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# Integration of renewables and reverse osmosis desalination – Case study for the Jordanian energy system with a high share of wind and photovoltaics

T. Novosel [a,*], B. Ćosić [a], T. Pukšec [a], G. Krajačić [a], N. Duić [a], B.V. Mathiesen [b], H. Lund [b], M. Mustafa [c]

[a] Faculty of Mechanical Engineering and Naval Architecture, Department of Energy, Power Engineering and Environment, University of Zagreb, Zagreb, Croatia
[b] Department of Development and Planning, Aalborg University, Denmark
[c] Department of Mechanical Engineering, Hashemite University, Zarqa, Jordan

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ABSTRACT

Jordan is a country faced with several environmental and energy related issues. It is the Worlds' fourth most water deprived country with a water consumption of only 145 $m^3$ per capita annually, less than a third of the established severe water poverty line. Jordan is also a country rich in wind and solar potential but practically no utilization with 99% of the produced electricity coming from imported fossil fuels resulting in high $CO_2$ emissions and a potential security of supply issue. The utilization of reverse osmosis desalination in a combination with brine operated pump storage units and wind and (PV) photovoltaic plants can tackle both issues. The desalination plants can produce the much needed water and act as a flexible demand to increase the penetration of intermittent renewables supported by the brine operated pump storage units. This paper presents six scenarios for the development of the Jordanian energy system until the year 2050. The results have shown that the demonstrated configuration can increase the share of intermittent renewables in the production of electricity up to 76% resulting in a high reduction of fuel consumption, $CO_2$ emissions and costs. These analyses have been performed using the EnergyPLAN advanced energy system analyses tool.



## 1. Introduction

A high level of water scarcity and heavy dependence on imported fossil fuels are both very serious issues facing Jordan. It is currently the Worlds' fourth most water deprived country with an annual consumption of only 145 $m^3$ per capita annually [1], less than a third of the established severe water poverty line of 500 $m^3$ [2]. This is an issue that will only become more serious in the future considering that Jordan's population is predicted to increase by 50% by the year 2030 [3]. It is also a country heavily dependent on imported fossil fuels with 5909 ktoe or 83.6% of the primary energy consumption coming from crude oil or oil products, 872 ktoe or 12.3% from natural gas and only 283 ktoe or 4.1% from renewables and electricity import in 2011 [4]. This represents an enormous expense. The Jordanian fuel bill exceeds 3 billion USD annually which is approximately 20% of its GDP for the year 2011 [5]. As with the water scarcity, this problem is bound to escalate in the upcoming future. The Jordanian official energy strategy predicts an annual increase of the electricity demand by 7.4% annually by the year 2020 [6]. This would double the demand in the period 2011 to 2020.

The utilization of an integrated system combining (RO) reverse osmosis desalination and pump storage systems that utilize brine water (brine operated pump storage or BOPS) with (RES) renewable energy sources, namely wind and (PV) photovoltaic energy, can help mitigate all of the aforementioned issues. The benefits of integrated solutions for the reduction of $CO_2$ emissions and the increase of the utilization of intermittent RES has already been discussed in the past, for example with a focus on wind energy [7] and the integration of the energy and transport sectors [8]. The

* Corresponding author. Tel.: +385 1 6168494; fax: +385 1 6156940.
*E-mail addresses:* tomislav.novosel@fsb.hr (T. Novosel), Boris.Cosic@fsb.hr (B. Ćosić), Tomislav.Puksec@fsb.hr (T. Pukšec), Goran.Krajacic@fsb.hr (G. Krajačić), Neven.Duic@fsb.hr (N. Duić), bvm@plan.aau.dk (B.V. Mathiesen), lund@plan.aau.dk (H. Lund), m_mustafa@hu.edu.jo (M. Mustafa).

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**Nomenclature**

| Abbreviation | Full name | Measuring unit |
|---|---|---|
| BOPS | brine operated pump storage | – |
| c | ionic molar concentration | mol/l |
| CEEP | critical access of electricity production | – |
| CHP | combined heat and power | – |
| $E_{tot}$ | total electricity demand for desalination per cubic meter of fresh water | kWh/m$^3$ of fresh water |
| g | standard gravity | m/s$^2$ |
| GDP | gross domestic product | – |
| h | height difference | m |
| IEA | International Energy Agency | – |
| NEPCO | National Electric Power Company | – |
| $P_p$ | installed power of pumps for the pumping of salt water | kW |
| $P_{RO}$ | installed power of pumps for the RO desalination itself | kW |
| $P_{tot}$ | total installed power of pumps for desalination | kW |
| PV | photovoltaic | – |
| R | gas constant | l bar/K mol |
| RES | renewable energy sources | – |
| RO | reverse osmosis | – |
| T | absolute temperature | K |
| v | volume flow of salt water | m$^3$/s |
| $V_{fresh}$ | volume flow of fresh water | m$^3$ |
| ρ | density of pumped water | kg/m$^3$ |

authors of [9] presented and discussed seven possible technologies mostly focussing on power to heat technologies, flexible electricity demand and electric vehicles while the work presented in Ref. [10] focused primarily on the integration of the energy and transport systems. The integration of wind [11] and PV [12] with desalination systems has also been discussed in the past. The authors of [13] have demonstrated that the utilization of RO desalination can reduce the amount of critical excess of electricity production, meaning excess electricity that cannot be stored or exported, (CEEP) by approximately 15% in their scenarios while our previous work demonstrated that the utilization of RO desalination and BOPS could separately increase the penetrations of wind power to roughly 32% and for PV power to roughly 37% of the total annual electricity demand [14]. These papers focused on the technical impact desalination has on energy systems of arid countries but not its cost. This issue is still unexplored. The work performed in Ref. [15] demonstrated the economic and environmental benefits of the integration of intermittent RES, pump storage and desalination in an island environment with a potential penetration of wind and hydro energy of up to 36%. The idea of water and energy integration has been discussed in the framework of the energy-water nexus. Work on this topic has demonstrated a positive effect on water and energy consumption as well as a reduction in $CO_2$ emissions in several case studies like China [16], the MENA region [17] and California [18].

Jordan is a country rich in the potential for economically viable wind [19], and PV [20], energy utilization with payback periods being as low as 6 years for wind [21] and 2.3 for PV [22] in some cases. The utilization of these RES could power the RO desalination plants which would in turn, aside from producing fresh water, further increase the potential for their penetration. The desalination system could also be fitted with BOPS to further increase this potential. The importance of energy storage in future energy systems for the purpose of increasing the penetration of renewables [23] as well as its' role in a market environment [24] has already been discussed by several authors in the past. RO desalination is the most widespread sea water desalination technologies in use today and its flexibility makes it suitable for utilization with intermittent energy sources like wind and PV [25]. The benefits of 100% renewable energy systems and systems with a high penetration of renewables are numerous including $CO_2$ emission mitigation [26], job creation and economic growth amongst others [27].

This paper presents a continuation of previous work where the beneficial influence of RO desalination on the increase of the potential for the penetration of renewables has already been demonstrated in EnergyPLAN [14] and in H2RES [28]. The goal of this work is to use the EnergyPLAN [29] advanced energy system analyses tool to present and compare 6 scenarios for the future development of the Jordanian energy system centred on the utilization of RES and RO desalination. Unlike the previous work, this paper explores the impact desalination and intermittent RES have not only on the energy system from the perspective of CEEP and $CO_2$ emissions but also on the total cost of the system Two desalination systems have been analysed, one modelled after a system focused on the reduction of energy consumption [30] and one focused on the increase of the potential for the penetration of renewables [14]. The results have shown that the second configuration could support an energy system where 76% of the electricity can be produced from wind and PV alone resulting in a drastic reduction of $CO_2$ emissions and fuel use and in turn also of the total cost of the energy system.

## 2. Methodology

The analyses performed in this paper were conducted with the EnergyPLAN advanced energy system analyses tool. EnergyPLAN is a deterministic input output energy system modelling tool able to create annual analyses of different energy systems on an hourly level. It requires a broad range of both hourly and annual aggregated data. The required inputs include the hourly distributions of electricity and heat demand as well as the distributions for the energy productions from wind, PV, river hydro and similar energy sources, the installed capacities of the individual energy producers, energy mix of the thermal power plants and the demand in the building, industry and transport sectors as well as the economic data related to the fuel costs and the costs of the investment and operation of the different systems. The provided results include the total annual $CO_2$ emissions, total cost of the system, analysis of the energy production, CEEP, fuel consumption and so on.

EnergyPLAN is a well-documented and widely used energy modelling tool that is specialized in the large scale integration of RES in energy systems [31] and optimal combination of RES [32]. It has been used in the past to recreate several different energy systems like Croatia [33], Denmark [35], Macedonia [36], Jordan [14] and so on.