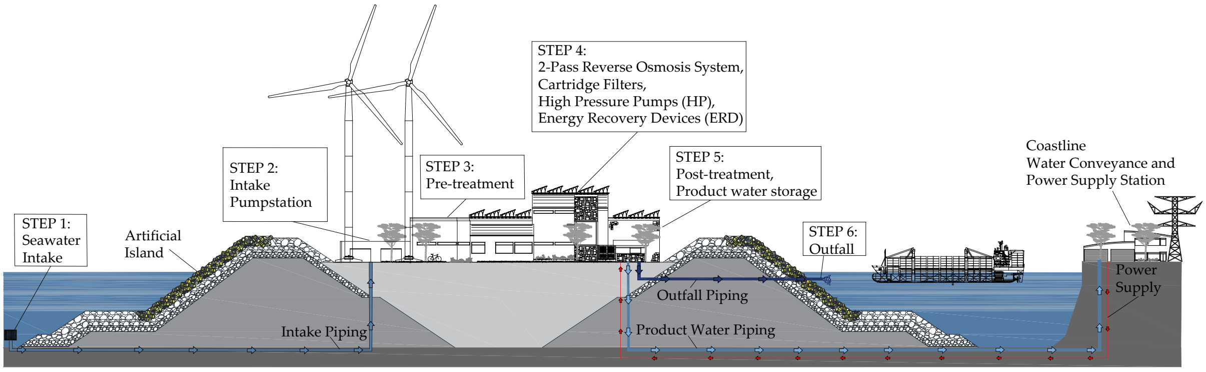

Figure 2 Desalination project layout on the artificial islands (Janowitz et al., 2022)

al., 2022). The specific water production cost is highly dependent on the specific footprint, the plant's capacity, and the financing structure of capital expenditures. However, the influence of energy cost on water production cost is still more significant (Janowitz et al., 2022). Therefore, the greatest potential for reducing the cost of water production lies in the reduction of the costs for energy generation. The specific costs of generating electricity from renewable energy sources, especially photovoltaic systems, have decreased significantly. Therefore, a large part of the electrical power needed could be covered by photovoltaic systems and energy transport from Jordan to Israel, according to the Water-Energy-SWAP concept, developed within the SALAM Initiative [Innovative Water-Energy-SWAP Concept between Israel and Jordan, p. 33].

CONCLUSIONS

An environmental impact assessment combined with a technical feasibility study is an essential next step to facilitate the realization of artificial islands for desalination. A pilot study should include an in-depth investigation concerning suitable sites, studying nearby quarries and possible dredging locations, and taking environmental concerns, especially water quality issues, into account (Janowitz et al., 2022). In addition, mapping and investigating the biodiversity at the offshore sites are essential to collecting location-specific data for quantifying the influences. The operating costs for the pre-treatment of the desalination plant could be reduced depending on the offshore water quality compared to conventional onshore desalination plants. From a mid-term perspective, an alternative chemical energy storage option such as hydrogen should be explored to facilitate the transition from natural gas-powered to a carbon-neutral seawater desalination industry in Israel. Renewable energy generation on the artificial islands, such as wind turbines or wave energy, could reduce energy storage needs. However, the increase in the share in renewable energy needs to be provided on a much larger scale from onshore facilities. The electricity generation cost for photovoltaics has significantly decreased in the last years, which has the potential to further reducing the water production cost. In this respect, concepts for exchanging water and energy between Israel and Jordan could be a win-win for both sides.

ESSENTIALS FOR REALIZING LARGE-SCALE DESALINATION PROJECTS

Reverse osmosis is the dominant technology for the realization of large-scale seawater desalination plants due to its technical maturity and scalability worldwide. The driving force in reverse osmosis is the pressure difference between the applied pressure and the osmotic pressure of the salt solution. Therefore, the high-pressure pumps need electrical energy based on conventional or renewable energy sources. In this respect, reverse osmosis will always be an energy-intensive process (Elimelech & Phillip, 2011). Private sector participation, including market-oriented tendering, is essential to reach competition, leading to fair-priced bids for the site-specific desalination project (Janowitz et al., 2022). Desalination plants are typically purchased according to the Build-Operate-Transfer scheme (BOT). Within BOT projects, governments usually provide take-or-pay guarantees reducing the commercial risk, so these schemes are attractive to the private sector.

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