
Shore of the Dead Sea, Jordan ©Nußbaum

Renewable Energy for Seawater Desalination in the Middle East: Case Study Aqaba, Jordan

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KEY FINDINGS

The overall strategy for minimizing water scarcity in Jordan should take seawater desalination plants on Jordanian territory into consideration.

Integrating renewable energy sources (e.g., solar energy) will reduce the costs of seawater desalination in Jordan.

Combining Nanofiltration, Reverse Osmosis and Multi-effect-desalination allows for tailor-made brine disposal into the Dead Sea and increases water recovery

MOTIVATION

Several factors hinder Jordan from harnessing seawater to cover the growing freshwater deficit, which is expected to reach ~700 Mio.m^3/a by 2050 [Future Freshwater Deficits in Palestine and Jordan, p. 18]. Jordan has a very short coastline along the Red Sea near Aqaba. In addition, the salt content of the Red Sea is up to 43,000 ppm, significantly higher than the salt content of the Mediterranean Sea. A further regional challenge is the sinking of the water level of the Dead Sea. This is accompanied by sinkholes on the Dead Sea coast that destroy infrastructure and loss of freshwater due to a modified groundwater regime (Yechieli et al., 2016).

While Jordan has no fossil energy resources, it is a country with high solar radiation. This huge solar potential can be exploited to power desalination plants. However, the bottleneck in this approach lies in energy storage technologies. Innovative concepts must be developed to combine available storage technologies with suitable energy production and desalination technologies. Therefore, solutions have been developed in which Jordan could counteract water shortages by utilizing its own renewable energy sources, thus lowering seawater desalination costs on Jordanian territory. In the SALAM Initiative, STEP has developed concepts that combine membrane-based and thermal seawater desalination technologies with suitable methods of solar energy production. Additional efforts have been made to develop a desalination concept that counteracts the Dead Sea drying by discharging suitable brines. The challenge here lies in the different compositions of the Dead Sea and the Red Sea and the large distances between them. Growing environmental awareness and potential conflict over land must be considered in finding regionally specific solutions.

METHODOLOGY

Jordan's existing seawater desalination infrastructure was analyzed, and the essential trends in the renewable energy market were identified. This approach enabled the selection of the most appropriate technologies for solar energy production in combination with membrane-based and thermal desalination. The SALAM partner DI identified the renewable energy potential in Jordan and calculated the resulting production costs for electricity. Optimizing the entire process chain is an iterative process that requires developing simulation tools. Our simulation tool developed by STEP combines the water flow, recovery and rejection data of RO and MED, resulting in electrical and thermal energy demand. Based on this, the capacity of concentrated solar power and photovoltaics can be estimated. Additionally, all concepts were evaluated using technical, economic, social, political and environmental criteria as a basis for the multi-criteria assessment of seawater desalination plants combined with renewable energy, which was carried out by UDE [Multi-Criteria Analysis of Water Resources Planning Options, p. 80].

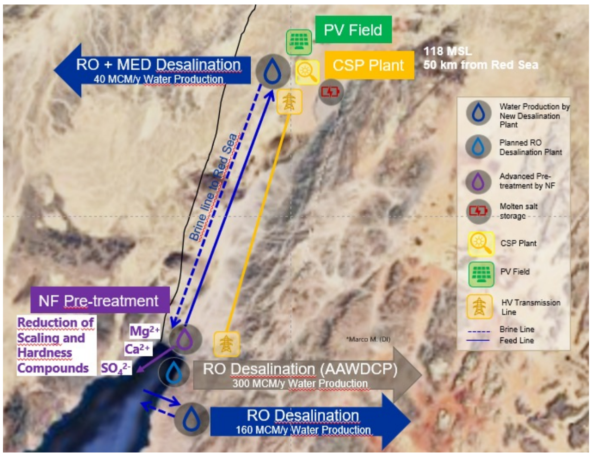
The saturation indices of the concentrate and Dead Sea water mixture were determined using the PHREEQC software package to analyze the impact of brine disposal into the Dead Sea. Based on these values, it was possible to determine whether implementing the concept would cause gypsum precipitation in the Dead Sea.

RESULTS

Concept A: Desalination at Aqaba – Brine discharge into the Red Sea

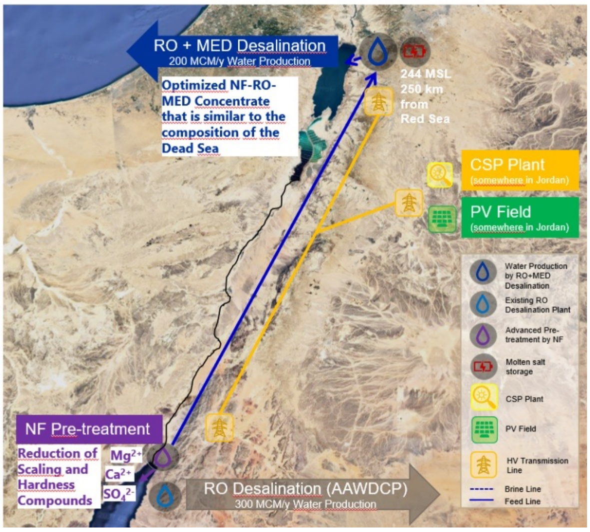
Beside the planned Aqaba-Amman Water Desalination and Conveyance Project (AAWDCP) for 300 Mio. m^3/a, 200 Mio. m^3/a freshwater are also produced by Reverse Osmosis (RO) desalination at Aqaba Port. The capacities chosen here are scalable. The electrical energy is generated from PV during sunshine hours and stored in molten-salt storage to generate electricity at night. The advantage is that the maximum temperature in the heat accumulator and the steam cycle is higher, as the accumulator can be heated up to ~600 °C with electricity. This increases the efficiency of the energy conversion.

Concept B: Desalination in Wadi Araba & Aqaba – Brine discharge into the Red Sea



The second solar concept includes both Photovoltaics (PV) and a Concentrated Solar Power (CSP) system to supply energy. The PV system produces low-cost electricity that is used directly for desalination. In addition, the CSP plant fills up the thermal energy storage. The seawater is pretreated at Aqaba with Nanofiltration (NF) to reduce scaling and hardness compounds, which protects the pipes from corrosion. The NF permeate is pumped inland to Wadi Araba. The CSP plant is located far enough away from the Red Sea that the collectors of the CSP plant are not affected by the salty sea air. For seawater desalination, RO and Multi-Effect Desalination (MED) are used. Due to the pretreatment by NF, higher water recoveries can be achieved. The steam cycle of the CSP plant is coupled with the MED as the waste heat from the CSP is utilized for thermal desalination. The concentrate is transported back to Aqaba and disposed into the Red Sea.

Concept C: Desalination at the Dead Sea – Brine discharge into the Dead Sea



Unlike the other concepts, this concept includes brine disposal into the Dead Sea and therefore counteracts the drying up of the Dead Sea. Like in Concept B, the seawater is pretreated with NF, and the NF permeate is desalinated at the Dead Sea using RO and MED. The desalination setup makes it possible to adapt the concentrate to the Dead Sea composition and prevents gypsum precipitation in the Dead Sea. As brine is discharged into the Dead Sea, this concept could prevent harm to the unique ecosystem of the Gulf of Aqaba. The energy supply is similar to Concept B.

CONCLUSIONS

Three possible desalination concepts for Jordan were identified. Desalinating seawater at the Dead Sea and discharging the brine there (Concept C) is a particularly innovative approach to address the regional challenges. In the current context, integrating renewable energy sources is the solution to decrease costs and promote the large-scale use of seawater desalination in Jordan. Using nanofiltration as an innovative pretreatment technology enables the separation of scaling compounds directly at the Red Sea. This would allow the desalination concentrate to be adjusted to the composition of the Dead Sea while simultaneously protecting the Gulf of Aqaba from harmful desalination brine disposal. However, further studies are required on the path towards implementing this innovative concept, including the safe transport of the NF permeate from the Red Sea to the Dead Sea. Furthermore, integrating renewable energies and storage technology like hydrogen into the concept needs to be further investigated.

CONCENTRATED SOLAR POWER

Solar radiation can be directly converted into electricity by photovoltaics. As seawater desalination plants should also be supplied at night, suitable energy storage is needed. The Concentrated Solar Power (CSP) technology offers a solution to this problem. In CSP, solar radiation is converted to thermal energy stored in molten salt storage systems. At night, the thermal energy can be extracted from the molten salt storage to produce electricity in a steam cycle. The waste heat from the steam turbine can be utilized in thermal seawater desalination plants to increase water recovery.

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Funding code: 02WM1533G

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