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Local cost of seawater RO desalination based on solar PV and wind energy: A global estimate

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HIGHLIGHTS

- Seawater reverse osmosis (SWRO) plants can be powered solely with renewable energy.
- Single-axis, fixed-tilted PV and wind energy offer optimal renewable energy systems globally.
- Batteries and power-to-gas provide the optimal energy storage solution.
- 2030 global water costs for the proposed system lie between 0.59 €/m^3–2.81 €/m^3.
- Costs include water production, transportation to water demand site and storage.

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ABSTRACT

This study demonstrates how seawater reverse osmosis (SWRO) plants, necessary to meet increasing future global water demand, can be powered solely through renewable energy. Hybrid PV–wind–battery and power-to-gas (PtG) power plants allow for optimal utilisation of the installed desalination capacity, resulting in water production costs competitive with that of existing fossil fuel powered SWRO plants. In this paper, we provide a global estimate of the water production cost for the 2030 desalination demand with renewable electricity generation costs for 2030 for an optimised local system configuration based on an hourly temporal and 0.45° × 0.45° spatial resolution. The SWRO desalination capacity required to meet the 2030 global water demand is estimated to about 2374 million m^3/day. The levelised cost of water (LCOW), which includes water production, electricity, water transportation and water storage costs, for regions of desalination demand in 2030, is found to lie between 0.59 €/m^3–2.81 €/m^3, depending on renewable resource availability and cost of water transport to demand sites. The global system required to meet the 2030 global water demand is estimated to cost 9790 billion € of initial investments. It is possible to overcome the water supply limitations in a sustainable and financially competitive way.

1. Introduction

It is estimated that there are 200,000 km^3 of renewable fresh water resources for all life on Earth (UNEP) [1]. The demand for this finite renewable resource is projected to increase due to the needs of the agricultural, industrial and municipal sectors. The United Nations World Water Assessment Programme (WWAP) estimates that by 2030, in a business as usual scenario, only 60% of the global water demand can be met [2]. The OECD expects that, in a business as usual scenario, by 2050, the global fresh water withdrawals will increase by 55%. Consequently, by the end of this period, 40% of the global population will be living in water-stressed regions. In particular, this will be evident in North and South Africa, and Central and South Asia [3].

In addition to the rapidly increasing water demand, climate change and water pollution will further limit the availability of fresh water. As water becomes a critical resource, there is a global drive to better manage and augment the existing fresh water supply [2].

Seawater desalination is growing as an alternative fresh water resource. The Global Water Intelligence (GWI) reports that in 2012, the installed global desalination capacity was increasing by 55% a year [4]. As of 2013, 150 countries have taken up desalination to augment the fresh water supply. This resulted in a global installed capacity of 80 million m^3 of fresh water a day [5].

Desalination has high specific energy consumption (SEC), compared to traditional water treatment methods. Grubert et al. [6] suggest that the typical energy usage for the treatment of surface fresh water is about 0.06 kWh/m^3. In contrast, the energy usage for seawater desalination is of the range 3.6–4.5 kWh/m^3. Ghaffour et al. [4] explain that, depending on the desalination technology, the total SEC can range between 0.5–16 kWh/m^3. Desalination technologies are broadly classified

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as thermal or membrane processes. Thermal processes utilise thermal energy and electrical energy. The thermal energy required is approximately of the range 4–12 kWh/m^3 and electrical energy of the range 1.5–4 kWh/m^3. Thus, the total energy required is of the range 9–16 kWh/m^3. Membrane processes utilise only electrical energy to produce the same amount of fresh water and is of the range 0.5–4 kWh/m^3. Membrane processes avoid the evaporation of the seawater leading to lower SEC than thermal processes.

Burn et al. [7] notes that by 2013, the membrane process reverse osmosis (RO) accounted for 65% of the total global installed desalination capacity. In addition, 59% of the installed global desalination capacity used seawater as the feed water type. Ghaffour et al. [4] explain that seawater RO (SWRO) will continue to remain the dominant desalination technology, owing to the lower costs, energy consumption and technological improvements.

Lienhard and Jameel [8] write that, as desalination becomes a staple water technology, there is ongoing concern about the energy consumption of the plants. This has driven research towards more energy efficient and cost-effective solutions. Reflecting similar concerns, Latorre et al. [9] explain that due to the unpredictable costs and availability of fossil fuels, there is increasing interest in the use of renewable energy to power desalination plants. This will make desalination accessible to regions with scant fossil fuel resources and high water scarcity.

Current concerns with the use of renewable energy systems plants are the intermittency and energy storage requirements. Mentis et al. [10] analysed the case for using completely renewable energy powered desalination units in the South Aegean Islands. Instead, it was decided to opt for PV–wind hybrid power plant and grid electricity to meet the energy demand of the desalination units. Novosel et al. [11] presented the case for using PV and wind energy for desalination in Jordan. Brine operated pump storage was used to allow for higher penetration of renewable energy. However, fossil fuel backup is necessary for optimal utilisation of the desalination plants.

The objective of our work was to determine if it is viable to meet the 2030 global water demand, with SWRO desalination powered solely with renewable energy. This was done by estimating the unit cost of water production (€/m^3) or the levelised cost of water (LCOW) for renewable energy powered SWRO plants in 2030 and comparing it with costs of existing fossil-powered SWRO desalination plants. Fig. 1 presents the SWRO desalination system envisaged in this work.

2. Methodology

2.1. Overview

The key aim in this work is to determine the LCOW for the system presented in Fig. 1 for the regions of desalination demand in 2030. For our analysis, a 2030 future scenario without thermal power plants was assumed. More and more researchers take this shift to power seriously into account [12–17] and as a consequence the share of thermal power plants can be expected to decrease due to economic and environmental reasons. Therefore, the results of this work are for the 2030 optimistic scenario, discussed in the IPCC 5th assessment report [18, 19].

Breyer et al. [20], based on Sort et al. [21], describe the approach to calculate the levelised cost of electricity (LCOE) of PV plants and fossil fired power plants. This approach can be adapted to calculate the unit production cost of water at the site of the desalination plant and the water transportation to the region of desalination demand as shown in Eqs. (1a) to (1h).

$$LCOW_{desal} = \frac{(Capex_{desal} \times crf_{desal} + Capex_{water\ storage} \times crf_{water\ storage}) + opex_{fixed}}{Total\ water\ produced\ in\ a\ year} + Opex_{var\ desal} \times SEC \quad (1a)$$

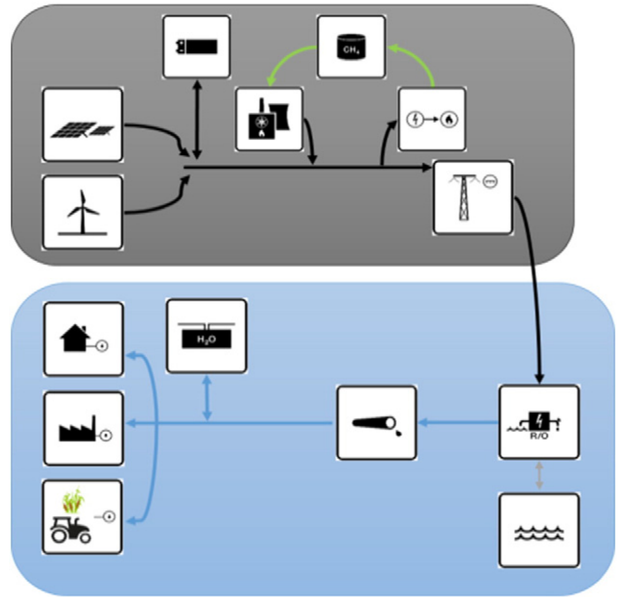

Fig. 1. The final desalination system. SWRO desalination plants are powered by hybrid renewable energy power plants being cost optimised by storage. High voltage DC cables transport power to the desalination plants on the coast. The water produced is transported to meet the demands of the municipal, industrial and agricultural sectors. Water storage at the site of demand ensures constant water supply.

$$Opex_{fixed} = Opex_{fixed\ desal} + Opex_{water\ storage} \quad (1b)$$

$$Opex_{var\ desal} = LCOE \quad (1c)$$

$$crf = \frac{WACC \times (1 + WACC)^N}{(1 + WACC)^N - 1} \quad (1d)$$

$$WACC = \frac{E}{E + D} \times k_E + \frac{D}{E + D} \times k_D \quad (1e)$$

$$LCOT_{desal} = \frac{(Capex_{hpumps} \times crf_{hpumps} + Capex_{vpumps} \times crf_{vpumps}) + Capex_{pipes} \times crf_{pipes}) + opex_{fixedt}}{Total\ water\ produced\ in\ a\ year} + Opex_{vart} \times SEC_t \quad (1f)$$

$$opex_{fixedt} = opex_{fixed\ pumps} + opex_{fixed\ pipes} \quad (1g)$$

$$opex_{vart} = LCOE \quad (1h)$$

$$LCOW = LCOW_{desal} + LCOT_{desal} \quad (1i)$$

Eqs. (1a) to (1h): Levelised cost of water (LCOW) for regions with desalination demand in 2030. Here, $capex_{desal}$ is the capex of the desalination plant in €/m^3, $capex_{water\ storage}$ is the capex of water storage tank at demand site in €/m^3, crf_{desal} is the annuity factor for desalination plant, and $crf_{water\ storage}$ is the annuity factor for water storage. *Total water produced in a year* is in m^3, $opex_{fixed\ desal}$ is the fixed opex of the desalination plant in €/m^3, $opex_{water\ storage}$ is the opex of the water storage tank in €/m^3, and $opex_{var\ desal}$ is the variable opex of the desalination plant. The variable opex is equal to the levelised cost of electricity (LCOE) of the plant and is in €/kWh. *SEC* is the specific energy consumption in kWh/m^3. The product of the *LCOE* and *SEC* is the energy cost of the desalination plant in €/m^3.

WACC is the weighted average cost of capital, *N* is the lifetime of the desalination plant or the water storage, *E* is the equity in €, *D* is the debt in €, k_E is return on equity, and k_D is the cost of debt.

$LCOT_{desal}$ is the levelised cost of power transmission for the electricity for desalination, $capex_{hpumps}$ is the capex of the horizontal pumps,