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Desalination using renewable energy sources on the arid islands of South Aegean Sea

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ABSTRACT

Water and energy supply are strongly interrelated and their efficient management is crucial for a sustainable future. Water and energy systems on several Greek islands face a number of pressing issues. Water supply is problematic as regards both to the water quality and quantity. There is significant lack of water on several islands and this is mainly dealt with tanker vessels which transport vast amounts of water from the mainland. At the same time island energy systems are congested and rely predominantly on fossil fuels, despite the abundant renewable energy potential. These issues may be addressed by combining desalination and renewable energy technologies. It is essential to analyse the feasibility of this possibility. This study focuses on developing a tool capable of designing and optimally sizing desalination and renewable energy units. Several parameters regarding an island's water demand and the desalination's energy requirements are taken into account as well as input data which concern technological performance, resource availability and economic data. The tool is applied on three islands in the South Aegean Sea, Patmos (large), Lipsoi (medium) and Thirasia (small). Results of the modelling exercise show that the water selling price ranges from 1.45 €/m^3 for the large island, while the corresponding value is about 2.6 €/m^3 for the small island, figures significantly lower than the current water cost (7–9 €/m^3).

1. Introduction

The water scarcity on the Aegean islands is a long-standing problem. Recently this problem became more intense due to increasing population, tourism and the higher needs of the current living standards. The Hellenic State has chosen as a temporary solution to this issue the transportation of vast amounts of water with tanker vessels, which results in significant expenditures that burden the state [17]. At the same time, desalination technologies have matured and several units have been installed on the Greek islands [25]. Still, they are quite energy intensive. This adds to the already autonomous island energy systems that are facing overloads -inadequate generation problems arise on the basis of several black-outs especially during the summer [24]. Additionally the electricity generation is mainly comprised by diesel generators which run on imported fuel [11]. This paper considers the combination of desalination units running primarily on renewable energy sources, which are abundant on the Greek islands.

The main objectives of this paper are:

- To develop a tool to design and size coupled desalination and RET (renewable energy technology) units that will also provide investment indicators;
- To apply the tool on three island cases and compare the water production cost with the current costs.
- To quantitatively examine the impacts of a new legislative framework for combining RES (renewable energy source) and desalination functions;

Initially this paper describes the current water supply situation on the arid islands of South Aegean Sea. Section 1 then considers a proposal published by the Ministry of Infrastructure, Transport and

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Nomenclature

RET	renewable energy technology
RES	renewable energy source
HRES	hybrid renewable energy system
RO	reverse osmosis
PV	photovoltaics
NPV	net present value
PBP	payback period
IRR	internal rate of return

Networks in 2010 and the new RES (renewable energy source) legislation framework regarding desalination are analyzed Refs. [51,52]. Then, in Section 2 a methodology is presented for sizing desalination plants on the islands that will run on RET (renewable energy technology) plants which will supply part of the energy requirements of desalination. Moreover energy balances and cost of the system as well as selling prices that would make the investment viable for the Hellenic State and profitable for the investors are enumerated. This methodology is applied on three characteristic islands (large, medium, small) in Section 3 and several scenarios are constructed based on the legislation and the potential for RES penetration. Finally the results of this work are presented and compared with current water costs and conclusions are drawn regarding the feasibility of such a project.

1.1. Previous assessments

There is a plethora of studies and projects performed recently about the combination of desalination and renewable energy technologies.

A remarkable approach regarding the provision of renewable electricity and water supply on islands is introduced by Ref. [41]. An integrated RES system based on pumped storage and wind turbines is proposed for Ios Island (another arid island of South Aegean Sea). Generated electricity is used to cover energy requirements of the island as well as to meet the demand of a desalination unit, which will not only supply water to the island but also function as a supplementary unit for supplying the tanks with water when required.

The combination of desalination and renewable energy technologies is presented in a paper by Bennett [4] which demonstrates the importance of integrating these two technologies. Solar and wind energy are the major renewable energy technologies which are used to power desalination worldwide. They hold the lion's share with more than 80% of the corresponding generation [34]. However, biomass, hydro power, and ocean thermal energy are utilized to a lesser extent to generate electricity that feeds smaller desalination plants. Another substantial study is made by Eltawil et al. [13] in order to review the current methods of integrating the technologies, the corresponding costs and the potential environmental impact. They conclude that a combination of these systems is a technically mature option towards solving problems related to energy and water scarcity.

Voivontas et al. [48] demonstrate also a significant techno-economic tool for the optimal selection of the most applicable RES and desalination technology. Several technical and economic parameters are taken into account and the users of the tool can vary these parameters according to the case study they are developing. The energy balances are being done on an annual basis.

Koroneos et al. [32] developed an integrated model for the use of wind and solar energy in the desalination of seawater, where they couple the two technologies to achieve the lowest system cost. Storage of the renewable electricity when necessary is implemented. Also in this direction by Hossam-Eldin et al. [20], investigate the use of hybrid renewable energy systems (HRES) in desalination using reverse osmosis (RO). In this case, unit production costs of both energy and desalinated water are compared for two existing small and medium RO plants powered with conventional electricity grid and electricity generated from the HRES. They conclude that hybrid systems remain an expensive source of power, which can be mainly used for remote power applications and are nowadays cost-effective, whereas extension of grid supply is expensive. Novosel et al. [38] have shown that a combined RE-desalination configuration can increase the share of intermittent renewables in the production of electricity up to 76% resulting in a high reduction of fuel consumption.

The aforementioned sources as well as other useful “state of the art” studies in (Refs [1,10,18,37]) are used to develop a methodology on how to fulfil the objectives of this study. This study constitutes the first approach to develop a techno-economic tool capable of dimensioning and integrating renewable energy sources and desalination units to the grid and carry out an overall analysis and energy balance on an hourly basis throughout the year. There are several parameters taken into account that have not been considered in the previously stated studies; such are the legislation framework which allows a certain penetration of the renewables on the islands, solar irradiation, wind regime, land availability and others that are mentioned throughout the paper.

1.2. Current situation

While some water is supplied by private and municipal wells (primarily water of very low quality and high salinity) supplemented by rainwater collection (unreliable due to the intermittency of precipitation), the bulk is shipped to the islands by marine based water shipments at significant expense. The cost for the Hellenic Ministry of Shipping is significant, e.g., 7.3 €/m^3 for Dodecanese cluster of 26 islands and 9.3 €/m^3 for the Cyclades cluster of 33 islands [2], while the cost in Athens is less than 0.70 €/m^3, which is the price of water for household consumption 5–20 m^3 per month [14]. There are also several desalination units in operation which absorb vast amounts of energy in already overloaded island energy systems [28]. The desalination units are predominantly operated by municipalities which, due to shortages of a skilled workforce, face problems with their efficient and effective operation.

So what are the alternatives to water shipments from the mainland? Greek islands are endowed with abundant renewable energy resources [42] with the potential to meet existing and future energy demands. Renewable energy supply and desalination can be (and have been) combined/integrated. Their integration alleviates in large part the energy intensiveness of seawater desalination [43] and would burden already overload island energy systems. Furthermore, renewable supplies avoid greenhouse gas emissions since at least part, if not all, of the energy for desalination would be supplied by renewable sources.

1.3. Practical implementation

Greece is a pioneer country in the field of combining these two technologies. The University of the Aegean in cooperation with the Region of South Aegean developed the first wind powered floating desalination unit in the world, which provides electricity to the island of Iraklia on South Aegean Sea, covers the desalination