

Simulation and Evaluation of a Hybrid Renewable Energy System for Supplying a Desalination Unit on the Island of Lipsi, Greece

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Abstract: Water scarcity is a serious problem for the Aegean Islands in Greece. Due to the fact that tourist development grows in a continuous way, the situation has deteriorated over the last years. Current water resources management practices involving the exploitation of the groundwater reservoirs have provoked the salty water intrusion into the aquifers and in many arid islands water is transported by sea, at a considerably high cost (reaches about 12 €/m³ in some cases). Desalination is foreseen as a solution to this problem and it has already been adopted in many islands, as it is a process that can provide fresh and potable water in the required quantities, at a much lower cost. The coupling of desalination with renewable energy sources (RES) constitutes an appealing and promising option. This paper presents an integrated case study regarding the design and operation of a water-energy system for meeting irrigation and potable water demand in Lipsi Island (Dodecanese complex, Greece). As the desalination unit operation depends on the wind power, a detailed description regarding the generation of synthetic time series of wind speed data is also presented. Finally, a Cost-Benefit Analysis is carried out to discuss each scenario we examine from a financial perspective.

Keywords: Water resources management; Desalination; Wind power; Remote islands; Cost benefit analysis; Synthetic time series.

1. Introduction

Water, energy and food constitute the fundamental elements for the maintenance of life, the development of society and they also reinforce the effort for sustainable development. In the future decades, phenomena such as the population growth, the urbanization and the change in alimentation habits will pose those three basic elements at serious threat [1]. Agriculture constitutes the largest consumer of water standing for the 70% of the global demand, while the energy demand approaches at 30% of the global demand [2]. Regarding the future projections in food and fresh water demand, it is expected that the needs will be increased by 50% until 2050 [3], while the energy demand is expected to double as a matter of the financial development. This aspect contradicts with the Sustainable Development Goal (SDG) No.6 [4] according to which the availability and the sustainable management of water and sanitation must be provided to every people now and for the future.

In Greece, the shortage of water resources constitutes a significant problem that devastates the progress and the development of many anhydrous islands, especially the most remote ones. For the majority of the Aegean Sea islands (Eastern Greece), water resources are quite limited and, in several islands, salty water intrusion into the aquifers has been observed, making the problem even worse [5]. Local water reserves are not adequate to cover the needs of the population and the problem deteriorates during summer months due to tourism, when the needs for fresh water supply increase up to five times above normal [6]. The islands that face water scarcity are the South Aegean complexes; Cyclades and Dodecanese, where, in recent years water demand is mainly met via water importation, a procedure that is not only financially unaffordable (a cost that in some cases exceeds 12.0 €/m³; [7]) but it also puts the islands' water supply at serious threat when ships are detained due to adverse weather conditions and it constitutes an unsustainable practice, as shipping results in air pollution. In addition, a large number of Mediterranean islands including the Aegean Sea islands depend on autonomous power stations to satisfy their energy needs [8] and, consequently, they face constant blackouts especially during the tourist season. The current state of water and energy management requires the investigation of alternative and more sustainable ways to meet the water and energy supply needs.

The fact that the Greek islands present a substantial wind potential [9] allows the adoption of various modes of renewable energy combined with the implementation of desalination methods [10] as a viable solution. Such solutions are also adopted in many Aegean Sea islands and they involve practices that combine wind turbines

operation with the construction of desalination facilities in order to both generate renewable energy-based electricity and provide desalinated water. Regarding the desalination methods applied, the reverse osmosis (RO) remains the most widely used. One aspect that makes this type of desalination process really competitive is the low energy consumption (around 2.5-7.0 kWh/m³; [11]). In many cases, especially in remote areas that cannot satisfy energy demand by their own, it is crucial to connect the desalination plant with a renewable energy system as the rudimentary form for energy supply.

The purpose of this research paper is the study of the performance of a hybrid renewable energy system for supplying a desalination unit through the design and simulation of each model component. The feasibility of the system is based on the concept of the reliability maximization in terms of quantity of desalinated water supply provided for irrigation and domestic use and also the energy supply generated for meeting the island's demand. The study area is the island of Lipsi, an arid island located in the South Aegean (Dodecanese complex). In the present analysis, the water-irrigation-energy assessment was based on available data regarding population, land use and arable land. The system is then simulated for a 25-year time period to examine the feasibility of the project, after conducting a stochastic simulation regarding the model parameters (i.e., wind speed). To determine if the project is financially feasible, a Cost-Benefit Analysis (CBA) is also performed, taking into consideration various schemes for energy production that correspond to different types of wind turbines and the optimal desalination plant capacity, as calculated to ensure water supply at a specific reliability.

2. Materials and methods

2.1 Study area and data

Lipsi Island is a complex of 30 small remote islands located in the south-east Aegean Sea, in the Dodecanese complex. The climate of Lipsi is Mediterranean, with mild winters and long warm and dry summers. The annual rainfall depth is about 576 mm. The total area of the complex is approximately 17.4 km², with the main island (Fig. 1), which is the only inhabited, covering an area of 15.8 km². According to the last census conducted in 2011, the population is 790 people, while tourism results in an increase of about five times during the period from April to September. The infrastructure system consists of a 20 km road network, which remains in generally good condition. Lipsi inhabitants are occupied in a limited variety of financial activities. Most of them are involved in the sector of tourism, trade, fishing, agriculture and livestock farming. Due to this fact, water shortage puts the island's financial domains at serious risk.



Figure 1. Map of the study area

In order to satisfy the demand for fresh potable water, it is primarily met by water hauling via ship with a mean cost of 10.8 €/m³, combined with the exploitation of the existing infrastructure of limited capacity, mainly consisting of water supply boreholes, with an average cost of 0.83 €/m³ [12]. The mean annual quantity of water transported to Lipsi between the years 2010 and 2014 is approximately 50000 m³, according to data provided by the technical report on the Directive 2000/60/EC implementation for the River Basin District (RBD) GR14 of Greece [12]. The local water supply system consists of six water tanks with a total capacity of 4600 m³ (four of about 1000 m³ each) and a reservoir of 36000 m³ capacity, which is not connected to the water supply system, as

it is only used for irrigation purposes and provides water to farms and agricultures [13]. For its electricity needs, the island is offshore connected with the Public Power Corporation (PPC) via the nearby autonomous power stations of Kalymnos and Kos islands.

Data about the island's water demand have been estimated in the context of this analysis both for agricultural and urban use, after considering the estimated trend for the population growth. Daily urban water requirements are presented indicatively for the first and 25th year of simulation per month in Figure 2a. The demand for water supply is increased during the summer months because of tourism and the irrigation season. Water for irrigation purposes is demanded from April to October, with the minimum monthly irrigation demand on these two months. Data about island's electricity demand are provided by the PPC for the nearby island of Patmos that presents similar characteristics and, after adjusting the hourly records to the population of Lipsi, their monthly variation is shown in Figure 2b indicatively for the first year of simulation. Based on one average 24-hour day of records, the demand for electricity is increased during the winter months, due to increased need for hot water and heating, energy consuming activities. Also, increased demand is observed during the months of July and August due to the increase of residents through tourism. The minimum electricity demand of 280000 kWh on average is observed in autumn months.

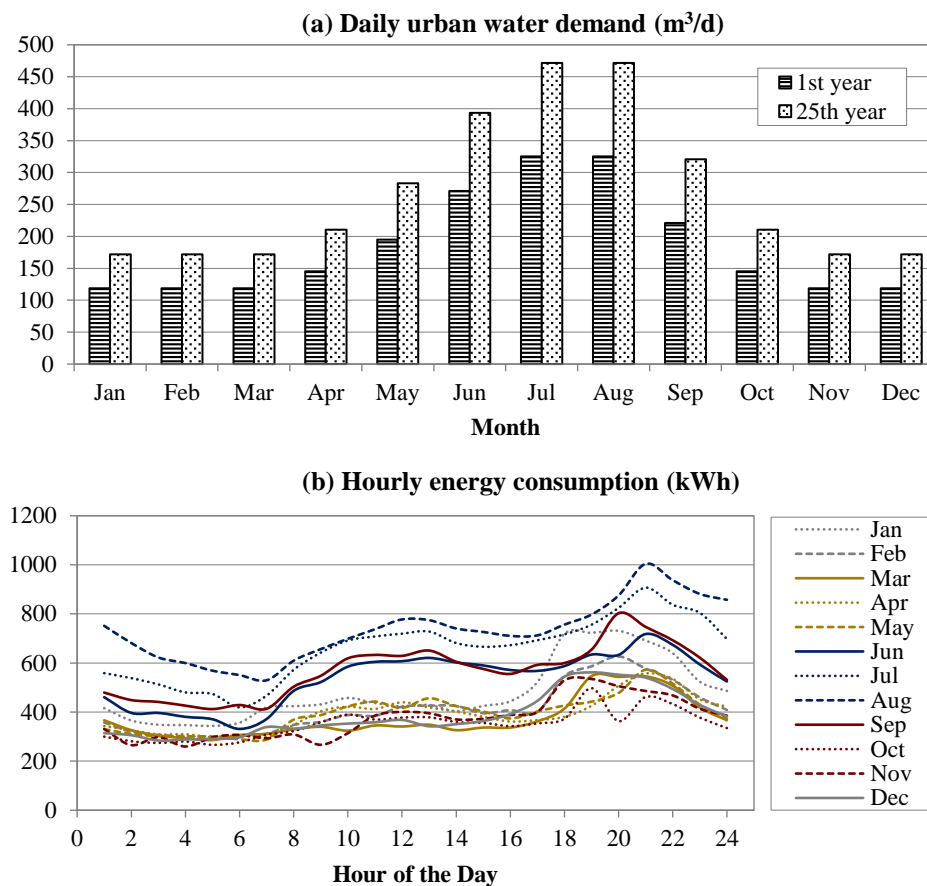


Figure 2. (a) Daily urban water demand per month for the 1st and 25th year of simulation; (b) Hourly energy consumption for the 1st year of simulation.

2.2 The concept of processing

The design and simulation of a system that incorporates a hybrid renewable energy generation source and a desalination unit is investigated for the island of Lipsi. Many desalination plants have already been used in numerous cases of Greek island in the regions of Cyclades and Dodecanese with effective results [6]. Additional researchers indicate the technical and financial feasibility of connecting the desalination plants facilities with wind turbines in order to provide those plants with RES (e.g., [14], [15]). Whereas other studies examine additional methods, such as hybrid systems or rainwater harvesting systems, giving emphasis in the analysis of different management scenarios of the water resources (e.g., [16], [17]), in order to optimize the effectiveness and financial viability of the system.

The analysis regarding sizing, as well as, the financial feasibility of such a project is performed to assess sustainable practices as means of overcoming the problem of water scarcity for the island. The examined system

is designed to mainly consist of wind turbines and a desalination plant. The choice of the size, number and type of wind turbines, as well as, the desalination unit sizing is achieved using optimization methods for a given reliability. Regarding the storage of water, the existing tanks on the island are also included in the designed system. These tanks are planned to store the urban water, while the biggest open tank of 36000 m³ is used to store water for agricultural use.

The first design principle is the optimal sizing of the renewable energy component to supply the desalination plant. The first priority of the system is to meet the urban water demand while agriculture is the secondary priority, given the storage capacity limitation. The operational rule followed is that in case of fully loaded urban water tanks in combination with an excess of energy, the remaining produced desalinated water is transferred to the reservoir used for storing agricultural water; thus, domestic water is set as a priority. Finally, regarding the supplementary rule of the system, in case the desalination plant reaches the limit of its total installed production capacity and there is observed a spillover in renewable energy generation, the remaining amount of energy is sent to the grid, to supply in meeting the island's energy requirements, in a way that the system can provide RES energy to the PPC. The main aspects of the system's design and simulation, as well as the Budget Methods applied in order to make decision regarding the feasibility of such an investment are described as follows. The methodology essentially includes the stages presented in Figure 3.

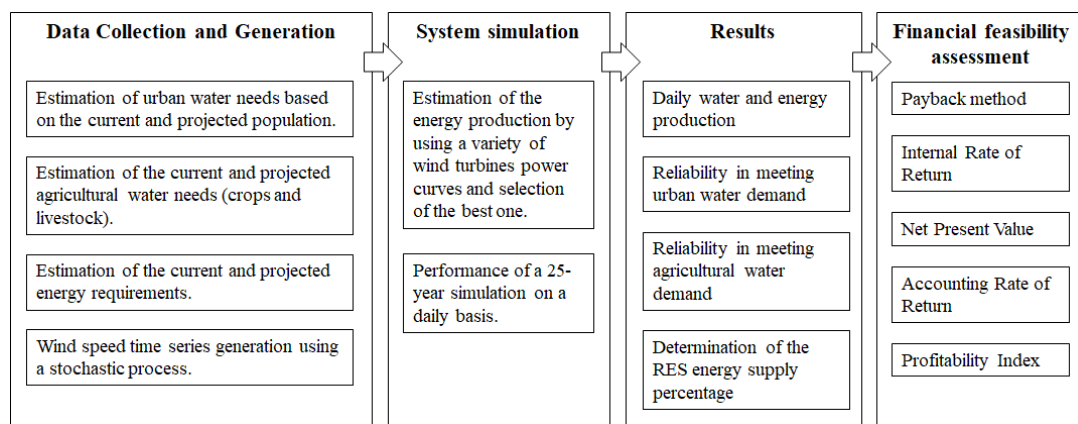


Figure 3. Stages of methodology

As regards future urban water and energy demand, it is expressed as a function of the projected population. Energy demand per capita is estimated using the available records of the nearby island of Patmos, while water requirements follow the national water resources management guidelines that indicate typical consumption about 150 l/d/person for the permanent population, 200 l/d/person for the summer residents and 150 l/d/person for tourists. Regarding water for agriculture, it is not introduced any change in the island's crops.

Based on the estimated annual change of population, the projected population (P) after n years can be calculated using the formula:

$$P_i = a P_{i-1} \quad (1)$$

where,

$$\alpha = 1 + \gamma \quad (2)$$

$$\gamma = \frac{P_i - P_{i-1}}{P_{i-1}} \quad (3)$$

where, P_i expresses the population during the year i ; γ expresses the change (rise or fall) of the population. The population after v years is then $P_v = \alpha_v * P_0$.

The last component regarding input data is the wind speed time series for a 25-year period of simulation. To perform this analysis for 25 years, given that the available historic time series are limited (10 years long), a suitable stochastic model that generates time series of daily wind speed is implemented in order to obtain further data sets for the model simulation, based on the methodology presented by Negra et al. [18]. The procedure is composed by two steps: in the first one, the information related to the measurements are extrapolated and a wind speed probability table is defined, whereas in the second one, wind speed time series are generated according to the information of the probability table. The model is also verified by Negra et al. [18] by considering four statistical aspects related to it: seasonal variations, autocorrelation functions (ACFs), average values and probability

distribution functions. Regarding the implementation of the method, the first step requires to produce 12 probability table, one for each of the 12 months, in order to describe the wind speed monthly characteristics and to finally maintain its seasonal characteristics. The table designed in this step contains (i) the classification of historic wind speed data based on their speed, (ii) the wind speed state probability, (iii) the state frequency, (iv) the average state duration and (v) the transition rates; one for the transition up and one for the transition down. A typical example in order to produce synthetic wind speed time series is presented in Table 1.

Table 1. Probability Table: Example for January

A/A	Wind Speed	Probability	Frequency	Duration	Up	Down
1	0-0.5	0.074866	14.5	0.005163	2324.17	0.00
2	0.5-1.5	0.075806	34.3	0.002210	3134.30	2295.32
3	1.5-2.5	0.055108	40.5	0.001361	4790.63	4028.49
4	2.5-3.5	0.077688	41.1	0.001890	3320.97	3027.49
5	3.5-4.5	0.080780	47.7	0.001693	3520.69	3565.26
6	4.5-5.5	0.096102	50.0	0.001922	2984.32	3259.03
7	5.5-6.5	0.083333	51.3	0.001624	3729.60	3657.60
8	6.5-7.5	0.093011	53.2	0.001748	3457.66	3406.06
9	7.5-8.5	0.086828	49.7	0.001747	3137.24	3731.52
10	8.5-9.5	0.069624	40.4	0.001723	3067.92	3895.23
11	9.5-10.5	0.057930	31.3	0.001851	2879.33	3604.34
12	10.5-11.5	0.044220	26.3	0.001681	3229.28	3907.70
13	11.5-12.5	0.037903	21.5	0.001763	3039.32	3767.49
14	12.5-13.5	0.025134	15.1	0.001665	3103.32	4105.93
15	13.5-14.5	0.018683	9.3	0.002009	2248.06	3725.35
16	14.5-15.5	0.008602	5.3	0.001623	3208.50	4185.00
17	15.5-16.5	0.004839	3.6	0.001344	3968.00	4960.00
18	16.5-17.5	0.004301	2.1	0.002048	1953.00	3906.00
19	17.5-18.5	0.001882	0.9	0.002091	1913.14	3826.29
20	18.5-19.5	0.001075	0.7	0.001536	4464.00	3348.00
21	19.5-20.5	0.000269	0.5	0.000538	8928.00	13392.00
22	20.5-21.5	0.000538	0.5	0.001075	4464.00	6696.00
23	21.5-22.5	0.000403	0.3	0.001344	5952.00	2976.00
24	22.5-23.5	0.000403	0.5	0.000806	5952.00	8928.00
25	23.5-24.5	0.000538	0.3	0.001792	2232.00	4464.00
26	24.5-25.5	0.000134	0.1	0.001344	0.00	8928.00
27	25.5-26.5	0.000000	0.0	0.000000	0.00	0.00

In the above Table, Frequency or state frequency $f_{ws,i}$ expresses how often the wind from the state i moves to the next state $i+1$ or the previous one $i-1$ per month. The frequency $f_{ws,i}$ is calculated as:

$$f_{ws,i} = N_{wsi,i+1} + N_{wsi,i-1} \quad (4)$$

Frequency is determined for every month for the whole period of available wind data. Additionally, Duration or state duration $d_{ws,i}$ expresses how long will the wind remain in the current state before moving to the next state $i+1$ or the previous one $i-1$ per month. The duration $d_{ws,i}$ is calculated as:

$$d_{ws,i} = \frac{p_{ws,i}}{f_{ws,i}} \quad (5)$$

where, $p_{ws,i}$ expresses the probability of each state.

Once the 12 probability tables (one for each month) are defined, the synthetic wind speed time series production follows. Then, the wind speed vector (ws) takes an initial value, while the time variable takes the initial value of 0 hour. In the context of this analysis, for the first simulation year, the initial wind speed vector takes the value that corresponds to the average historic wind speed. Two random numbers (U_1^1 & U_2^1) are created in the interval (0 1); one for the transition up and one for the transition down. Furthermore, the calculation of time to up (TTU) and time to down (TTD) follows. Index h represents the simulation period which is one year (i.e., 8760 hours). If $TTU < TTD$ the wind speed goes to the upper state after TTU hours, while if $TTD < TTU$ the wind speed goes to the lower state after TTD hours. Vector ws and variable t are updated using the equation:

$$ws(t^{i-1}:t^i) = ws^{i-1} \pm 1, t^i = t^{i-1} + TTU^i(TTD^i) \tag{6}$$

The procedure is repeated until t is equal or exceeds $h=8760$ hours. Finally, this methodology is performed 25 times to generate 25 independent synthetic wind speed time series. To connect each year, for each synthetic time series the initial wind speed vector takes the last value of the previous synthetic wind speed times series. The resulting synthetic time series are verified regarding their statistical characteristics compared to the historic one. As a further means of comparison, one can observe the slight difference in frequencies per class of wind speed between synthetic (25 time series) and the historic ones (10 years long) in Figure 4.

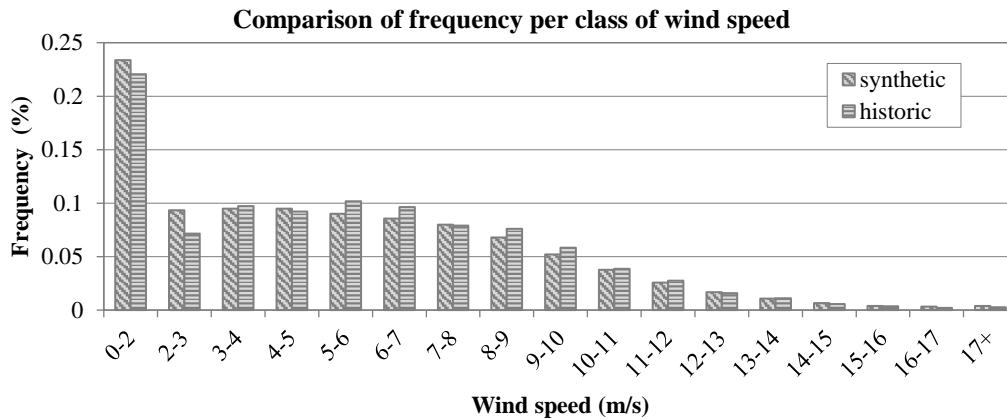


Figure 4. Frequency for each wind speed class; comparison between historic and synthetic time series

Finally, after the generation of the wind speed time series, energy production can be estimated for various wind turbines in order to choose the most efficient one according to the local wind potential. Three indicative distributions of energy production, as a function of wind speed, are presented in Figure 5. As shown, three models of wind turbines are compared and the ENERCON E53-800kW is finally selected as the most suitable for the examined case study.

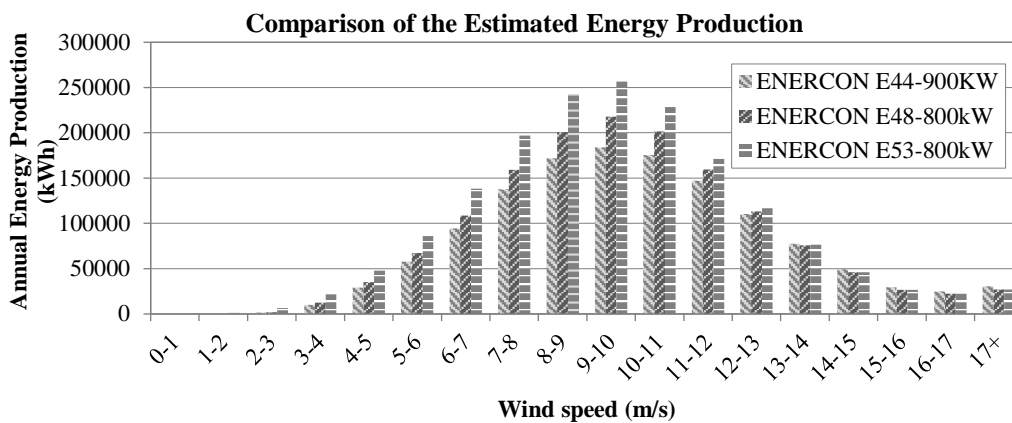


Figure 5. Estimated annual energy production as a function of wind speed for different wind turbines

Finally, under the same research, the examination of the project comes to an end with the estimation of its financial feasibility. In terms of cost, despite the fact that a high initial investment is typically required, various budget methods for making decisions are applied in order to highlight that funds expended are recouped and to determine the corresponding payback periods.

3. Results

Coupling desalination processes with RES could prove to be an effective solution for water supply in isolated islands. Based on the methodology presented in the previous section and after the preparation of the input datasets for the model simulation, some limitations regarding national legislation, space capacity etc. are considered in

order to size the model components. Two wind turbines with technical characteristics such as those of ENERCON E53-800kW can satisfy the high reliability target and simultaneously they are a suitable solution for an island of limited available space. In addition, a desalination plant of a daily capacity equal to 650 m³/day is the one that can meet the island's water demand using the existing water tanks of the island. Regarding energy supply, the desalination plant requires about 4 kWh in order to produce 1 m³ of water. The annual energy production and the monthly variation control the reliability of the system. The variation of these quantities, as a function of the characteristics of wind, is shown in Figure 6.

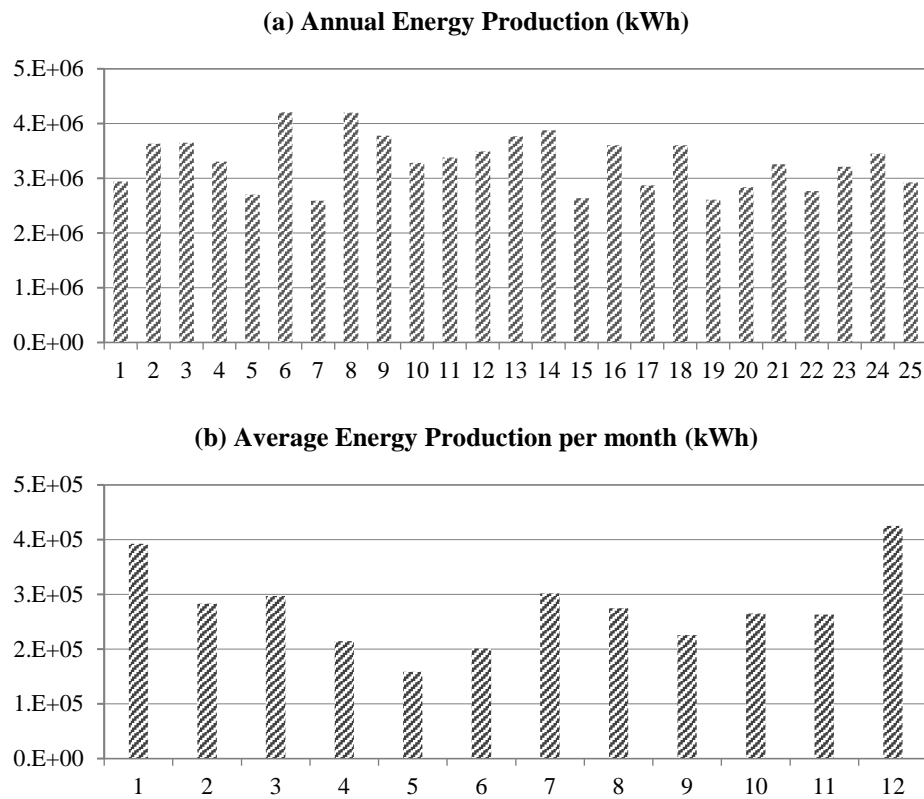


Figure 6. (a) Annual energy production; (b) Mean monthly energy production

The second model output is the quantity of desalinated water produced (Figure 7). Water production for urban use is constantly being increased due to the increasing needs for urban water, as a function of the island's population growth. Another interesting feature is the limited production of water for agriculture during summer months; as, to satisfy this particular need using this source of water, a desalination plant of higher capacity and also further energy supply are required. This fact is justifiable as, during summer the demand of water is much higher due to the significant number of tourists and the fact that urban water demand coverage is a design priority for this system. During winter and transitional seasons, the urban water tanks are full, thus, surplus of water produced by the desalination plant is transmitted to the reservoir that stores water for agriculture use. As urban water demand met is set as a design priority, reliability regarding urban water is maximum. However, the quantity of water supply for agricultural use is affected by three parameters; the storage and desalination unit capacity and the wind speed variability that controls the RES energy availability. One indicative result is shown in Figure 7a, where in the 6th year of simulation the wind potential is high and this results in the maximum annual agricultural water production, for a given storage capacity.

Regarding system reliability, it is assessed on a monthly basis and separately for the urban water demand and for agriculture. The sizing of the system resulted from a monthly reliability target of 99.99% for urban water and for 90% for agriculture. As it can be clearly seen from Figure 8, the urban water demand reliability stands at approximately 100%, while agriculture water demand reliability reaches a percentage just below 90%. Generally, only a few days during summer months the system is unable to cover the urban water demand. In addition, reliability regarding agricultural water demand met decreases mainly between July and September, a fact that is controlled by the reservoir capacity, and partly one to two months before and after this period; a fact that is controlled by the wind potential.

RES energy supply as a secondary priority is provided when the system produces the total water required to meet the daily demand and there is observed an energy surplus. The energy produced by wind turbines is then

distributed to the local grid. Figure 9 depicts the estimated annual RES energy proportion that can be provided to the island. This percentage per year fluctuates between 28 and 43%, reaching on average 33%. As the energy and water requirements become more demanding due to the increasing population throughout the years, the percentage has a slightly negative trend.

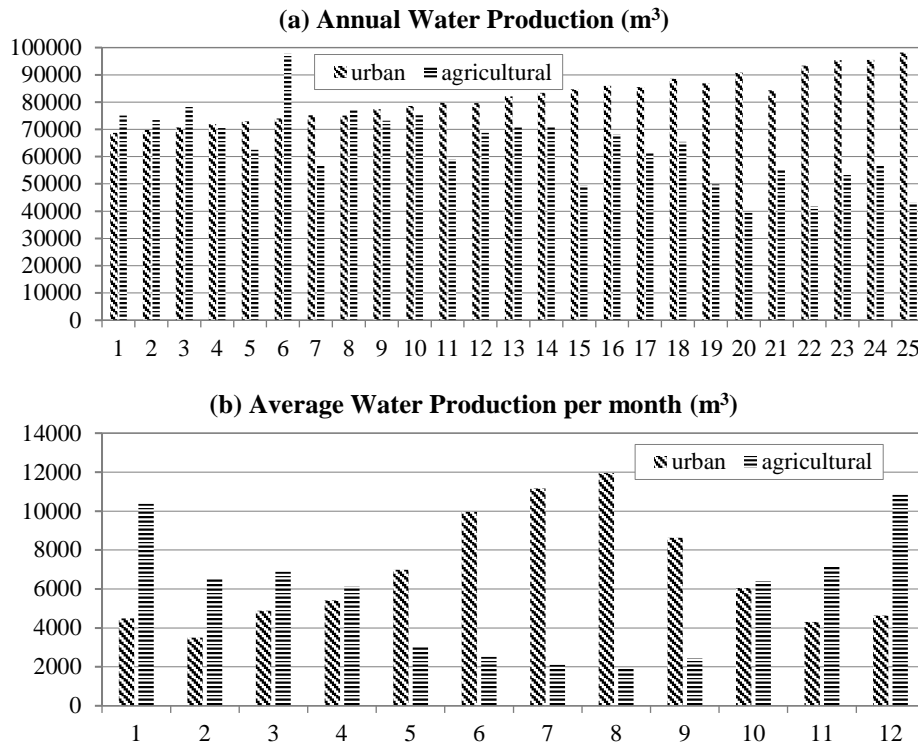


Figure 7. (a) Annual water production, (b) Mean monthly water production for urban and agriculture use

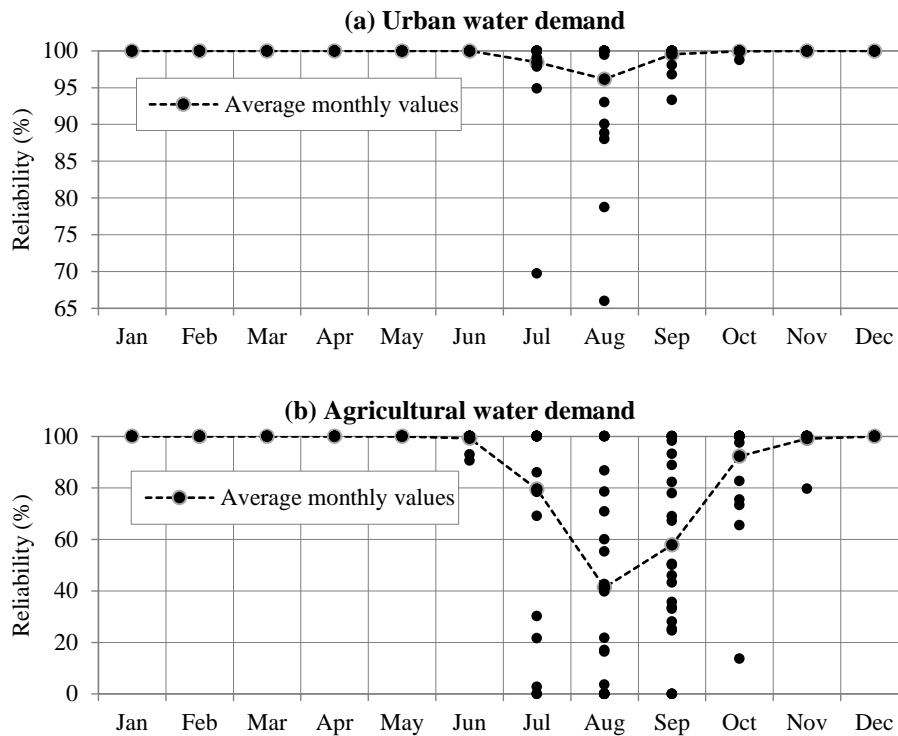


Figure 8. (a) Monthly urban water demand reliability per year, (b) Monthly agricultural water demand reliability

Finally, the economic evaluation of the project takes place in order to assess the payback periods of such an investment. Different methods [19] are applied and the corresponding results are displayed in Tables 2-6. Values regarding total investment cost are adopted from [7] that analyze similar systems in the Aegean Islands. The selling price of the water is under investigation (from 0.965 to 2 €/m³), to determine the effect on the financial measures, while the selling price of energy is taken stable, according to the current pricing policy (0.09945 €/kWh). The method of Payback Period estimates the necessary amount of time to recover the cost of the investment. As generally, investments with Payback Period longer than 8 years are considered to be of high risk [20], this investment is proved as feasible only if the water selling price is about 1.8 €/m³, as this is the selling price of water that corresponds to the above return year period.

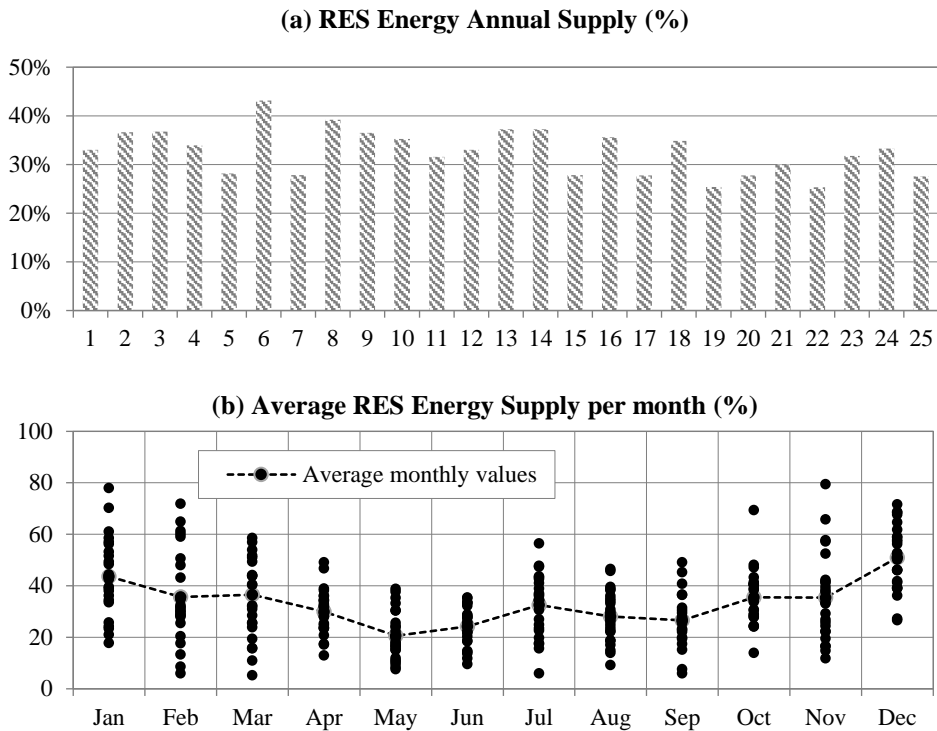


Figure 9. (a) Annual energy coverage percentage throughout the years, (b) Monthly energy coverage percentage

Accounting Rate of Return (ARR) method assesses the amount of profit compared to the initial cost that is also improved for higher prices of water [21]. This method focuses on the general outcome of the investment by comparing the annual income with the mean cost of the investment. Net Present Value method calculates the difference between the inflows and outflows throughout the investment’s life expectancy [22]. It is a widely used method to estimate the profits whether the investment will be profitable or not in present amount of money. Internal Rate of Return method is a budgeting method that calculates the discount rate cost that zeroes the Net Present Value [23]. In general, higher IRR values indicate that the investment is more desirable and safer to create profits. Finally, the Profitability index is the ratio of payoff to investment cost of the project [24]. The investment must present $PI > 1$ in order to create profits. The higher the PI is, the more profitable the investment is. Based on the results presented below, the investment can be characterized as profitable, even for the cases of low water prices. In fact, the selling price that makes the investment neutral is 0.965 €/m³, which is comparatively lower than the cost of transferring water by ships for this island (12.77 €/m³). It can also be observed that for a small variation in the selling price of water (0.2 €/m³) significant increases are noticed in the adoptive investment decision methods.

Table 2. Payback Period for different selling prices of water

Selling Price of Water (€/m ³)	Payback Period
0.965	25 years & 0 months
1.000	23 years & 3 months
1.200	16 years & 0 months
1.400	12 years & 9 months
1.600	10 years & 7 months
1.800	7 years & 11 months
2.000	5 years & 9 months

Table 3. ARR (%) for different selling prices of water

Selling Price of Water (€/m ³)	ARR (%)
0.965	0.00
1.000	1.37
1.200	8.43
1.400	14.94
1.600	21.43
1.800	27.91
2.00	34.39

Table 4. NPV for different selling prices of water

Selling Price of Water (€/m ³)	NPV
0.965	0.00 €
1.000	67,996.39 €
1.200	418,776.52 €
1.400	742,273.50 €
1.600	1,064,259.05 €
1.800	1,386,244.59 €
2.000	1,708,230.13 €

Table 5. IRR (%) for different selling prices of water

Selling Price of Water (€/m ³)	IRR %
0.965	3.0
1.000	3.8
1.200	7.6
1.400	11.0
1.600	14.5
1.800	18.1
2.000	21.8

Table 6. PI for different selling prices of water

Selling Price of Water (€/m ³)	PI
0.965	1.000
1.000	1.076
1.200	1.476
1.400	1.827
1.600	2.186
1.800	2.545
2.000	2.879

4. Discussion and conclusions

As far as water demand increases in the last decades in small Greek islands [25], mainly as a result of the increasing number of tourists and because of the limited local water resources and the unsustainable current water management practices of water importation by ship, renewable energy powered desalination systems gain ground as a sustainable solution to provide fresh water in remote areas and to supply the local energy requirements. Such systems are able to provide water and energy complete or partial independency to these areas, depending on the sizing of each component.

Concerning the case study that is examined in the context of this research work, it is found that the energy production experiences many fluctuations throughout the year, as this is a function of the local wind potential. In the case of Lipsi Island, the months with the highest RES energy production are January and December, while these with the lowest are May and June. As far as it concerns the designed system's reliability in meeting both the urban and agricultural water demand, urban water demand is satisfied in most of the cases (for a target of 99.9% on an annual basis) and any failures are observed the period July-September; however, reliability is systematically higher than 95%. Moreover, reliability for agricultural water reaches 90% throughout the life period of the project, however, as this use of water is not set as priority, there are many cases of failure in meeting the monthly demand. On the contrary, the gradually increase of the population, the stochastic nature of the wind and the sharp increase of the population during summer months result in a relative incapability to cover the agricultural water demand in

many occasions mainly during summer months. Concerning the energy requirements of the island, the designed project is estimated to cover about the 1/3 of total energy demand, as the target of about 30% has been also investigated as a feasible one (e.g., [17]). Due to the sufficient size of the existing reservoir of Lipsi, the introduction of additional reservoirs does not influence the reliability of the system, as it is observed that reliability is only driven by the desalination unit sizing. As expected, reliability rises when both the number of wind turbines and desalination plant capacity increase, an issue worth considering in the context of future research. The main conclusions concerning the economic evaluation of this project are that the selling price of water that makes the project feasible is calculated at 0.965 €/m³, which is comparatively lower than the current cost of transferring water by ships to the island (12.77 €/m³). The same selling price results in coincidence between the payback period and the life expectancy of the project (i.e., 25 years). Finally, it was observed that a short rise in the selling price of water results in significant increase in the estimated Net Present Value and decreases rapidly the Payback Period.

Taking into consideration overall results, there are some points that requires further research. In this respect, the evaluation of a scenario that increases the reliability and eliminates the failures can be evaluated. Such scenarios include the introduction of additional wind turbines and the increase of the desalination plant capacity. Solar panels offer a sustainable solution, given the fact that Lipsi are characterized by high sunshine duration. Another interesting issue for investigation is how the off grid power produced by the wind turbines could be stored. The introduction of a hydroelectric station in the context of a Hybrid Renewable Energy System design (e.g., [7]) constitutes a very common practice especially in remote islands, which are not connected with the grid (e.g., [17], [26-31]). Finally, not only the reliability of the water-energy requirements met must be examined, but also the financial feasibility can be more detailed in the framework of a Cost Benefit Analysis (e.g., [32], [33], [34]).

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