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Preliminary assessment of wave energy use in an off-grid minor island desalination plant

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Abstract

Small islands are often characterized by water availability problems becoming critical in summer time during the touristic season. The current water supply systems rely on the shipping of water from the mainland, with relevant fall backs in terms of water price and CO_2 emissions. On the other hand the recur to local desalination raises the other issue in minor islands: energy supply. In this respect, the use of renewable energy appears to be the most natural option to the power mix pending the adequate consideration of the environmental constraints. In minor islands, the high environmental quality could often results in more severe landscape conservation rules as such introducing limitations to the most common renewable energy based installations. To this end, this paper discusses the use of near-shore wave energy technologies as a solution to cope with low impact energy generation to the water demand of a typical island in the Tyrrhenian Sea, the island of Ponza. The preliminary assessment focuses on the analysis of the impact on diesel fuel oil use and GHG emissions reduction.

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Keywords: desalination, wave energy, small island

1. Introduction

The island of Ponza, part of the Pontinian Islands Archipleago in the Thyrrenian Sea, has a total area of 10.16 km^2 with a distance of 24 miles from the nearest mainland port (San Felice Circeo). Within the last three decades, its population has been of around 3200 inhabitants with a summer-time fluctuation going up to 100% due to its tourist attraction. In return, this circumstance stresses the utilities. While the

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energy demand, already discussed in [1, 2], is a typical subject of interest the impact on island water need is not fully studied.

Looking at the water supply condition, as Ponza totally lacks of natural water reserves, water is adducted to the island with tanker ships from Naples (63 miles from Ponza), with a strong impact on the supply cost (11.30 €/m^3) and on the issue linked to the continuity of the service. To this end, the recur to a desalination plant may overthrow or at least it could be seen as a remedial option to the water delivering problems.

Among the various thermal and electric desalination processes, Reverse Osmosis (RO) features in general the higher water production, easier plant design lower energy consumption and smaller environmental footprint [3-6]. As such, RO-based plant are the customary desalination technology on small islands [7-11]. Based on the available literature on energy-related issues in small islands, the main objective is still the definition of RES-based sustainable desalination process. In fact, beside water shortage problems, stand-alone power grids also share the challenge to meet the energy needs in a sustainable and reliable way, as their gen-sets usually relay on oversized low-efficiency oil-fired diesel engines. The dependency on oil import entails a high vulnerability to oil price volatility besides additional costs. On the demand side, like the mainland, islands experienced a decline in electricity demand throughout the recent economic slump, correlated with a decrease in Gross Domestic Product. However, most European islands are expecting increases in electricity demand. with an average increase of 24% from 2009 to 2020 (note that the EU-27 increase is expected to be 14%) [12].

At this stand point, also in view of the emission limits defined by the Industrial Emissions Directive (IED) for islands within 31st December 2019, the use of renewable energy power systems appears as an opportunity to realize a desalination plant without increasing fuel oil consumption and moving toward sustainable systems. Up to date, the literature review shows a significant activity around RES application to desalination systems, showing interest on optimal RES-desalination match [13, 14] control strategy [15-17], as well as the application of single RES technologies alone or in hybrid RES plants with a special focus on wind power [18-20]. Two additional aspects enrich small island eco-system in RES initiatives. First, the scarce land availability and the enforcement of environmental and landscape restriction laws should be considered as factors limiting the possibility of dedicated RES installations. Second, islands are by definition surrounded by the sea that should be taken into consideration as a valid energy source. To this end, only few studies have investigated the matching between wave energy and desalination (usually RO-based). To mention but a few, either the direct use wave energy converters to directly feed pressurized water to the desalination system [21-23], or electric energy generation to run the desalination plant [24-27] where studied.

In contrast to such a broad interest on wave energy converters, Mediterranean Sea has not been interested by large ocean energy projects due to its low potential (in terms of low significant wave heights and periods). Moving to Ponza island a recent wave energy potential assessment was given in [1, 2], but the generation capability evaluation focused on on-shore Oscillating Water Column was affected by the specific wave energy decrease determined by bathymetry and installation localization point. For this reason the present investigation concentrates on off-shore energy converters, specifically modelling the ISWEC (Inertial Sea wave Energy Converter) [28] plant, recently developed for Mediterranean Sea dedicated device.

On the basis of the literature review findings, the present work will assess the RO desalination option for clean water supply in the island of Ponza. In the following two different scenarios are compared to the reference one with water shipping: Scenario 1 - desalination plant fed with grid energy from island's diesel engine generator set; Scenario 2 - desalination fed by wave energy. Scenario 1 and 2 are modelled by means of hourly-step-based transient simulations taking into account water load and local meteorological and sea states data. The comparison is carried out using emission metrics.

2. Reference scenario: present clean water supply to Ponza Island

Ponza island clean water demand amount to 400000 m^3/y, with a month distribution summarized in Table 2. The water supply of Ponza is completely entrusted to ships transport from the Port of Naples, 63 miles far from the port of Ponza. The transport is made by using a dedicated fleet of ships typically with a water capacity of 1690 m^3, and a 970 kW Diesel engine propulsion. In the hypothesis that the ship engine works at 85% MCR, its specific Diesel consumption will be 168 g/kWh, and considering a mean velocity of 8 kn, a single round trip for water transportation will cause 9.01 t_{CO2eq} by taking an emission factor of 3.538 g_{CO2eq}/g_{Diesel} (value defined by a sector screening). As for the entire supply about 237 ships are needed, the corresponding emissions will be about 2133 t_{CO2eq}/y.

Table 2. Shipping water supply related emissions.

Month	Fresh water need [m^3/month]	Number of ships trips	Round trip transport emissions [t_{CO2-eq}]	Water loading and unloading emissions [t_{CO2-eq}]	Total emissions [t_{CO2-eq}]
1	17000	10	90.67	23.47	114.14
2	17000	10	90.67	23.47	114.14
3	17000	10	90.67	23.47	114.14
4	22000	13	117.34	30.37	147.71
5	38000	22	202.68	52.46	255.14
6	45000	27	240.02	62.12	302.14
7	70000	41	373.36	96.64	470.00
8	75000	44	400.03	103.54	503.57
9	45000	27	240.02	62.12	302.14
10	20000	12	106.67	27.61	134.28
11	17000	10	90.67	23.47	114.14
12	17000	10	90.67	23.47	114.14
Total	400000	237	2133.49	552.20	2685.69

The ship also has a 150 m^3/h flowrate pump station aboard for water loading and unloading operations, powered by a 120 kW Diesel engine in view of a 95 kW absorption, with a corresponding specific consumption of 332.06 g/kWh and by taking an emission factor of 3.282 g_{CO2eq}/g_{Diesel}. The result is an emission of 2.33 t_{CO2eq} for the loading/unloading operations and yearly emissions of about 552 t_{CO2eq}/y.

Concluding, the water transport by ships entails a specific emission of 6.71 kg_{CO2eq}/m^3.

Furthermore, the described water shipping service has a cost of 11.30 €/m^3, that means 4520000 €/y.

3. Methodology

In order to analyze the desalination system scenarios, hourly-based time step transient simulation models for a reference year were developed in TRNSYS by adding in-house made components for Reverse Osmosis desalination unit, water and energy control and ISWEC wave energy converter.

Figure 1 shows the flowchart of the transient model. The scheme works on a twofold level: water and power fluxes. At the water side, the storage takes into account the water load (W_{req}) the desalinated water flux (W_{RO}) and the water level at a previous time-step in order to define the actual water level (W_{level}). The control logic of the water production is aimed at maintaining a two days autonomy water level in the storage tanks in case of plant default, by indicating the power needed to activate the proper number of RO units (P_{req}). To this end the storage capacity request will vary in a range of 1100 m^3 in the winter period to a 3000 m^3 in the summer time. It is worth noting that the capacity goal for two days autonomy in summertime exceeds 4800 m^3, but, due to the storage size limit it is reduced to 3000 m^3, corresponding to 1.24 days.

The power control level defines the sources needed to supply the requested power to the RO units (P_{RO}) by giving priority to the renewable source (P_{RES}) in scenario 2 and recalling the DEGS contribution in RES deficit events.

The initial water storage condition is settled to 1100 m^3 as, whatever value is given, due to the water request scarcity the system is able to guarantee such value at the end of the year (start of a new year) for any water level starting value.

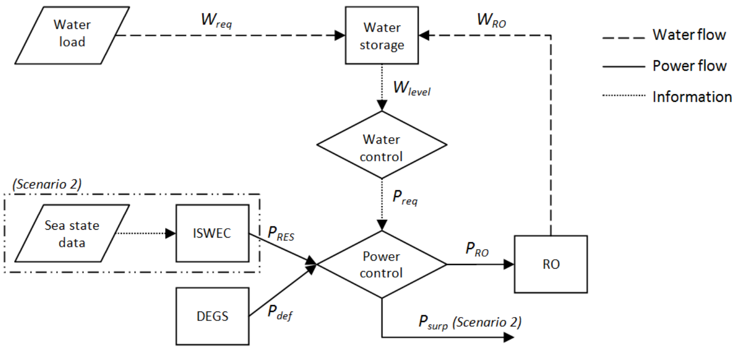


Fig. 1. Water and power flow diagram.

3.1. Water load curve

The water load curve is depicted in Fig. 2. The curve has been obtained from the resident, commuters and tourists presence on the island, distributed on a hourly based scheme. Specific water consumption distributions were assigned. The water request shape shows a variable request in the 10-40 m^3/h for winter period and a peak of 240 m^3/h in summer.

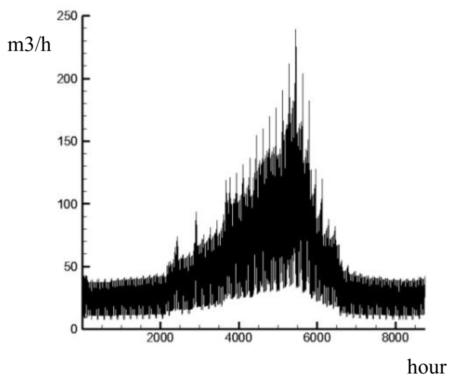


Fig. 2. Water load hourly-based curve.

3.2. Local electric energy generation system

The energy generation at Ponza is entrusted to two diesel engine generation sets, respectively a main station of 6.2 MW and peak shaving station of 2.6 MW. The yearly energy request is approximately 12 GWh/y, with a maximum power request peak of about 5 MW in the summer period, while in winter the request amounts to 1-2.5 MW.

3.3. Desalination plant

The RO desalination plant for Ponza island clearly should have a size able to completely cover the water needs. The system will be equipped with the global 3000 m^3 capacity water storage tanks already present on the island. The size choice has been made trying to merge two essential but opposite aspects: a reduced number of units and a size able to properly exploit the variable energy contribution of renewable energy sources. To this end the selected plant has eight 300 m^3/d capacity units with a seawater feed flow of 32.00 m^3/h and a permeate flow of 12.5 m^3/h. The power consumption of the RO units, equipped with an energy recovery device, is 2.41 kWh/m^3.Furthermore considering the power request for sea-water draw, fresh water raise and brine rejection the specific energy request increases to 44.93 kW.

3.4. Wave data and energy conversion

Year 2007 has been selected as reference year for the wave data obtained from [29] after the comparison of years from 2001 to 2010. The yearly mean wave height and period are respectively 0.88 m and 4.37 s with a maximum of 6.45 m and 9.34s.

For the ISWEC technology, the energy matrix data associated to mean wave height and wave period of the 60 KW prototype [28] were used in order to create the TRNSYS model.

4. Results

4.1. Scenario 1: local grid fed desalination plant

As can be seen from Fig.3, during summer, the water load hardly exceeds the water storage capacity and the full-duty desalination water production. In this scenario, although the storage level goal is not maintained, there are no water deficits and a minimum of about 590 m^3 reserve is reached. The energy required to produce the 389350 m^3/y water is of 1496 MWh/y, corresponding to 1196.80 t_{CO2eq}/y.

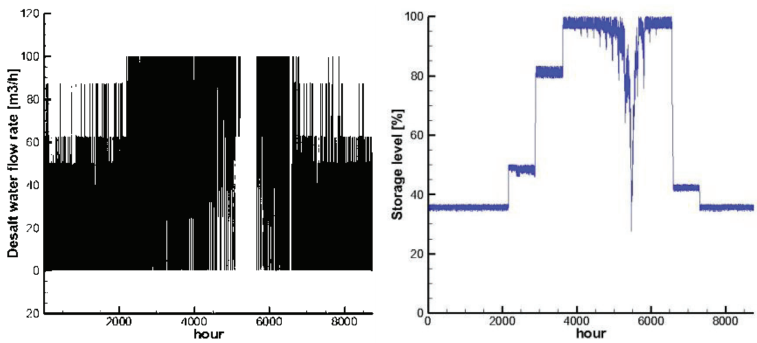
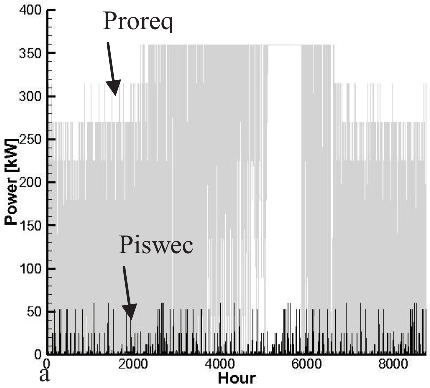


Fig. 3. Water production flow rate and storage level hourly-based curve.

4.2. Scenario 2: wave energy-based desalination plant

In this scenario, as the required power is delivered by DEGS in case of wave power deficit, the water production data represented in Figure 3 remain unvaried.

A single ISWEC unit works for 1306 h/y generating 20.94 MWh/y. Aiming at understanding the optimal ISWEC number of units and their energy penetration to the system, a sensitivity analysis was made (Figure 4.b) analyzing generated wave energy (*Eiswec*), Wave energy surplus (*Esurp*) and deficit (*Edef*) with respect to the desalination plant request (1479 MWh/y) and the fuel oil consumption of the diesel engine generator set needed to cover *Edef* (*Vliq*).The lower frequency of the ISWEC power generation (1306 h/y) with respect to the RO power request (5751 h/y) (Figure 4.a) entails a scarce benefit from the hard increase of ISWEC units, leading to low energy deficit decrease and high Surplus power increase (Figure 4.b). It is evident that, without the recur to an energy storage solution, the ISWEC units should be limited to 8 in order to obtain a DEGS recur decrease without too high surplus energy values. With such a number of units, the wave energy sent to the desalination system amounts to 88.89 MWh/y (that is 48.88% of the total generated wave energy), with a recur to the diesel engines of 1397.48 MWh/y corresponding to 1117.98 t_{CO2eq}/y.



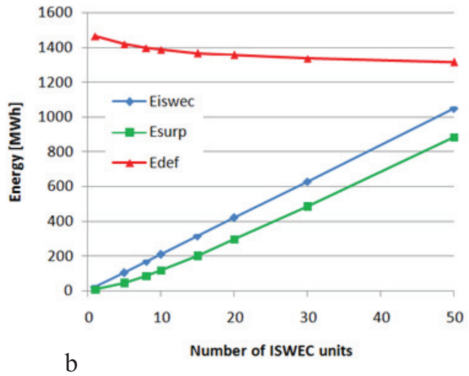


Fig. 4. a) Comparison among RO power request (Pro-req) and single ISWEC generated power (Piswec)Water and b) sensitivity analysis on ISWEC units.

5. Conclusion

The paper illustrates the present water supply procedure for Ponza island and tackles a preliminary analysis of the possibility to insert in the island context a desalination system and a wave energy generation system.

The first result is that the desalination system will be able to completely cover the water load. This achievement, considering a simple grid fed desalination plant, will bring to an equivalent CO_2 emission reduction of 55.44%. Water desalination costs oscillates in the 0.8-1.5 €/m^3 range [30]. It is evident that, in the worst case of 1.5 €/m^3 desalination cost, the water price is 7.5 times lower with desalination than with shipping, reaching, foa an equivalent amount of water, an annual expenditure of 600000 € in place of 4520000 €.

When analysing the ISWEC-DEGS fed hypothesis, the results show that the lack of an energy storage system heavily influences the RES penetration, conducting to a necessary limitation of the number of

ISWEC units to 8. Nevertheless, the wave contribution allows a further 3% equivalent CO_2 emissions reduction, reaching the 58.37% reduction with respect to the shipping scenario. As ISWEC is still a non commercial technology, authors are not allowed to evaluate the final water cost when part of the desalination energy needs derive from wave energy exploitation.

Aiming at obtaining a fully wave energy based desalination system, a storage solution is essential, In this case, a wave farm composed by 70 ISWEC units, i.e. 4.2 MW nominal power, will be able to completely run the desalination plant.

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Biography

Eileen Tortora is Environmental Engineer. She received her PhD degree in Sustainable Development and International Cooperation at Sapienza University of Rome in 2011. She is involved in energy systems researches based on conventional and renewable technologies mix.