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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 €/m³–2.81 €/m³.
- 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 $0.45° \times 0.45°$ spatial resolution. The SWRO desalination capacity required to meet the 2030 global water demand is estimated to about 2374 million m³/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 €/m³–2.81 €/m³, 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 km³ 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 m³ 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/m³. In contrast, the energy usage for seawater desalination is of the range 3.6–4.5 kWh/m³. Ghaffour et al. [4] explain that, depending on the desalination technology, the total SEC can range between 0.5–16 kWh/m³. 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).

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

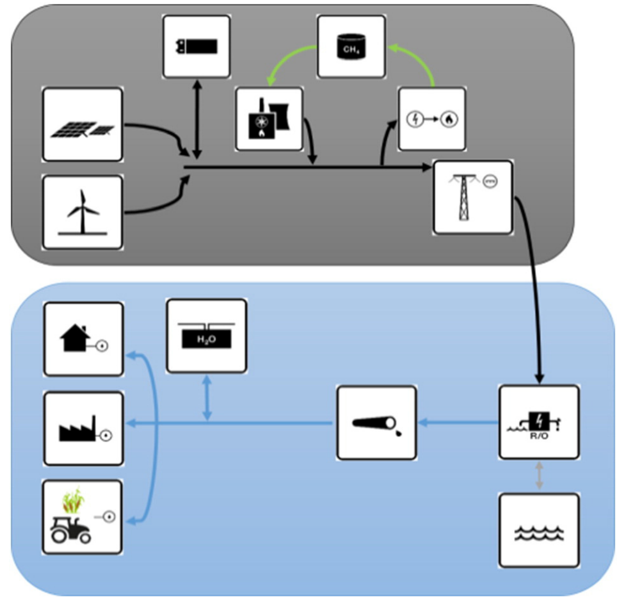

Fig. 1. The final desalination system. SWRO desalination plants are powered by hybrid renewable energy power plants being cost optimised by storage. High voltage DC cables transport power to the desalination plants on the coast. The water produced is transported to meet the demands of the municipal,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

$$Opex_{fixed} = Opex_{fixed\ desal} + Opex_{water\ storage} \tag{1b}$$

$$Opex_{var\ desal} = LCOE \tag{1c}$$

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

$$WACC = \frac{E}{E + D} \times k_E + \frac{D}{E + D} \times k_D \tag{1e}$$

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

$$opex_{fixedt} = opex_{fixed\ pumps} + opex_{fixed\ pipes} \tag{1g}$$

$$opex_{vart} = LCOE \tag{1h}$$

$$LCOW = LCOW_{desal} + LCOT_{desal} \tag{1i}$$

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,

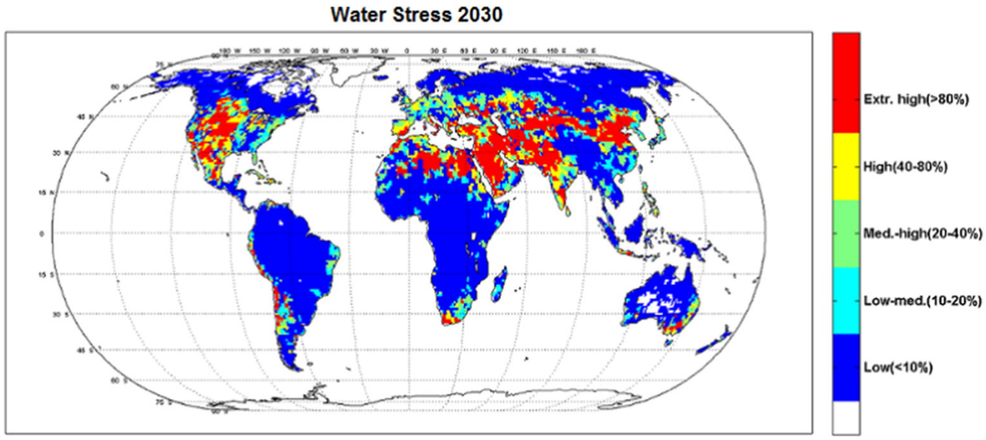

Fig. 2. Projected water stress for the 2030 optimistic scenario. The water stress is the ratio of the total water demand in the region to the annual renewable water resources available in that region [18].

crf_{hpumps} is the annuity factor for the horizontal pumps, $capex_{vpumps}$ is the capex of the vertical pumps, crf_{vpumps} is the annuity factor for the vertical pumps, $capex_{pipes}$ is the capex for the vertical and horizontal pipes, $opex_{fixedt}$ is the fixed operational expenditures of the pipes and pumps, $opex_{fixed\ pumps}$ is the fixed operational expenditures of the horizontal and vertical pumps, $opex_{fixed\ pipes}$ is the fixed operational expenditures of the horizontal and vertical pipes, $opex_{vart}$ is equal to the *LCOE*, SEC_t is the specific energy consumption of the pumps in kWh/m^3, and *LCOW* is the resulting levelised cost of water in €/m^3.

Breyer et al. [15] describe the approach to calculate the LCOE for a region as summarised in Eq. (2).

$$LCOE_r = LCOE_{prim,r} + LCOC_r + LCOS_r + LCOT_r \tag{2}$$

Eq. (2): Levelised cost of electricity for a region. Here, $LCOE_{prim,r}$ is the levelised cost of electricity for primary a generation source, $LCOC_r$ is the levelised cost of curtailment, $LCOS_r$ is the levelised cost for energy storage in the region and $LCOT_r$ is the levelised cost of transmission of electricity in the region r.

2.2. Model and input data

The energy model, used and further developed at LUT (based on previous results at the Reiner Lemoine Institut), is used to determine the global LCOE and LCOW [14, 15]. The model allows for the design of different energy systems and can be modified to model local, national or global energy systems. The energy model is based on the linear optimisation method with interior point optimisation and designed in an hourly temporal and 0.45° × 0.45° spatial resolution.

To determine the LCOW based on (1a) to (1h), the following are the data parameters utilised by the model:

1. Regions with high or extremely high water stress in 2030. That is, regions where more than 40% of the renewable water resources are being withdrawn. Fig. 2 illustrates the regions in a global water stress map for the 2030 optimistic scenario. The water stress data for baseline and future scenarios are provided by the World Resources Institute (WRI) Water Atlas [18].
2. Total water demand in the regions with higher or extremely high water stress in 2030. The total water demand is the sum of the water withdrawals for agriculture, domestic use and industry. It is assumed that a future scenario does not include thermal power plants and therefore the water withdrawal of thermal power plants is excluded. This results in a reduction of the total global water demand [22]. The Water Atlas provides the water demand increase factors from the 2010 water demand for all future scenarios, including the 2030 optimistic scenario. The total water demand in 2010 was obtained from the FAO Aquastat database [23]. These data in conjunction with the water demand increase factor were used to calculate the total water demand for a region in 2030.
3. The desalination demand is calculated based on a logistic function of the total water demand and the water stress level. A logistic function allows to express the variation in increase in desalination demand

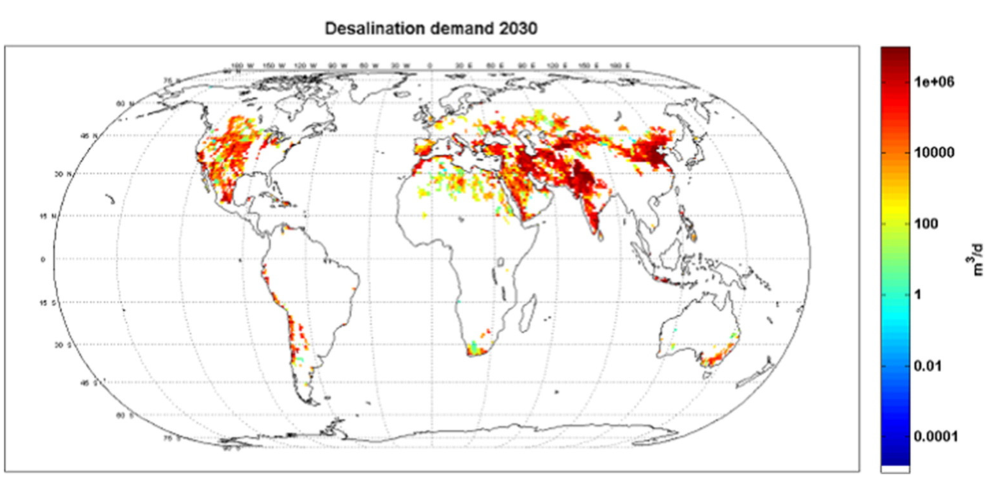

Fig. 3. Desalination demand for the optimistic scenario 2030. The desalination demand is calculated as per Eqs. (3a) to (3e), based on ref. [18, 19, 23] and projected on a mesh of 0.45° × 0.45° for further calculation.

Table 1
Key assumptions for the SWRO plant, water storage, and water transportation in the model for 2030 [28–33].

SWRO desalination system		
Capacity	m^3/a	Equal to desalination demand of region
Capex	€/(m^3·a)	2.23
Fixed Opex	€/(m^3·a)	4% of Capex
Full load hours	hrs	System optimum
Energy consumption	kWh/m^3	Calculated for desalination site. Approximate range is 2.80–3.30. See Fig. 4
Lifetime	yrs	30
Water storage		
Capex	€/m^3	65
Fixed Opex	€/(m^3)	2% of Capex
Lifetime	yrs	30
Horizontal pumping and piping		
Horizontal pipes Capex	€/(m^3·a·km)	0.053
Horizontal pipes Fixed Opex	€/(m^3·a·100 km)	0.023
Horizontal pump Capex	€/(m^3·h·km)	19.23
Horizontal pump Fixed Opex	€/(m^3·h·km)	2% of Capex
Energy consumption	kWh/(m^3·h·100 km)	0.04
Lifetime	yrs	30
Vertical pumping and piping		
Vertical pipes Capex	€/(m^3·a·km)	0.053
Vertical pipes Fixed Opex	€/(m^3·a·100 km)	0.023
Vertical pump Capex	€/(m^3·h·m)	15.40
Vertical pump Fixed Opex	€/(m^3·h·m)	2% of Capex
Energy consumption	kWh/(m^3·h·100 m)	0.36
Lifetime	yrs	30

with the increase in water stress. This is explained in Eqs. (3a) to (3e). The resulting global desalination demand is presented in Fig. 3. The desalination demand for a region is equal to the required installed SWRO capacity for the region.

4. Water transportation costs, for the horizontal and vertical distance, from the desalination plant to the demand site. These costs are comprised of the pumping and piping capex and opex costs.
5. Energy consumption of SWRO plants, based on location, and the energy costs for water transportation. This provides the energy required to meet the desalination demand in a region.
6. Solar irradiation and wind energy data for the year 2005 as a reference in hourly temporal and 0.45° × 0.45° spatial resolution as described in more detail in Breyer et al. [15].
7. Hybrid renewable power plant costs for 2030. These costs are comprised of single-axis tracking PV, fixed-tilted PV, wind, batteries and power-to-gas (PtG) power plant capex and opex costs. SWRO desalination plant capex and opex values for 2030, including water storage costs at the desalination site. More information on the PtG technology can be found in Sterner [24], Lehner [25] and Götz et al. [26].

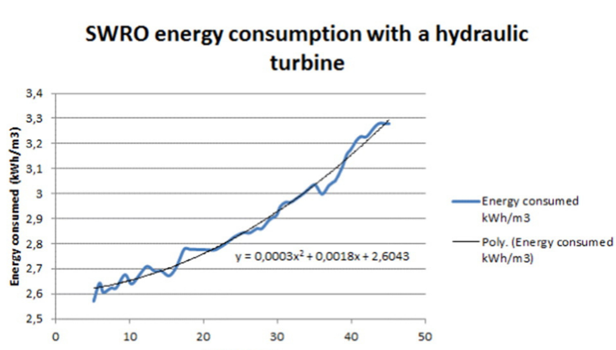

Fig. 4. SWRO energy consumption with a hydraulic turbine [33].

Table 2
Costs and technical assumptions for PV, wind, battery and PtG hybrid power plants in 2030 [15, 36, 37].

Fixed-tilted PV plant		
Capex	€/kW	550
Opex	€/(kW·a)	1.5% of Capex
Lifetime	yrs	35
Single-axis tracking PV plant		
Capex	€/kW	620
Opex	€/(kW·a)	1.5% of Capex
Lifetime`	yrs	35
Wind plant		
Capex	€/kW	1000
Opex	€/(kW·a)	2% of Capex
Lifetime	yrs	25
Batteries		
Capex	€/kWh	150
Fixed Opex	€/(kWh·a)	10
Lifetime	yrs	15
Efficiency	%	90
PtG		
Water electrolysis Capex	€/kW_{H2}	380
Water electrolysis Fixed Opex	€/(kW_{H2}·a)	13
Efficiency	%	84
Lifetime	yrs	30
CO_2 scrubbing Capex	€/kW_{SNG}	356
CO_2 scrubbing Opex	€/(kW_{SNG}·a)	14.24
Efficiency	%	78
Lifetime	yrs	30
Methanation Capex	€/kW_{SNG}	234
Methanation Opex	€/(kW_{SNG}·a)	5
Efficiency	%	77
Lifetime	yrs	30
Gas storage	€/kWh	0.05
Efficiency	%	100
Lifetime	yrs	50

Based on the above parameters, the model compares the use of different hybrid renewable energy power plant combinations. The least cost system that meets the 2030 desalination demand of regions with water scarcity is the optimal system.

$$\text{If } 40\% < WS < 50\% : \text{desalination demand} = (WS - 40\%) \times \frac{\text{Total water demand}}{WS} \times \text{logistic}(40\%) \tag{3a}$$

$$\text{If } 50\% < WS < 60\% : \text{desalination demand} = (WS - 50\%) \times \frac{\text{Total water demand}}{WS} \times \text{logistic}(50\%) \tag{3b}$$

$$\text{If } 60\% < WS < 70\% : \text{desalination demand} = (WS - 60\%) \times \frac{\text{Total water demand}}{WS} \times \text{logistic}(60\%) \tag{3c}$$

$$\text{If } 70\% < WS < 80\% : \text{desalination demand} = (WS - 70\%) \times \frac{\text{Total water demand}}{WS} \times \text{logistic}(70\%) \tag{3d}$$

$$\text{If } WS > 80\% : \text{desalination demand} = (WS - 80\%) \times \frac{\text{Total water demand}}{WS} \tag{3e}$$

Eqs. (3a) to (3e): Desalination demand for a region based on 2030 optimistic scenario [18, 19, 23]. Here, *WS* is the water stress for a region based on the 2030 optimistic scenario, *Total water demand* is the total water demand for the region based on 2030 optimistic scenario, excluding thermal power plants.

2.3. Technical and financial assumptions

Table 1 presents the key assumptions used for the model for the SWRO desalination plant, water storage at the desalination demand site and water transportation from the desalination site to the demand site. For the purpose of our work, SWRO plants with hydraulic turbine energy recovery devices (ERD) are considered [27]. Water storage of a minimum of 7 days at the desalination site is assumed. A weighted average cost of capital (WACC) of 7% is considered. Where specific data of the opex is not available, it is assumed to be 2% of the capex.

The SEC of SWRO desalination plants vary with the salinity, temperature of feedwater and the type of energy recovery device used [34]. The minimum SEC variation for SWRO plants with hydraulic turbine ERDs is represented in Fig. 4.

The second order polynomial $y = 0.0003x^2 + 0.0018x + 2.6049$, where x is the salinity in Practical Salinity Unit (PSU), represents the trend line. The salinity, x, of the feed water can be found for a specific region from the NCEI World Ocean Database [35]. Therefore, the minimum SEC for SWRO plants with hydraulic turbine ERDs, located in different regions, can be calculated.

Table 2 presents the cost and technical parameters for the renewable energy power plants used for the simulation. A WACC of 7% is considered. Where specific data of the opex is not available, it is assumed to be 2% of the capex. The high voltage direct current (HVDC) transmission grid is assumed to have a power loss of 1.6% per 1000 km as explained by Bogdanov and Breyer [36].

3. Results

The model's results show that the least cost system to meet the 2030 desalination demand is comprised of a combination of fixed-tilted PV, single-axis tracking PV, wind energy plants, batteries and PtG power plants. This energy system allows for a 10% reduction in the global average LCOW compared to the energy system without PtG power plants. The use of batteries and PtG enable higher full load hours of the renewable energy plant and therefore, better utilisation of the installed SWRO capacity. This results in lower LCOW.

The figures that follow present an overview of the energy system, desalination system and the resulting global LCOW.

Fig. 5 (top) presents the required installed capacities of hybrid PV–wind power plants to meet a region's 2030 global desalination demand. A region is defined as an area of 50 km × 50 km (exactly 0.45° × 0.45° in units of latitude and longitude). Fig. 5 (bottom) presents the contribution of PV to the PV–wind hybrid power plant energy generation.

PV power plants provide up to 82% of the total global energy demand with single-axis tracking accounting for 70% of this supplied energy. The higher contribution of PV power plants is attributed to the fact that there is higher desalination demand, and thus higher SWRO capacity, in regions where PV is more favourable than wind. Based on Fig. 5 (top) the global installed capacities of fixed-tilted PV, single-axis tracking PV, wind power plants required are approximately 1040 GW, 1960 GW and 550 GW, respectively.

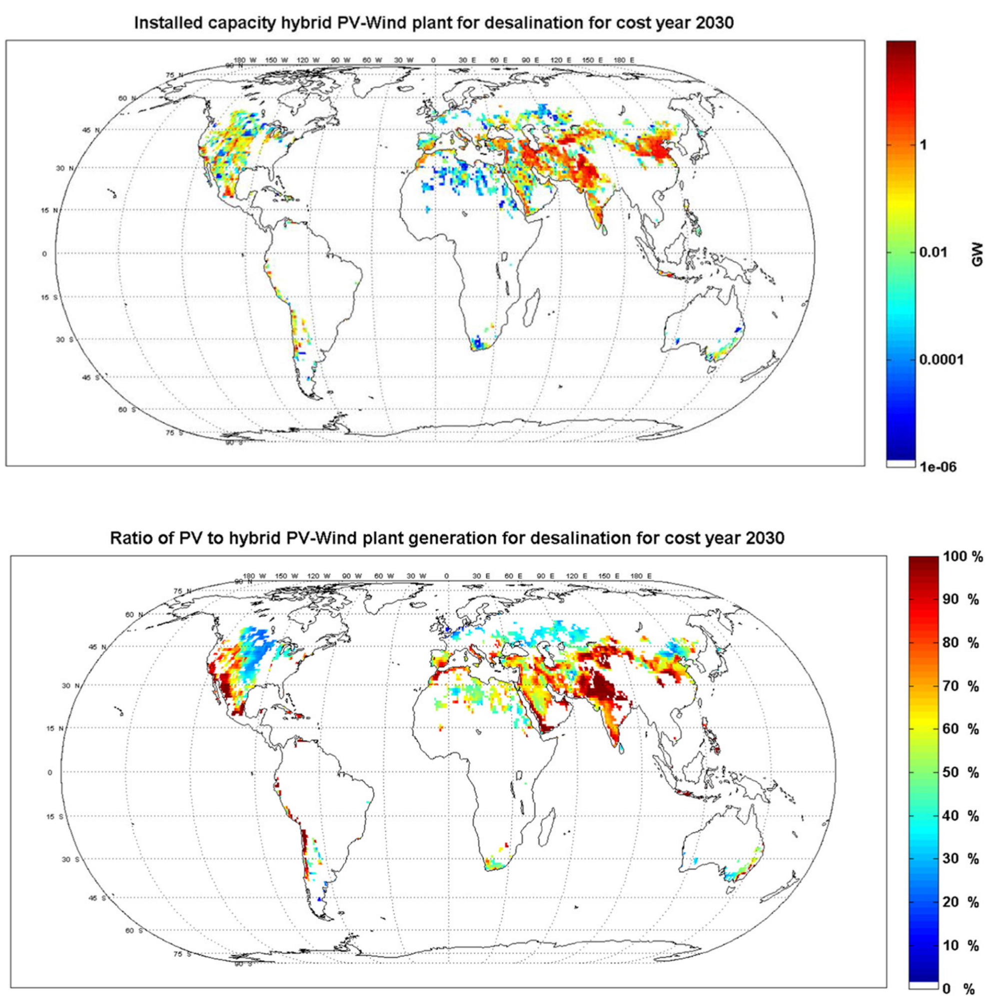

Fig. 5. Top: Installed hybrid PV–wind power plant capacity for the 2030 desalination demand. Bottom: Contribution of PV to the PV–wind generation for the 2030 desalination demand.

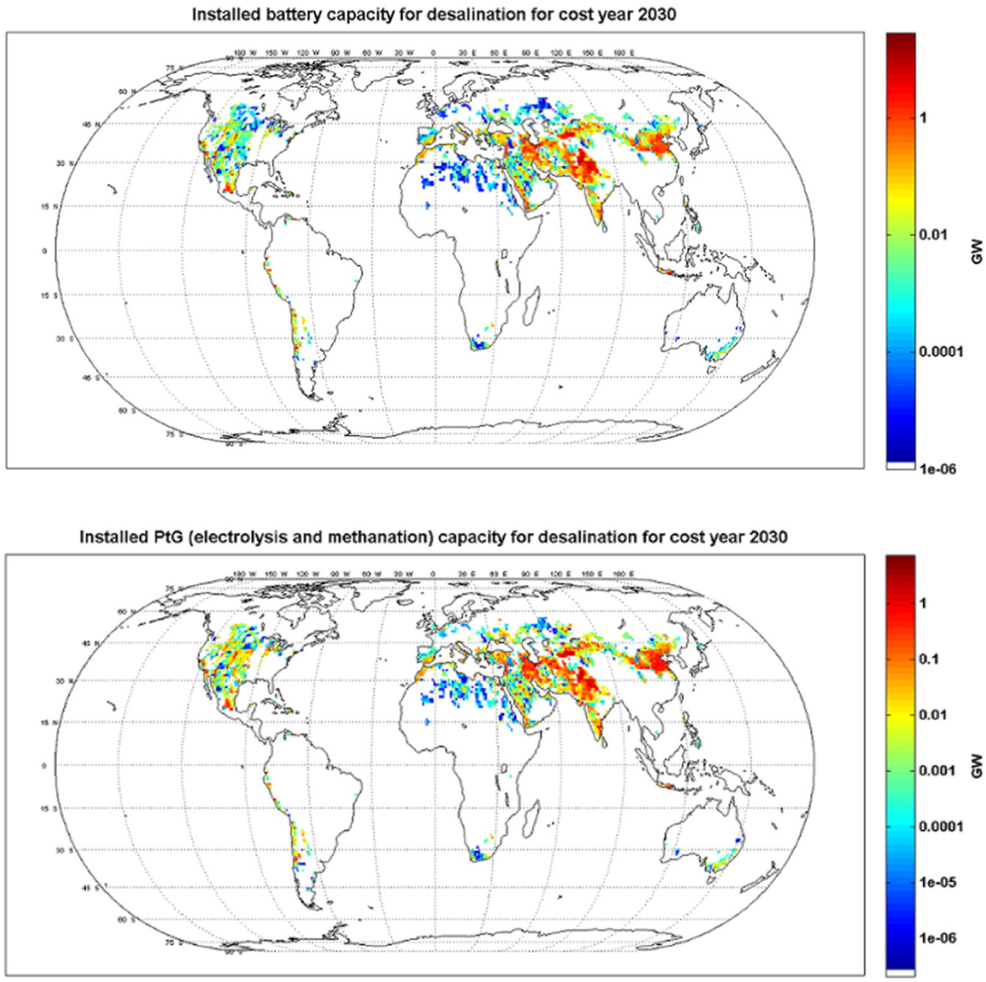

Fig. 6. Top: Installed battery capacity required for the 2030 desalination demand. Bottom: Installed PtG capacity required for the 2030 desalination demand.

Fig. 6 (top) and (bottom) shows the additional required capacities of batteries and PtG power plants. Batteries and PtG plants allow high full load hours (FLH) and therefore, better utilisation of the desalination capacity.

The required installed battery capacity is approximately 5480 GWh. These batteries are cycled almost every day reaching about 350 cycles per day and therefore providing up to 24% of the total global energy demand for the desalination demand. PtG contributes up to 15% of the total global energy demand with a required installed capacity of approximately 300GW. The results in Fig. 7 (top) show the optimal water storage required to obtain the lowest LCOW in all regions. The value ranges between 7–8 days. This can be explained through Fig. 7 (bottom). The figure illustrates the excess energy generated by the complete system. In the global average, the excess energy is about 6% of the total generated electricity.

The LCOE of the complete system to meet the 2030 desalination demand is presented in Fig. 8 (top). The LCOE of the system ranges from 0.06 €/kWh–0.13 €/kWh. The prevalent LCOE range is 0.09 €/kWh–0.12 €/kWh. Fig. 8 (center) presents the resulting global LCOW. The final LCOW range is between 0.59 €/m^3–2.81 €/m^3, mostly prevalent between 0.70 €/m^3–2.00 €/m^3.

Fig. 8 (bottom) explains the significance of the water transportation costs to the LCOW. The energy required for water pumping, and therefore the pumping electricity costs, are significant in regions where the demand site is distant from the desalination site. This includes both the vertical and horizontal distances. In regions like Central Asia, the LCOW can contribute up to 40% towards the LCOW. The corresponding LCOW in this region is approximately 3 €/m^3–4 €/m^3. Globally, the average pumping electricity cost contribution to the LCOW is about 17% and the total Opex contribution to the LCOW is approximately 39%.

To conclude, Fig. 9 illustrates the cost contribution to the final LCOW. Fig. 9 (top) highlights the contribution of the total system Capex to the LCOW for regions with desalination demand in 2030. The Capex contributes between 50–80% to the final LCOW. The average global Capex contribution to the LCOW is approximately 62%.

Fig. 9 (bottom) illustrates the contribution that PtG has to the reduction of the LCOW. The reduction in LCOW of about 10% in the global average is brought about by the PtG storage capacities. The required PV, wind and battery capacities are reduced by 24%, 14% and 33%, respectively.

4. Discussion

The global LCOW range when desalination plants, in 2030, are powered by hybrid PV, wind, battery and PtG plants is found to be

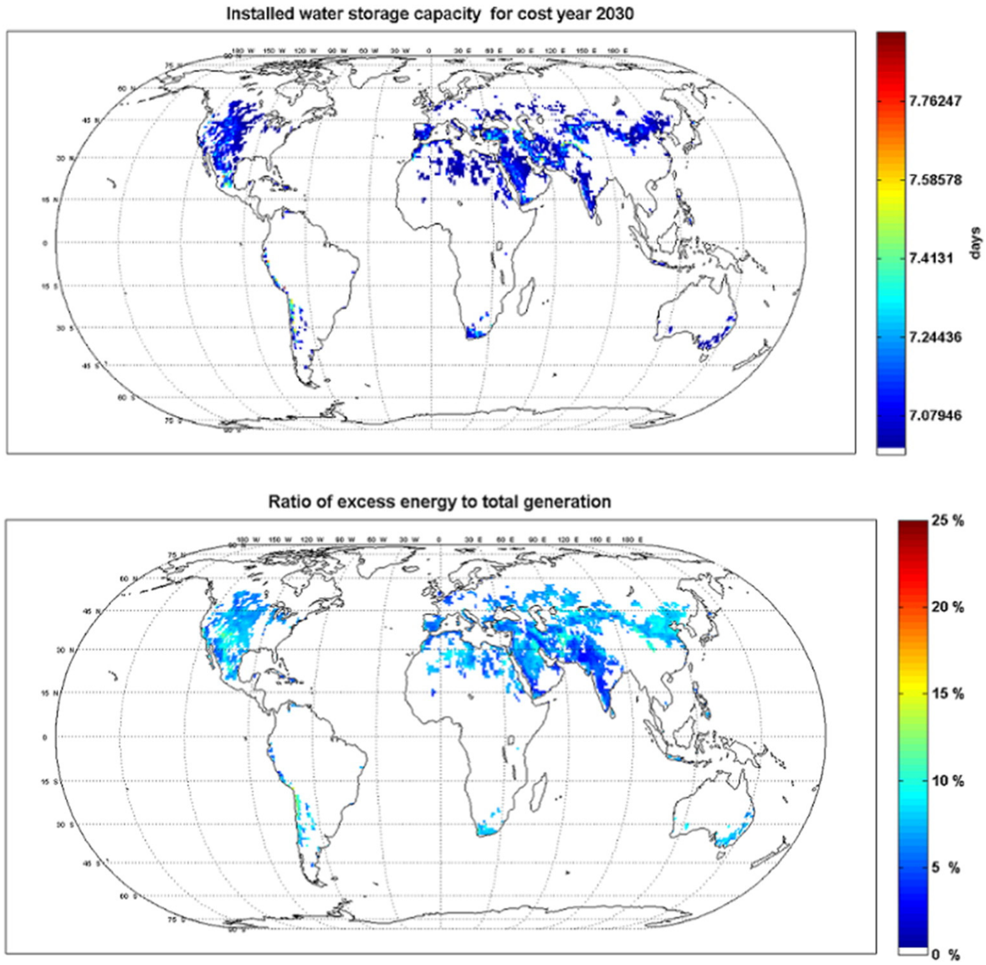

Fig. 7. Top: Optimal water storage capacity needed for the 2030 system. Bottom: Ratio of the excess energy to the total energy generated for the 2030 system.

between 0.59 €/m^3–2.81 €/m^3. The prevalent LCOW range is between 0.70 €/m^3–2.00 €/m^3.

Fichtner [38] presented water production costs for fossil powered SWRO desalination plants, located in different regions. The costs range approximately between 0.60 €/m^3–1.90 €/m^3. The higher LCOW range of the model can be attributed to the high water transportation costs, as shown in Fig. 8 (bottom). The costs presented by Fichtner do not include water transportation costs. The electricity costs for water pumping, in both horizontal and vertical distance, can make a substantial contribution to the final water production cost. On average, globally, electricity for pumping contributes up to 17% towards the final LCOW.

The results show that it is indeed possible to meet the increasing water global demand with SWRO desalination plants powered by hybrid renewable energy power plants. In the near future the production cost of water from the hybrid system will be competitive with the cost of fossil powered SWRO plants today. This will be driven by the increase in desalination demand and the decrease in PV and storage costs due to learning curve effects.

The energy model utilised optimises the cost of the system for the different components of the hybrid power plant and their relative configuration. The total Capex of the above system to meet the 2030 global desalination demand is estimated to be 9790 billion €, with annualised costs of 1230 billion €. This is for a WACC of 7%. The 2030 global desalination demand, for an optimistic scenario, is found to be about 2374 million m^3/day. The average global excess energy generated is minimised to 6% through the use of battery and PtG storage. Table 3 summarises key aspects of the necessary global system.

5. Conclusions

An energy model is used to estimate the viability of meeting the 2030 global water demand, based on the optimistic scenario, solely with SWRO plants powered by renewable energy. Hybrid renewable energy power plants are used as they offer higher full load hours and therefore allow for better utilisation of the desalination plant capacity. The 2030 costs for different renewable energy technologies are used.

The least cost system is found to be a combination of fixed-tilt PV, single-axis tracking PV, wind energy, batteries and PtG power plants. The LCOW range is predominantly between 0.70 €/m^3–2.00 €/m^3.The current LCOW range of fossil powered SWRO plants, excluding water transportation, is between 0.60 €/m^3–1.90 €/m^3. Therefore, in the near future, SWRO plants powered by renewable energy will produce water at similar prices to that of today's fossil plants. Furthermore, depending on the terrain, the water transportation costs can contribute significantly to the final LCOW.

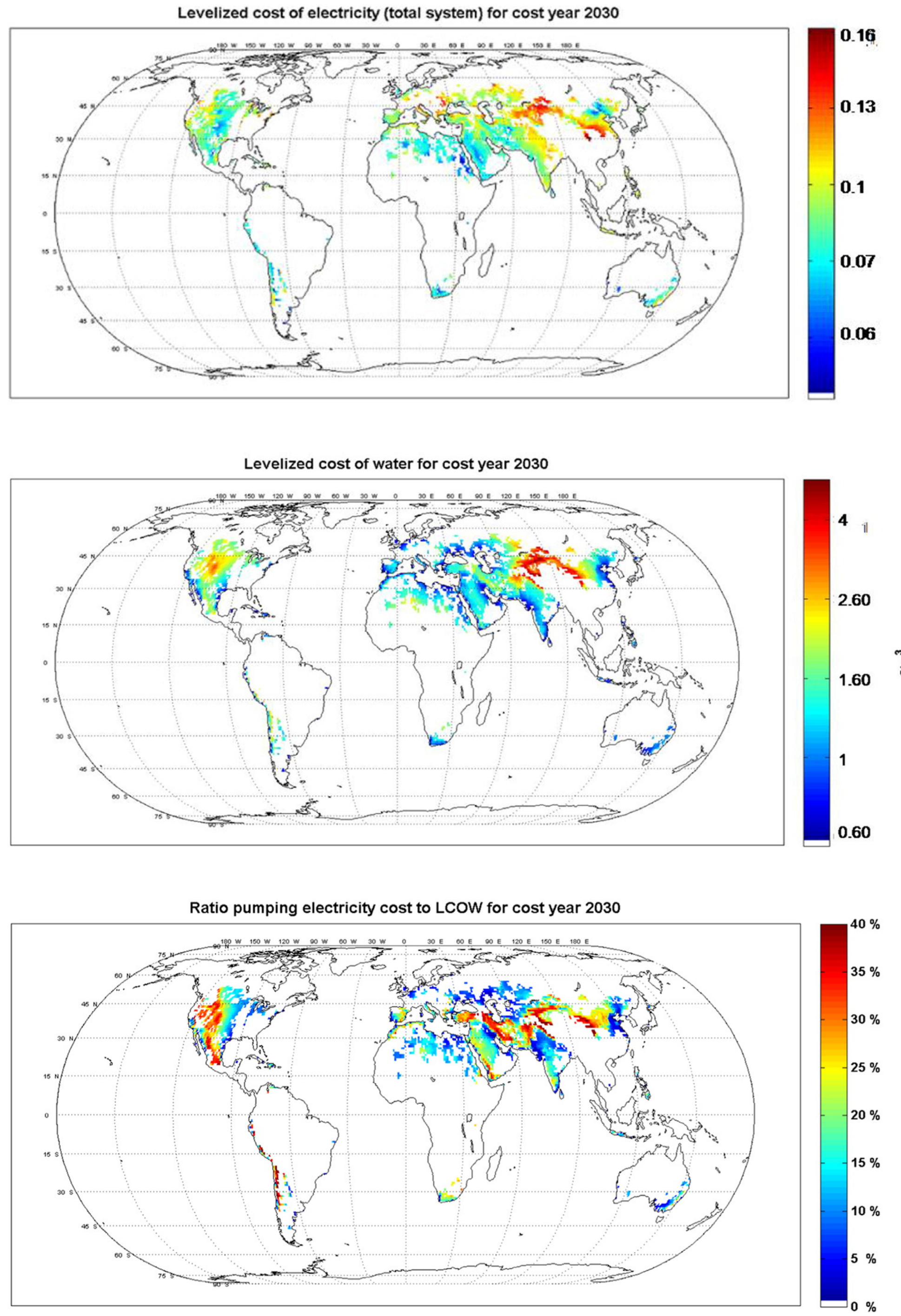

Fig. 8. Top: LCOE of the complete system for 2030 system. Center: LCOW of the complete system for 2030 system. Bottom: Pumping electricity cost contribution to the LCOW for the 2030 system.

It has to be noted that there are gaps in the data assumptions used for this research work. These gaps can be summarised as below:

1. No well-defined learning curve for SWRO desalination plants. This makes it difficult to project the future SWRO costs.
2. Lacking updated water transportation costs. Recent literature makes reference to 1993 water transportation costs.
3. Need of a more accurate model of the future water stress and demand. For instance, water stress should take into account the impact of climate change. Water demand should consider the complete removal of thermal power plants.

By filling in the data gaps, a more accurate model of the future global water scenario and water production costs can be built. This will enable us to better understand the potential role for SWRO desalination and renewable energy systems in meeting the water supply challenges of the decades to come.

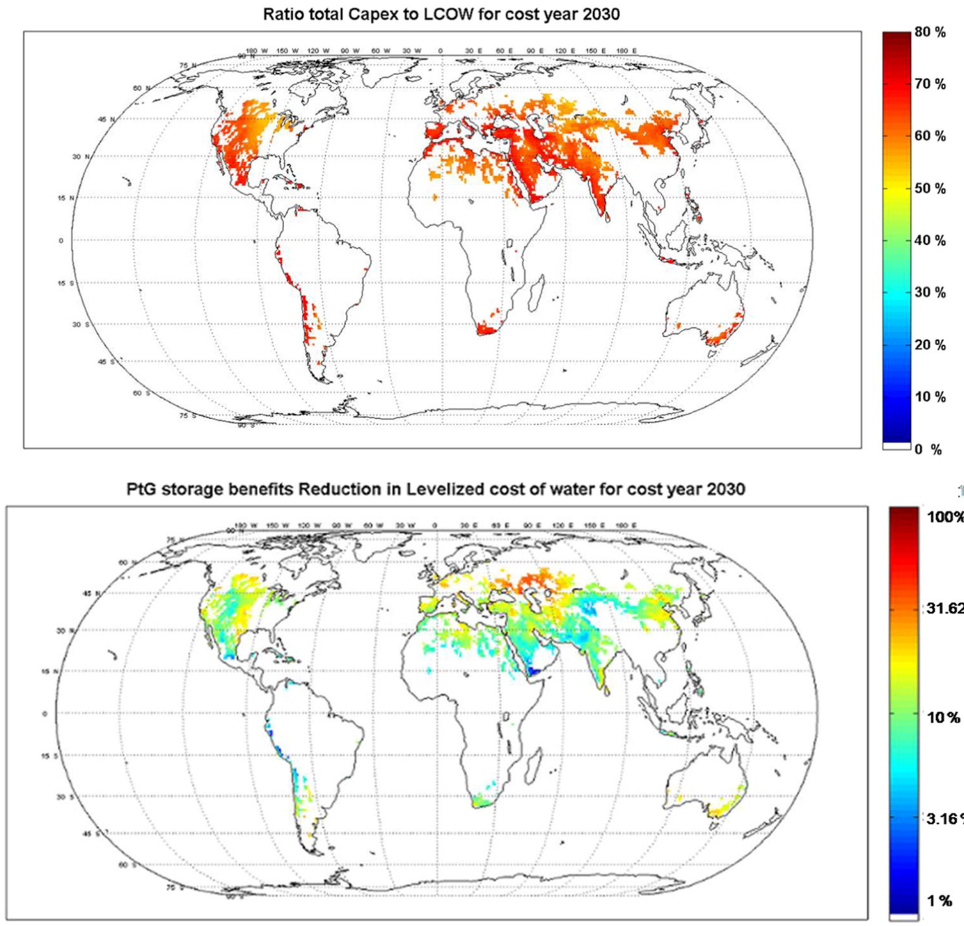

Fig. 9. Top: Total system Capex contribution to the final LCOW. Bottom: Contribution of PtG the reduction of the LCOW.

Nomenclature

a	annum
Capex	capital expenditures
crf	capital recovery factor
LCOE	levelised cost of electricity
LCOW	levelised cost of water
Opex	operating and maintenance expenditures
PtG	power-to-gas
PV	photovoltaic
SEC	specific energy consumption
SNG	synthetic natural gas
SWRO	seawater reverse osmosis
WACC	weighted average cost of capital
WS	water stress

Table 3
Summary of the key technical and cost data for the 2030 global system.

		2030 global system
SWRO total global desalination demand per day	m^3/day	2374 million
Installed PV capacity	GW	2996
Fixed-tilted PV	GW	1036
Single-axis tracking PV	GW	1960
Installed wind capacity	GW	550
Installed battery capacity	TWh	1930
Installed PtG capacity	GW	300
Average global excess energy generated	%	6
Total Capex	bn€	9790
Annualised costs	bn€	1230
LCOW range	€/m^3	0.60–2.80
Prevalent LCOW range	€/m^3	0.70–2.00

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