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An Economic Evaluation Towards Sustainability: The Case of a Hybrid Renewable Energy System in Greece

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Abstract: There is a global effort to integrate renewable energy sources (RES) into the energy balance, setting out to develop a more sustainable future. The dependence of RES on natural phenomena and their low reliability can be mitigated by hybrid renewable energy systems (HRES). In this paper, an evaluation of an under-study HRES in Leros, Greece, is carried out in order to examine the economic viability of the project and its contribution to sustainability. Two scenarios are being examined, according to the eligible grant. In the first case, the project receives a 40% State subsidy in contrast to the second, which receives a 60% funding from the Innovation Fund 2020 (IF). The main difference, between these two scenarios, is the size of the loan taken, whereas in the IF scenario it is 20% less than the first one. Several results can be obtained by this study, as follows: i) in both cases, the project is considered profitable for water and energy selling prices, 91.7% and 67% lower than the current ones respectively. ii) in the case of IF scenario, the same internal rate of return (IRR) index is achieved, with 0.15 €/m^3 less compared to the price in the case of State subsidy.

Keywords: Sustainability, Cost-benefit Analysis, HRES, Innovation Fund, Island

1. Introduction

There is a growing recognition of the global challenges posed by issues such as climate change, limited natural resources and population growth. These challenges are addressed through a constantly increasing global effort to develop sustainable technologies and solutions [1-2]. Nowadays, sustainability is usually defined as the processes and actions taken through which humankind avoids the depletion of current natural resources, in order to keep an ecological balance that does not compromise life quality of future generations. These actions are mainly aimed at reducing carbon dioxide (CO_2) emissions and are dictated by the international community laws, policies and goals. The Kyoto Protocol marks the beginning of these acts, while others such as the UN's 2030 Agenda for Sustainable Development and the Paris Climate Accord have been added to the initiative. The imposition of a tax on CO_2 emissions, as well as the introduction of the European Union Emissions Trading System (EU ETS), the flag-ship EU policy on climate change mitigation, the largest carbon market, are all crucial in reducing CO_2 emissions by at least 55% by 2030 in a cost-effective way [3-6, 47, 48].

Sustainability is composed of three pillars; the environmental, the social and the economic. In terms of the first pillar there is an effort to increase the contribution of RES into the global energy supply to offset the conventional energy sources (fossil fuels, gas, coal) - that would otherwise be used to meet the ever-increasing energy needs rising from a fast paced population growth [7, 8]. Increasing the share of RES in the energy mix would help deal with environmental pollution, global warming and therefore climate change, since the combustion of conventional fuels would release large amounts of CO_2, which significantly contribute to the greenhouse effect. However, the energy produced by RES, such as wind and solar, cannot be fully reliable due to the intermittent nature of wind speed and sunlight.

Therefore, RES face the potential problem of time mismatch between production (supply) and energy consumption (demand) and, as a result, sometimes energy is not available when needed, while in other cases the energy surplus is not utilized [9, 10, 45, 52-54].

The dependence of RES on natural phenomena and, therefore, the variability in their energy production can be decreased by the design and implementation of a HRES. HRESs enable the storage of energy from wind parks and photovoltaics, as well as intelligent energy management, depending on the variation of demand required to cover. Such a system may include a conventional power plant in combination with at least one form of RES, storage devices, surveillance and control systems, as well as a load management system. In addition to being developed as autonomous and independent systems, HRESs can be integrated into an existing network. Consequently, they are considered a very attractive solution for applications in remote areas or non-interconnected islands, whose connection with the electricity grid is yet an uneconomical choice [11-15].

In this study, a simulation and an evaluation of a HRES is carried out coupled with a desalination plant, to meet the energy and water needs of the island of Leros, one of the largest Greek arid islands in the eastern Aegean. Greece, and, particularly its islands, is known for its high wind and solar potential [16-18]. In fact, Greece's high wind potential is of great importance, enough to tilt the balance of its energy mix towards RES. This stems from its inexhaustible nature and the technological development, which has improved its efficiency and the exploitation cost [19, 43, 44]. Meanwhile, the energy needs of these islands are covered either by a local autonomous power station (LAPS) or by an underwater connection to remote power plants. Both use conventional fuels which lead to energy dependence on other areas, low power quality and environmental pollution [20]. Furthermore, these islands face the problem of water scarcity, which significantly burdens socio-economic activities negatively, impacting the livelihood of their inhabitants. This arises from the eminently costly process for meeting water needs, as the required water is transported to the islands by watercraft [21]. On amount of that, the development of an HRES seems to be a promising asset for attaining local sustainability.

In this paper, the operation of an HRES, which utilizes wind energy to power mainly the operation of the desalination plants, is being considered. At the same time, energy storage offers the possibility of greater energy supply to the electricity network of the island. Thus, the development and coordination of the individual units aim to achieve greater reliability in meeting the needs of the inhabitants, without burdening either the environment or the people in the future. The results presented in this paper concern the third pillar of sustainability, i.e. the economic. They constitute the cost – benefit analysis of the hybrid project, which is considered necessary to determine whether the project is feasible, economically viable and perhaps even profitable.

2. Study Area and Data Processing

2.1. Geospatial Data of Study Area

Leros is located at the southeastern end of the Aegean Sea and in the northwest of the Dodecanese. Its area is about 54 km^2, and its coastline is 71 km, making it the ninth largest island in the Prefecture of the Dodecanese. It is mainly a rocky island, with small plains between its various hills, and rocky coastline. Its geographical location is of great importance, since it is about 317 km from Piraeus port and, just 13 km from the coast of Asia Minor, hence forming a bridge between mainland Greece and Asia Minor.

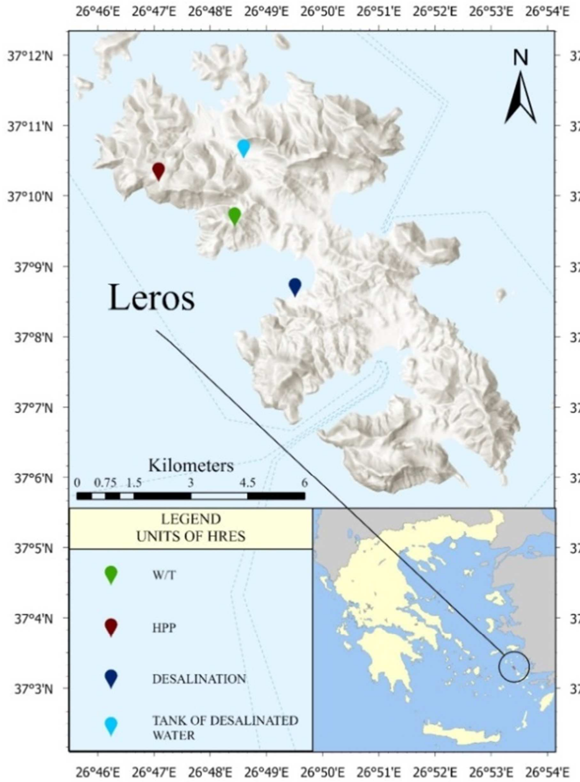

***Figure 1.** The study area (Leros Island).*

The climate of Leros is described as Mediterranean and is characterized by mild winters with plenty of rain, strong winds at times, and periods with relatively increased sunshine. According to Leros' meteorological station of the National Meteorological Service (NMS), the average annual temperature is 18.55°C, while the average monthly minimum air temperature is 7.35°C, which is observed in February, and the average monthly maximum temperature is observed in August and is 29.65°C.

2.2. Energy, Water and Irrigation Data Processing

The island of Leros covers its energy needs from two LAPSs located in Kalymnos and Kos, linked through submarine cables. At the same time, the growing trend for electricity consumption, as well as the huge increase in energy demand during the summer months due to tourism influx, led to the installation of a wind farm. Concerning meeting water needs, Leros has two reverse osmosis (RO) desalination units with a total capacity of 2,000 m^3/d, ensuring low operating costs and high reliability [22-24]. However, this innovation has not been fully utilized, as the frequent power supply fluctuations on the island make it impossible for the desalination system to operate uninterrupted. In that event, the water needs of the island are covered by the transport of water by watercraft, an effective, yet a very expensive process.

Regarding the water and energy needs of the island, the variation of the population is the main factor that determines their scale. As the evaluation of this data concerns the whole lifespan of the project under study, the future population of Leros is estimated through a steady geometric increase. Concerning the drinking water needs, these are estimated based on per capita consumption (Figure 2), in addition to the estimation of the irrigation needs which result from the sum of the livestock needs and the needs of the crops in water (Figure 3). On the other hand, the energy needs are estimated based on those of the neighboring island of Patmos, owing to the similarity between the two islands in socio-economic features. As a result, the energy needs of Leros are calculated from the data of Patmos with appropriate reduction to the population of the island [25].

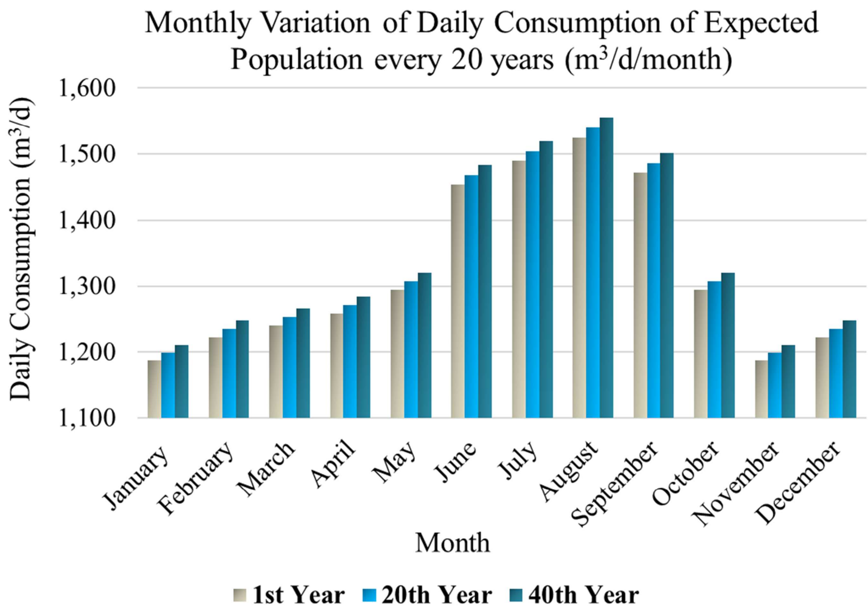

Figure 2. *Monthly variation of daily water consumption of expected population every 20 years.*

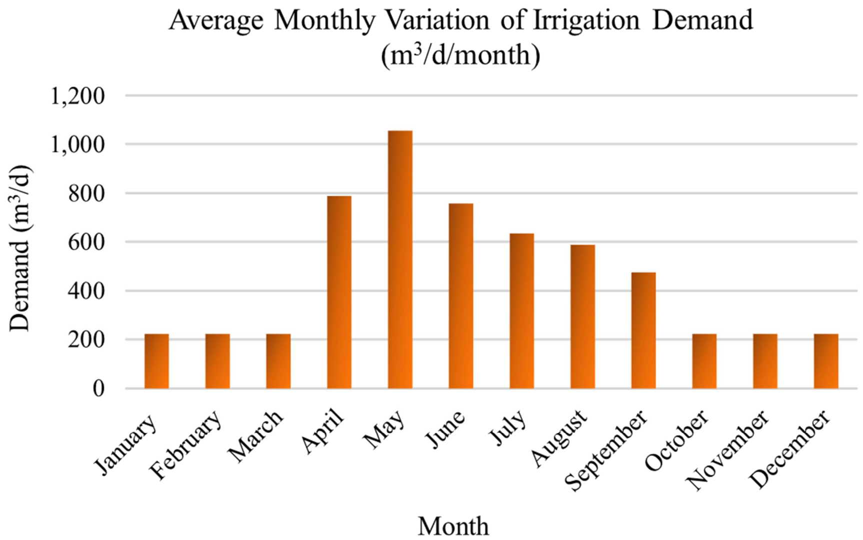

Figure 3. *Average monthly variation of irrigation demand.*

In contrast to the drinking water and energy needs, the water needs of the crops are estimated using the Blaney – Criddle method [26, 27]. Rain and temperature are some of the parameters of this method for which their long-term estimation is required. As these parameters are hydrological and meteorological variables, their estimates and predictions are derived after processing the available historical data with stochastic methods. In addition to estimating irrigation needs, stochastic methods are also used to estimate wind energy for the next 40 years of the project's lifespan, as wind is also a meteorological variable. A similar procedure is followed for the estimation of wind energy, as it is included in the meteorological variables, and its prediction is recommended by stochastic methods [28, 45]. In effect, for both rain and temperature the AR (1), AR (2) and the ARMA (1,1) methods are examined, where the latter is finally used, as according to the Anderson test produces more realistic results [29, 46]. On the contrary, in the case of wind, the Negra et al. [30] method is used in order to maintain seasonality.

3. Methodology Development

The HRES in this study consists of a 4.2 MW wind park, two desalination plants with a total capacity of 2,000 m^3/d in combination with a desalinated water reservoir 785,000 m^3 (which is the existing dam of the island), a 2 MW pumping station, a hydroelectric supply station 5 m^3/s and a seawater reservoir with a capacity of 780,000 m^3 at a height of 170 m above sea level. For the examined HRES, an operation scenario is examined and simulated, which sets as a priority the coverage of the energy needs of the desalination plant and then the coverage of the energy demand. Specifically, as shown in Figure 4, 30% of the electricity generated by the wind park is distributed directly to the grid, while the remaining 70% goes to the desalination plant for drinking water production. After producing the required drinking and irrigation water, the excess energy - if any - is stored by the Pumped – Storage Hydroelectricity (PSH) method, which has the form of a reversible HP and is suitable and environment friendly, along with being a low-cost method of storing electricity for the Greek islands [20, 31, 32, 45, 54].

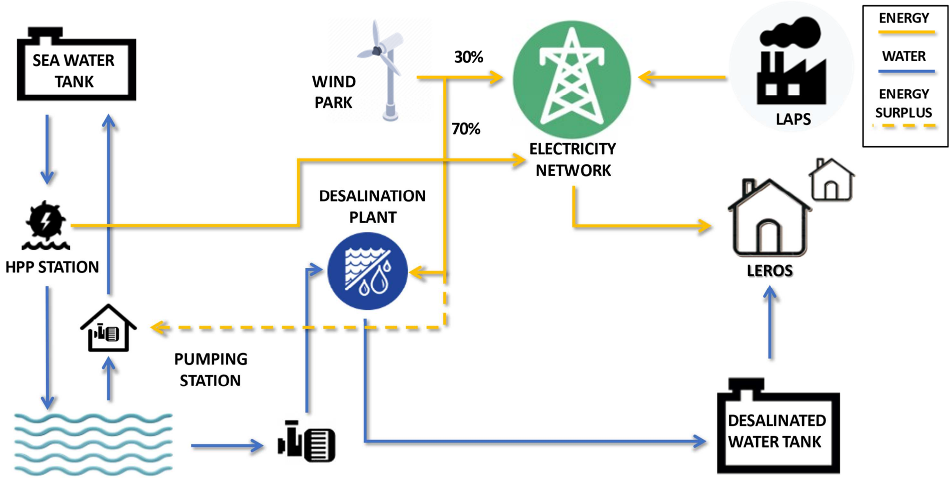

Figure 4. *HRES' operation simulation scenario.*

The operation of the HRES is simulated for two different lifespans. The first is for a period of 40 years, so that the reliability of the project can be seen in the long-term timescale. On the other hand, the second simulation takes place over a period of 20 years, in order to examine the suitability of this study for funding from the Innovation Fund (IF) of the European Union 2020 [33]. The IF is one of the largest funding programs in the world for the demonstration of innovative low-carbon technologies. With a total budget of around € 10 billion, it is a key financial instrument for meeting the EU's economic commitments under the Paris Agreement and its goal of making the EU climate neutral by 2050. The selection of projects for funding is based on their effectiveness in avoiding greenhouse gas emissions, in their degree of innovation, their maturity and scalability and their cost-effectiveness. The reduction in operating years is due to the EU's goal of becoming climate neutral by 2050. Therefore, the simulation results should refer to a realistic operating time from the implementation of the HRES to 2050.

The first step in the financial analysis of the project is the estimation of the total construction costs, alongside the annual operating and maintenance costs of the project [34]. The above costs are estimated through research of each project that contributes to the HRES separately and through communication with companies that undertake such projects. As mentioned earlier, Leros has part of the necessary infrastructure of the HRES, the construction of which is being examined. However, the analysis of the financial viability of the system takes place for a theoretical situation, in which the project is constructed entirely from the beginning (Table 1 and Table 2).

Table 1. *Estimated Costs of Supply and Equipment Installation.*

Estimated Costs of Supply and Equipment Installation for the HRES in Leros		
S/N	**Job Description**	**Estimated Cost (€/lifespan)**
1	Research - Licencing - Supervision	125,000
2	Desalination plant	987,000
3	Pump Station - Pipelines	250,000
4	Tanks	3,000,000
5	Hydroturbine	800,000
6	Windturbine	5,560,000
	Total	10,722,000
	VAT (24%)	2,573,280
	Total with VAT	13,295,280

Table 2. Estimated Costs of Annual Operation and Maintenance.

Estimated Costs of Annual Operation and Maintenance for the HRES in Leros		
S/N	**Job Description**	**Estimated Cost (€/y)**
1	Project Administration - Management Expenses	80,000
2	Desalination Plant	150,000
3	Pump Station - Pipelines	7,000
4	Tanks	30,000
5	Hydroturbine	10,000
6	Windturbine	52,000
	Total	329,000
	VAT (24%)	78,960
	Total with VAT	407,960

Finally, in order to draw conclusions about the financial viability of the project, a cost-benefit analysis is performed by calculating Net Present Value (NPV) and Internal Ratio Rate (IRR). NPV is the value obtained by discounting to present all of the annual net cash, provided throughout the term life of an investment (in this case 40 and 20 years), and is calculated through Equation 1 and 2 [35-37].

$$NPV = \left[\sum_{t=1}^{n} \frac{NPV_t}{(1+e)^t}\right] - K \quad (1)$$

Where:

n: the lifespan of the project in years

t: the discount period in years

e: the discount rate

K: the initial investment

If NPV is equal to zero, this means that the financial income from the project repays the initial investment, without benefit or loss for the investor. If the NPV is positive, then the income is enough for the investment to be considered profitable, while the higher the NPV, the higher the profit of the investment. In case of the NPV being negative, then the income is such that the investment ends in loss.

On the other hand, IRR is the discount rate (e) at which the NPV becomes zero. This discount rate reflects the internal return on investment (IRR) and is calculated by solving Equation 2 [38].

$$NPV = 0 = \left[\sum_{t=1}^{n} \frac{NPV_t}{(1+IRR)^t}\right] - K \quad (2)$$

The discount rate ultimately incorporates the risk taken by an investor to carry out a project [39]. Specifically, if the return on an investment is equal to the discount rate, i.e. IRR=e, then the investment is considered marginal, as it may not be profitable. If the return is greater than the discount rate, then the investment is identified as financially viable and, ultimately, is approved. In case that the return is less than the discount rate, the investment is rejected, as the project is unprofitable.

In addition, part of the financial analysis of the project is the depreciation. Depreciation is an accounting method of allocating the cost of a tangible asset over its useful life or life expectancy, as also of representing the capitalization of an asset's value. Depreciating assets helps the investor earn revenue from an asset, as it enables the gradual recovery of the purchase cost of fixed assets and their replacement. In practice, the method of constant depreciation is used to calculate the depreciation of a project, according to which the depreciation rate is constant each year and is calculated based on the initial value of the asset [40].

Finally, it is worth mentioning that the total cost of an investment is rarely, if ever, covered exclusively by the investor (equity). Essentially, the investor looks for other sources of financing, such as grants, if there is such an opportunity for the specific investment and for the specific time, or loans from credit institutions and firms (foreign or loan funds). Moreover, in the calculation of depreciation, the total cost of the money given as a grant is not included. The residual value of the project is considered zero, as it is assumed that the State grants the right of exploitation to a private company for a certain period. After this time, the project is transferred back to the State, which can take advantage of the project itself or to transfer it again to another company [41, 42, 49-51].

4. Results and Discussion

4.1. Results for the First Pillar of Sustainability: Environmental

For both lifespan's scenarios, the HRES is simulated for operating with primary aim the coverage of the energy needs of the desalination plant and then the coverage of the energy demand.

Simulating the HRES for 40 years of operation, the system seems to meet its primary goal and is significantly close to meeting its secondary goal as well. Specifically, in terms of water needs, the HRES achieves 99% reliability in coverage of both drinking and irrigation water needs. This high reliability is explained by the large volume of the desalinated water reservoir, combined with the production of the necessary energy for the operation of the desalination plant; a conclusion that complies with several studies about HRESs coupled with RO desalination plants [55, 56]. In addition, this reliability is the first indication that Leros can be autonomous in terms of meeting water needs, while not being financially burdened by the costly process of water supply by aquifers.

On the other hand, as shown in Figure 5, the system reduces remarkably the operation of the LAPS, as the contribution of RES to energy production reaches 73.86%. This reliability results from the high wind potential that defines Leros and the Greek islands and from the efficiency of the PSH method for energy storage. It is noteworthy that even though PSH storage method is very efficient, the research community evolves and hybrid energy storage systems (PSH, batteries, hydrogen, etc.) seem to be and even more promising and operant solution [57-62].

From the significant reduction of LAPS operation, the environmental benefit becomes apparent, since it is associated with a corresponding reduction in the combustion of conventional fuels and finally CO_2 emissions. Additionally, as resent research substantiates [63-65], grid-connected systems (like this HRES) excel in terms of reliability and economics, compared to stand-alone systems that tend to be better only regarding the CO_2 emissions.

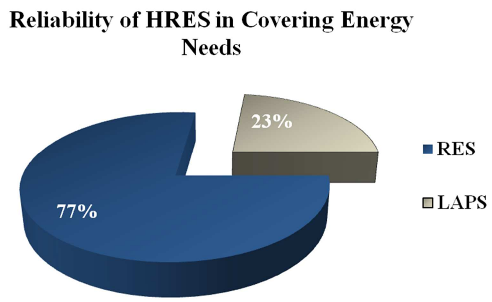

Figure 5. *Reliability of HRES in Covering Energy Needs.*

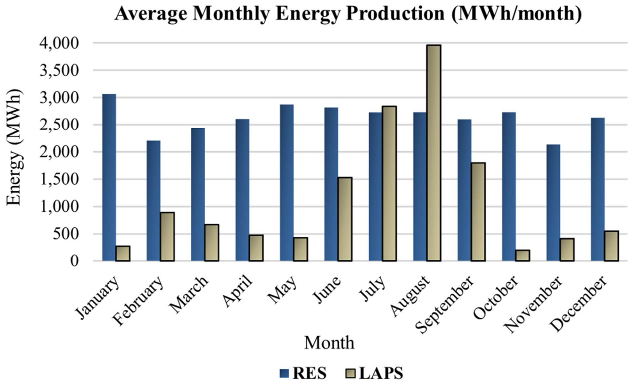

Figure 6. *Average Monthly Energy Production.*

The principles, governing the operation of the system for 20 years of operation, are exactly the same as those for 40 years of operation. Therefore, the results for each year individually for the first 20 years are identical, while collectively the reliability of the system in meeting the water, irrigation and energy needs is somewhat improved. As mentioned, the energy and water needs that the system comes to cover correspond to the population of the island that is growing geometrically every year. Therefore, the increase in reliability is entirely a result of the reduced population that the system comes to serve in 20 years of operation, compared to that of 40 years. Thus, for both water supply and irrigation, the percentage of coverage of the needs is, yet again, 99%, while there is an additional decrease in the operation of the LAPS by nearly 0.25%.

4.2. Results for the Third Pillar of Sustainability: Economical

Regarding the cost-benefit analysis of the two cases examined, there are some common assumptions to be made. Initially, the investment income corresponds to the sale of the produced energy and the desalinated water, while the expenses to the purchase of the energy and water required covering the deficit. According to the institutional framework for RES, the selling price of energy is set at 0.0875 €/kWh, while the purchase price from the LAPS amounts to approximately 0.25 €/kWh. Similarly, the selling price of desalinated water ranges between 0.24 and 2.00 €/m^3, while the purchase and transport of drinking water by aquifers usually reaches the price of 12 €/m^3. Consequently, for each case the annual total production of energy and desalinated water is used to calculate revenues and their annual deficit to calculate costs. Finally, the tax rate on net profits is 35% and the discount rate is 3%. The depreciation of the project is defined over a period of 10 years, with an annual fixed depreciation rate of 10%.

The total investment for the implementation of the HRES amounts to € 13,295,280; Figure 7 and Figure 8 show the structure of the investment for the 40 and 20 years of operation, respectively. For 40-year time scenario, 40% subsidy will be provided through an operational program for the propulsion of RES in the islands, while for that of 20 years the funding will be received from the Innovation Fund and is about 60% of the investment. The rest of the investment will be covered with a bank loan and own participation (equity), in such a way that the own participation is € 1 million. The repayment period of the loan is considered equal to 10 years using the equity method. On account of that, the essential difference between the financial analysis of the two cases is the different size of the bank loans that will be taken for the implementation of the project.

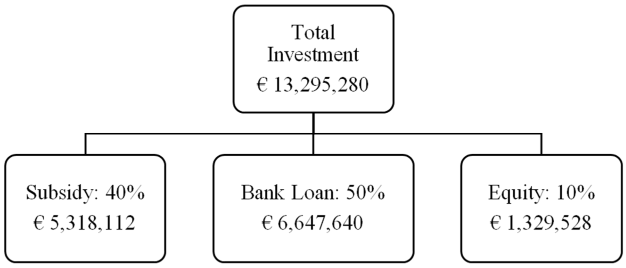

Figure 7. *Financial structure of HRES for 40% subsidy.*

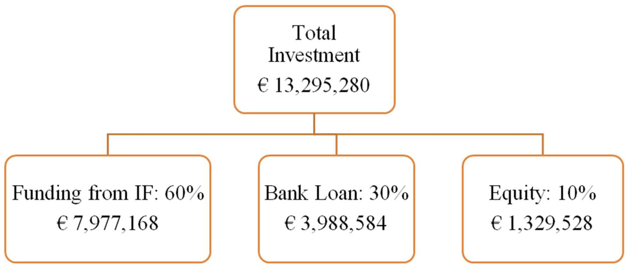

Figure 8. *Financial structure of HRES for 60% funding.*

In the case of the subsidy of 40% of the investment, i.e. € 5,318,112, the bank loan corresponds to 50% of the investment and amounts to € 6,647,640. Based on the assumptions mentioned above, for a fixed selling price of energy at 0.0875 €/kWh the NPV of the investment is eliminated for water price equal to 0.88 €/m^3. For the same selling price of water, the IRR is equal to the discount rate and the investment is marginally profitable. Figure 9 shows the NPV and IRR for different water selling prices in order to show the efficiency of the project depending on the price per cubic meter. A similar procedure is followed in the case, where the selling price of the energy is selected as a variable. With a fixed selling price of the cubic meter at 0.975 €/m^3, it appears that the NPV is eliminated for 0.0861 €/kWh, hence making the investment marginally profitable. Figure 10 shows the NPV and IRR for different energy prices, in order to show the efficiency of the project depending on the selling price per kWh.

It is observed that the large amount of energy and water produced enables the system to keep their selling prices low, while at the same time making the investment quite profitable. Specifically, it is observed that for water and energy selling prices approximately 8.3% and 35% of the present selling prices respectively, the project can generate profit. This ensues from the fact that for an excessively small increase in the selling price of either water or energy the NPV increases significantly. In addition, it is worth noting that compared to the selling price of water; small changes in the selling price of energy have greater effect on NPV. Indicatively, an increase of NPV by approximately € 400,000 corresponds to an increase of just 0.0005 €/kWh in energy sales. Respectively, for the same increase of NPV, an increase in water price of at least 0.028 €/m^3 is required.

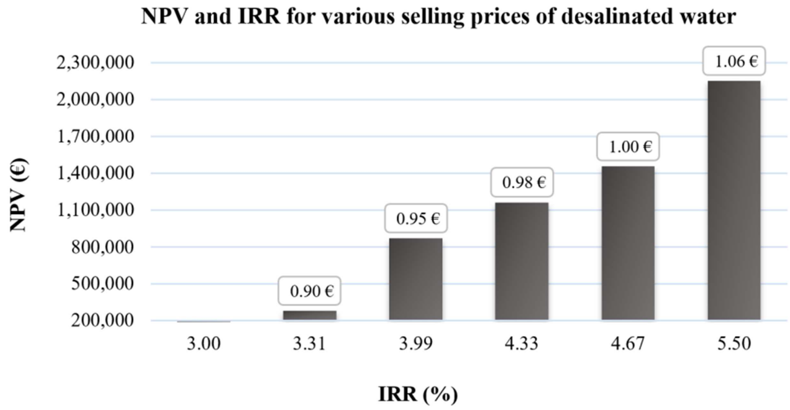

Figure 9. *NPV and IRR for various selling prices of desalinated water.*

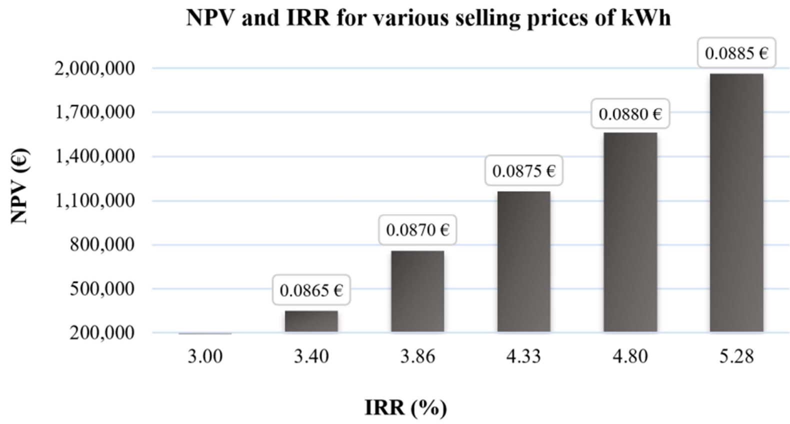

Figure 10. *NPV and IRR for various selling prices of kWh.*

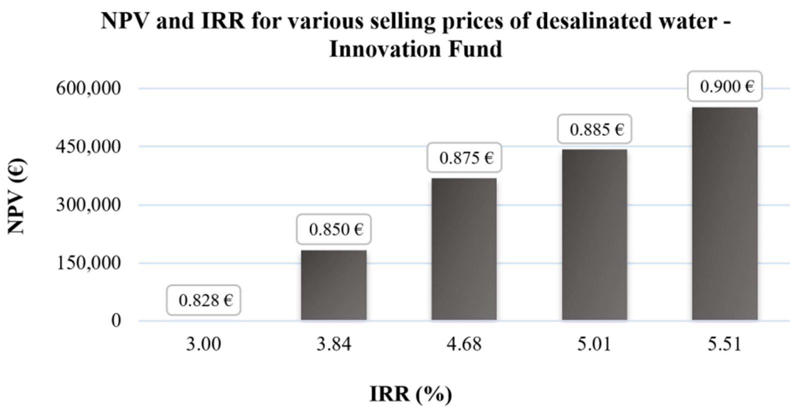

Figure 11. *NPV and IRR for various selling prices of desalinated water - Innovation Fund.*

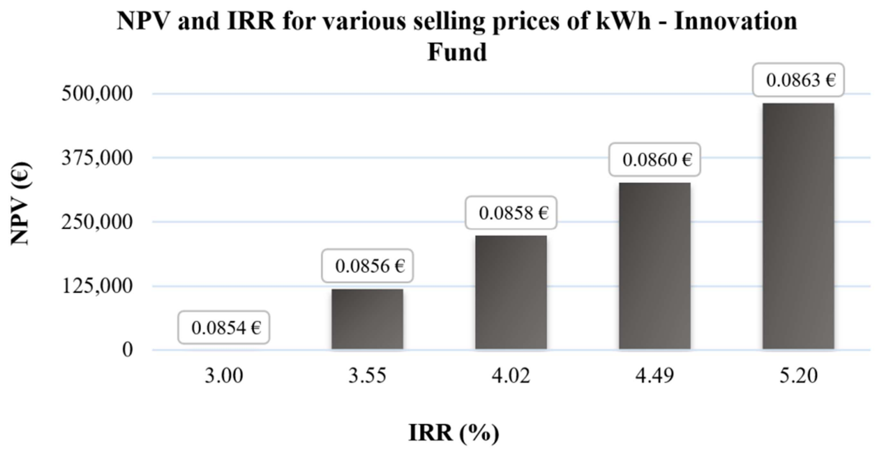

Figure 12. *NPV and IRR for various selling prices of kWh - Innovation Fund.*

Finally, in the case of funding from the IF, the loan received accounts for 30% of the total investment and amounts to € 3,988,584. As in the previous case, Figure 11 shows the NPV and IRR for different water selling prices, from which it results that for a fixed selling price of energy at 0.0875 €/kWh, the investment is marginally profitable for a selling price of water at 0.828 €/m^3. Respectively, NPV appears to be eliminated for a fixed selling price of water at 0.975 €/m^3 and an energy selling price at 0.0854 €/kWh, as shown in Figure 12.

As results from the financial analysis of the two cases, the investment in the case of IF financing seems to be more profitable than the State subsidy, since for lower water and energy selling prices, it achieves corresponding IRR prices. This is shown by the fact that the same IRR is achieved for 0.15 €/m^3 less, compared to the price in the first case under evaluation.

5. Conclusions

This paper presents a research carried out on the development of a HRES in the Greek island of Leros, with the aim of promoting its contribution to local sustainability and energy independence. As the contribution of RES to the environmental part of sustainability is more widespread and evident, this paper focuses on the financial part, i.e. the economic, that such a project can yield, in addition to the environmental and social benefit.

In order to evaluate the project in terms of its financial viability and profitability, a cost-benefit analysis is performed for two different operating periods. The first period concerns the case where the project is eligible for a State subsidy for 40% of the total investment cost, while the second period concerns the case where the project is eligible for funding from the IF for 60% of the investment. The main difference in the financial analysis of the project, for the two operating periods, is the size of the bank loan taken. The conduct of this research led to the following conclusions:

1) In both cases, it turns out that for energy and water selling prices much lower than the current ones, the project is considered economically viable or even slightly profitable. In particular, even in the case of the largest loan taken – State subsidy – it is observed that for less than 40% and 10% of the current energy and water selling prices respectively, both the NPV is positive and the return on investment exceeds the discount rate by 2%.
2) In the case of IF, the smaller loan required is an implement for achieving greater profits for the same selling price of both energy and water. This is evident from the fact that in the case of IF the same IRR index is achieved, with 0.15 €/m^3 less compared to the price in case of State subsidy.
3) It is also observed that, for a very small increase in the price of either energy or water, there is a significant increase in the profitability of the project. In consequence, for prices similar to the current ones, the project is considered profitable for the investor, without financially burdening the residents of the island, i.e. the second pillar of sustainability, the social.

In conclusion, in the ambit of the global effort to promote projects that contribute to sustainability, additional project funding, whether State or not can provide additional incentives for potential investors to invest in its implementation. Such a project could be a HRES with a RO desalination plant on the island of Leros, as it can contribute to the mitigation of climate change by reducing CO_2 emissions, while generating a profit for the project's investors.

Based on this paper and its results, further research is suggested concerning the production of additional profits, as well as an extension of the financial analysis of the project. In terms of greater return on investment, the interconnection of areas, such as Leros, with a wider network, such as mainland, could enable the power output, and ultimately increase profits. For additional revenue, it is also suggested to sell the excess desalinated water to the neighboring islands via watercraft, due to the high selling price of the transported water. Finally, the extension of the economic model of the project, so that it constitutes a multifactorial economic analysis, is vital as it may include the coal market. The estimation of CO_2 emissions, both in the current situation and in that of the HRES, and the calculation of taxes, along with the estimation of the prices of the EU ETS emission allowances in each case, give a more comprehensive economic study and image of the expected project.

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