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Investigation of the energy coverage for wastewater treatment and desalination in the island of Kos based on a hybrid renewable energy system

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Abstract.

The lack of fresh water and the high-cost electricity generation in remote islands leads to the investigation of hybrid renewable energy systems (HRES). In this paper, the implementation of wind energy for meeting energy and water demands on Kos, a Greek island, is examined. In particular, the energy coverage of the wastewater treatment plant (WTP) and the production of desalinated water are examined. The inability of controlled wind energy production leads to the introduction of energy storage units. The system was designed in order to store excess wind energy through pumping to an upper reservoir, and produce hydropower in order to cover the energy deficit. The HRES under study consists of a wind farm with a total capacity of 2.55 MW, which is composed of 3 wind turbines of 0.85 MW. In addition, it consists of two desalination plants with a total capacity of 1920 m^3/d and a capacity of 6.5 kW/m^3. The operated scenario aims to meet the energy needs of the WTP and the water needs of Kardamena, on Kos island (1650 inhabitants). The simulation model operates with hourly meteorological and energy demand data for five years. The results show that the system is reliable in covering the needs by offering low-cost energy and at the same time a large reduction of CO_2 emissions is achieved on the island. Finally, the production of desalinated water solves the problem of water scarcity in the settlement of Kardamena.

Keywords: Renewable Energy, Wind power, Water management, Desalination, CO_2 emissions

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1. Introduction

The continuous growth of the Earth's population and the modern way of life entails increasing energy needs. Thus, it is necessary to reduce the use of fossil fuels, as their reserves are not inexhaustible. Renewable Energy Sources (RES) and mainly wind, sun, and water, are potential sources of energy whose supply never runs out (Bundschuh et al., 2021). Greece has considerable potential that can offer a real alternative solution to cover energy needs, in the effort to limit carbon dioxide (CO_2) emissions worldwide (Sarris et al.,2019). In Greece, the contribution of RES in its insular part and especially in the non-interconnected islands has a particular interest (Bertsiou et al., 2018). Most islands of Greece are impossible to connect to the country's main grid. In order to meet the energy needs of the country's islands, energy is usually produced by the autonomous local station for electricity production where fossil fuels are used. Renewable energy sources such as solar, wind and hydropower can both reduce emissions from burning fossil fuels and reduce the cost of energy production.

However, the level of utilization of wind energy in the Greek islands is not particularly high, despite the rich wind potential. Wind farm installations have certain peculiarities in the production of electricity. One of the most significant problems they present is the sudden peaks and instability seen in electricity production due to wind stochasticity. Thus, it is not a reliable source of energy and is not manageable (Kaldellis, 2020). However, if different forms of energy are combined to store excess energy, these systems can be much more reliable and could meet the electricity demand needs of non-interconnected islands through the development of hybrid systems (Bertsiou et al., 2022).

At the same time, another problem faced by the greek islands, in addition to meeting energy demand, is meeting water needs. There is a lack of water in the island area, since rainwater is lost due to the intense geomorphology (Kourtis et al., 2019). In addition, groundwater often mixes with seawater, particularly due to over-pumping. The situation worsens in the summer months due to higher temperatures, drought and increased population due to tourist traffic. The use of desalination units can provide a permanent solution to the water supply problem of isolated islands since it is a stable and guaranteed method. A disadvantage of this method is the large energy requirement for the production of drinking water. However, if the desalination units are combined with RES from where they can be supplied with the required energy, this problem ceases to exist (Subiela-Ortin, 2022).

The paper's contribution is summarized in the methodology for the assessment of an HRES for the water and energy demands fulfillment and, also, the estimation of CO_2 emissions before and after the application of HRES on the island of Kos, which is used as a case study. Finally, the reliability and efficiency in meeting the energy needs of the wastewater treatment plant is evaluated. It is an energy-intensive facility that operates all year round and places a significant burden on the local budget.

2. Study area and methodology

2.1 General description of the study area

Kos is a Greek island, part of the Dodecanese Island chain group in the southeastern Aegean Sea. It is the third-largest island of the Dodecanese after Rhodes and Karpathos. The surface of the island is 295.3 sq. km. with a coastline of 112 km. The capital of the island is Kos, which is the main port of the island. The entire island is morphologically complex, with distinct areas dominated by mountains, hills and plains. This morphological image is the result of the existence on the one hand of rocky carbonate and volcanic rocks, but also of the coverage of a large part of the island by volcanic materials. The climate of Kos is Mediterranean, characterized by mild winters, with plenty of rain, strong winds, and periods of relatively high sunshine. The dry or hot season lasts from the end of April until mid-September. The population of the island according to the 2011 census amounts to 33388 permanent residents. The island has tourist traffic during the whole year, due to the easy access to the island, by sea or by air. The population, especially during the summer months, is double.

In the settlement of Kardamena water supply doesn't exist. Thus, the limited underground water reserves are used and the problem of salinization intensifies, as the settlement of Kardamena is by the sea. Thus, the water gradually becomes unsuitable for drinking. The island's energy needs are served by an autonomous power generation station with a capacity of 138.74 MW located in the area of Mastichari, west of the island. The fuels that are used are low-sulphur fuel oil and diesel fuel, making the power generation particularly harmful to the island's environment.

2.2 Electricity and water need in Kos

The monthly variation of the electricity needs of the wastewater treatment plant is shown in Fig. 1 (personal communication with the local technical service of Kos). Also, the mean monthly water demand of Kardamena, is shown in Fig. 2. The demand for electricity and water is increased during the summer months because of the tourism season. The energy demand peaks at 250000 kWh in August and the water demand at 14000 m^3 in July. In the months when there is no tourist traffic, the energy demand from WTP is stable because the population that is served are the permanent residents. The water demand is not stable because of irrigation and tourism.

Figure 1: Mean monthly energy demand of WTP (kWh/month)

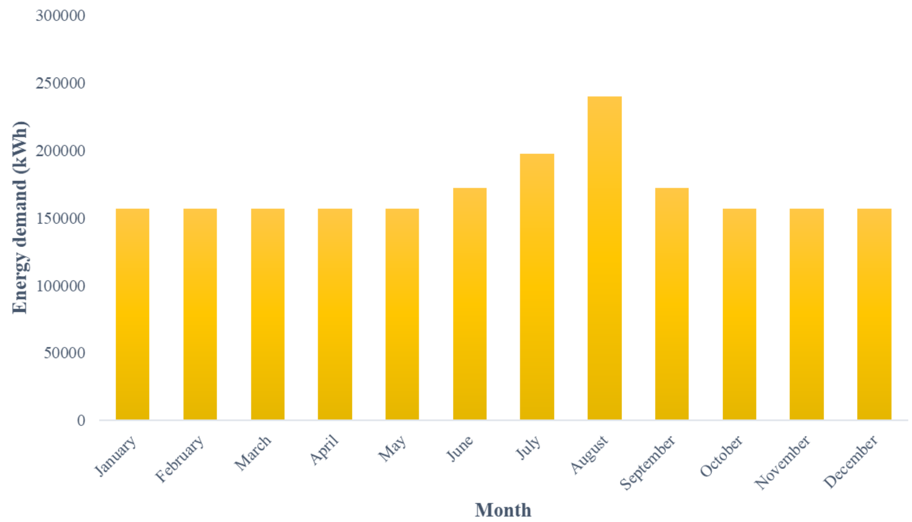
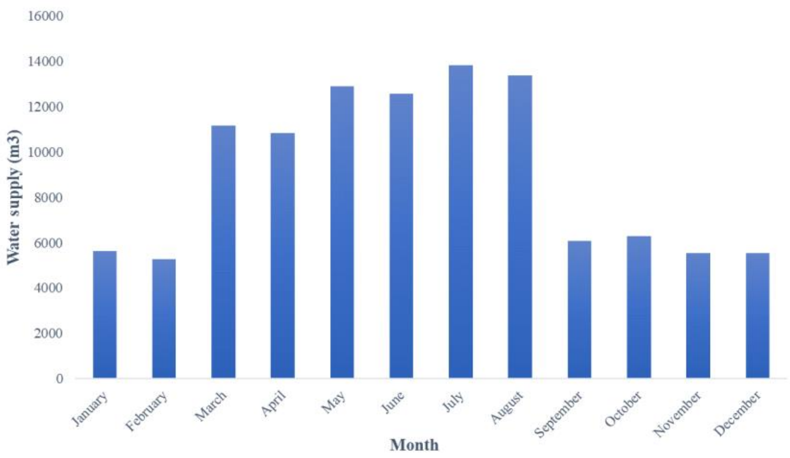


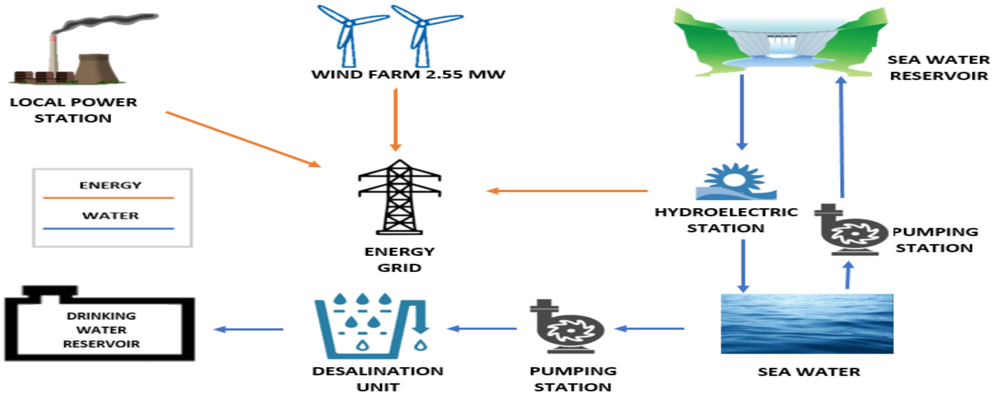
Figure 2: Mean monthly water demand (m^3/month)



2.3 Technical description

The examined HRES consists of a wind farm with a total capacity of 2.55 MW, which is composed of 4 wind turbines Vestas V-52 of 0.85 MW. The wind farm is located at an altitude of 140 m, in an area where the installation of wind turbines is permitted by law and is technically feasible. The energy produced by the wind farm ends up in the island's power grid via power distribution cables. Thus, the energy is immediately available to cover the needs, which are particularly extensive in the summer months due to tourism. In addition, the HRES consists of a desalination unit with a total capacity of 1920 m^3/d and a capacity of 6.5 kW/m^3, in order to produce drinking water. The desalination method chosen is reverse osmosis. It is a method that does not require large amounts of energy, is technologically mature and environmentally friendly. In addition, there is experience in the use of the method as it has been applied in many islands of Greece. The desalinated water is then stored in the drinking water reservoir, so there are available quantities to cover possible water deficits. The desalination unit is accompanied by a 10-kW pumping station to pump the produced desalinated water to the drinking water reservoir with a capacity of 160000 m^3. The desalinated water reservoir is connected to the water supply network of Kardamena. Due to the altitude difference, the water is distributed by gravity and no amount of energy is required for pumping. Thus, the island will no longer have a problem of water scarcity, especially in the dry and hot summer months when water reserves are limited, creating problems for the local community. The HRES also consists of a hydro turbine of 4 m^3/s that produces hydroelectric energy. Finally, the seawater reservoir with a capacity of 500000 m^3 is located at a height of 75 m above the hydroelectric station and is accompanied by a 350 kW pumping station. The sizing process is taking into account local needs. The existing local power station (138,42 MW) meets the demand when the required energy is not produced by the HRES. The schematic representation of the HRES is shown in Fig. 3.

Figure 3: Schematic representation of the HRES



2.4 Methodology

Wind speed measurements are collected from the local meteorological station (on the island of Kos) of the National Observatory of Athens Automatic Network (NOANN) in order to calculate the estimated wind energy production (Lagouvardos et al., 2017). The wind data are measured every 10 minutes for a total period of 5 years. Processing time series and converting them to hourly step, is done using the free software application Hydrognomon (Kozanis et al., 2010). The wind speeds measured at the meteorological station are converted according to the height at which the wind turbines are installed. Using the altitude of the meteorological station, which is 42 m, and the height of the wind turbine rotor, which is 91 m, the conversion of the wind data is made. As mentioned above, the Vestas V-52 wind turbine model is selected. Based on the power curve, provided by the manufacturer, the generated wind energy is calculated. The energy produced by the wind turbines is distributed as followed: 30% is available directly to the grid, while the remaining 70% is utilized according to energy demand. The aim of the system under consideration is the energy coverage of the WTP and the desalination unit. If the produced wind energy does not adequately cover the needs, the seawater reservoir supplies the hydroelectric power station, which covers the energy deficit. If the electricity demand cannot be met by the produced hydro energy, then the deficit is covered by the local power station. In case there is an excess of offered energy, it is available for pumping seawater to the upper reservoir. The pumping of seawater in the upper reservoir in case of excess energy and the operation of the hydroelectric power station in case of deficit smooths out the sharp fluctuation of the produced energy. The system is simulated for 5 years with an hourly step. Fig. 4 shows the average hourly wind energy produced per month. It is observed that the month of July is the month with the strongest winds, therefore the highest energy production.

Figure 4: Average hourly wind energy produced per month

2.5. Results and discussion

As mentioned above, the goal in the operating scenario is to cover the water supply of the settlement of Kardamena (population 1650 inhabitants) with desalinated water and the energy coverage of WTP. Fig. 5 shows the management of the total wind energy for each month. The strong fluctuation of the wind is reflected in the generated wind energy per month.

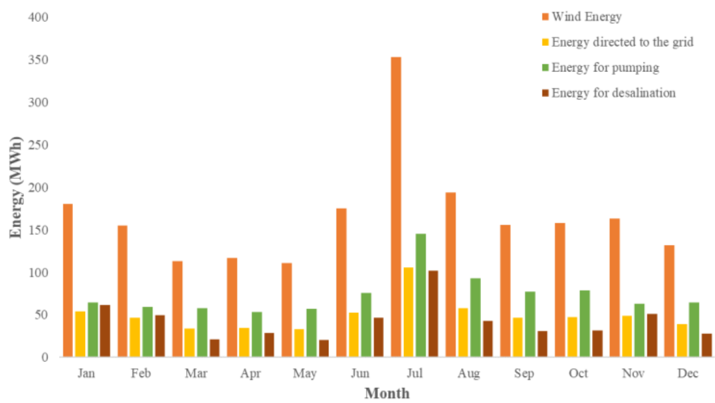
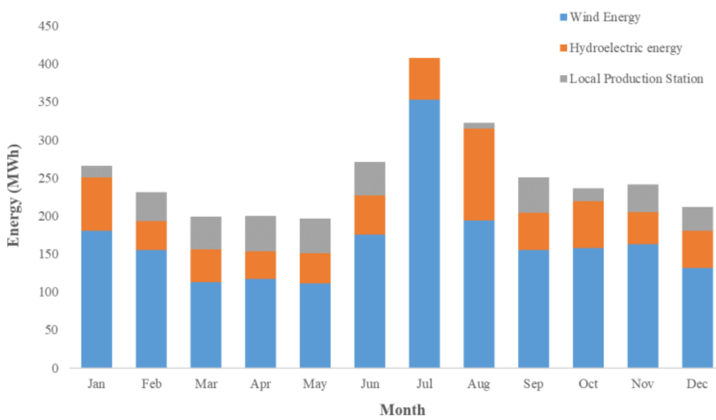


Figure 5: Wind energy management

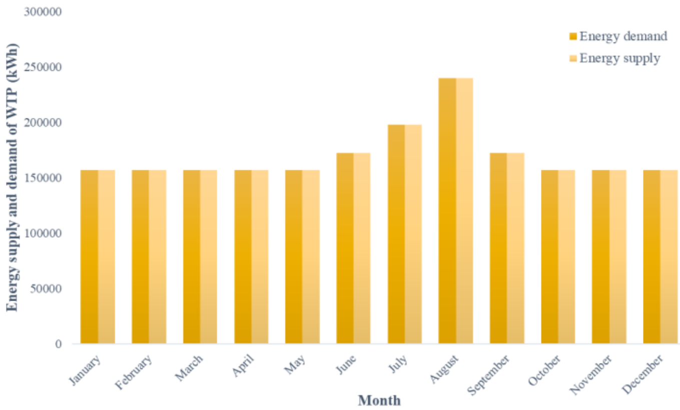
Fig. 6 shows the energy production per month and how energy needs are met. It is observed that the maximum monthly energy production occurs in July and reaches 400 MWh, due to high wind energy production. Demand in July and August is high, due to tourism, but due to the high wind energy production, the local power station operates only in August and less than in other months. The contribution rates of each energy source are wind energy, hydroelectric energy and the local power station.

Figure 6: Energy production per month (MWh/month)



The energy supply and demand of WTP per month are shown in Fig. 7. The needs of the WTP are covered throughout the year by the hybrid system. Thus, the facility becomes energy independent and operates 100% with environmentally friendly renewable energy.

Figure 7: Energy supply and demand of WTP per month (kWh/month)



Drinking water supply and demand per month are shown in Fig. 8. The volume of desalinated water produced is stored in a reservoir and is used to meet water supply needs. For the population of 1650 inhabitants of the settlement of Kardamena, the percentage of coverage by the desalination unit is 100%.

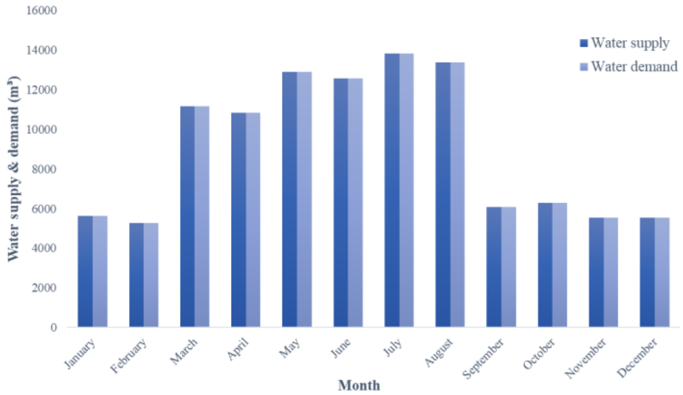
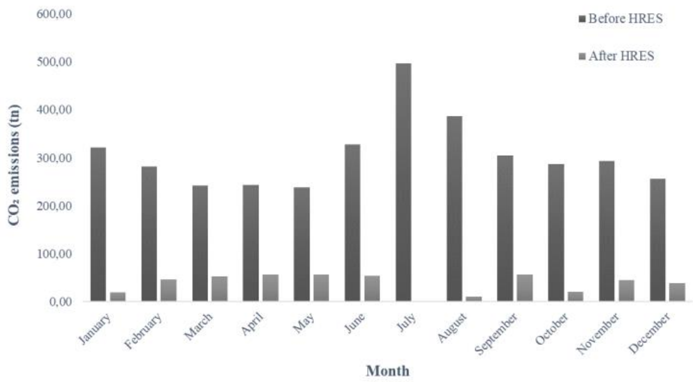


Figure 8: Water supply and demand per month (m^3/month)

Finally, a comparison of CO_2 emissions is made before and after the integration of the hybrid system in Fig. 9. The CO_2 emissions of the local production station are considered about 0.92 kg CO_2/kWh (Hawkes, 2010). A reduction of CO_2 emissions for the energy consumed for WTP needs is observed by 83.00% in the considered scenario. Therefore, the environmental contribution of the HRES is also perceived with the offered energy produced, which is free from emitted pollutants. Throughout the year the emissions are particularly reduced, with a typical example in the month of July when the CO_2 emissions for energy production are zero.

Figure 9: $CO_{2\ emissions}$ before and after the HRES (tn/month)



3 Conclusions

The studied system can satisfy the goals that were set with great reliability, namely the energy coverage of WTP and the water supply. Firstly, CO_2 emissions are significantly reduced as the use of fossil fuels is reduced on the island, as there is extensive renewable energy production. In addition, with the production of desalinated water in the seaside area of Kardamena, the problem of water scarcity is solved. The settlement is supplied with drinking water throughout the year. Thus, no more underground water reserves are pumped and the level of the aquifer is expected to increase. Therefore, it will limit the severe problem of salinization and reduced water quality for water supply and irrigation. The settlement will have access to high-quality salt-free water.

As perceived, the island becomes autonomous and self-sufficient, by producing drinking water and energy for its annual needs. At the same time, however, there are side benefits from the development of a hybrid energy system. For example, the area of the reservoir can be a place of recreation and green spaces can be developed around it. The permanent population as well as tourists will be able to have access to a place with a developed green landscape. Also, the local livestock and the poultry of the island of Kos will be strengthened, which consists of many rare species. Thus, the HRES will make a significant contribution to the development of the area and the improvement of the quality of life.
Concerning future research, the application of this methodology is suggested in other islands of Greece, interconnected and not, contributing to the local independence from the electrical network, increasing the contribution of RES, and reducing CO_2 emissions. Finally, a multi-criteria analysis for the installation of each subsystem could enhance the minimization of the environmental impact of the HRES.

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