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Water scarcity, energy independence and the role of hybrid renewable energy systems

BERTSIOU M.*, BALTAS E.

Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, 5 Iroon Polytechniou, 157 80, Athens, Greece

*corresponding author:
e-mail: mbertsiou@chi.civil.ntua.gr

Abstract Water scarcity problems and the need for reduced consumption of fossil fuels lead to the transition to renewable energy sources (RES). The proper management of RES is the key issue, especially in small not interconnected islands. In this research work a Hybrid Renewable Energy System (HRES) on a small island in the Aegean Sea is evaluated for ten years of hydrometeorological data. The objective is the production and storage of the required energy for the electricity needs of the area, as well as, for the desalination of seawater for domestic and irrigation water fulfillment. Results concerning the reliability of the system, the fulfillment of water and energy demands and the loss of load expectation are presented. The simulations will give valuable information about the produced and stored energy, its controlled distribution for the water and energy demands of the island and HRES's potential in these demands of the local society over one decade.

Keywords: HRES, water scarcity, energy management, energy storage

1. Introduction

Water scarcity and energy independence are two critical issues facing many countries around the world, particularly in regions, like the non-interconnected island of Greece, which have limited access to conventional sources of energy and to freshwater. In recent years, the adoption of hybrid renewable energy systems (HRES) has emerged as a promising solution to address these challenges (Spiller et al., 2022, Kakoulas et al., 2022). Hybrid renewable energy systems combine one or more renewable energy sources (RES), such as wind, solar, and hydroelectric power, with one or more storage technologies, to respond to the intermittent nature of RES, to enhance the reliability and the performance of the network and finally to provide reliable and sustainable energy and water solutions (Panagopoulos, 2021).

Especially in the Greek islands, the integration of HRESs with desalination plants can convert seawater into freshwater. The use of renewable energy to power these plants reduces dependence on conventional energy sources, such as fossil fuels, and ensures a sustainable supply of freshwater. Furthermore, HRES can also power irrigation systems, providing a reliable and sustainable water supply for agriculture, which is crucial for food security. Among all desalination technologies that can be used in conjunction with RES, reverse osmosis is the main desalination technique because it uses little energy and has low associated costs (Esmaeilion, 2020). The energy consumption for a RO system varies between 3.7 and 8 kWh/m^3 (Xu et al., 2019) and is influenced by both the water's quality and the size of the desalination unit (Navarro Barrio et al., 2021).

The use of HRESs can play a critical role in addressing water scarcity and energy independence challenges. HRESs can reduce energy and water costs, increase the reliability of energy and water supply, and reduce the environmental impact of conventional energy sources.

2. Study area and demand data

The study area is Fournoi Korseon island (Fig.1) in the northeastern Aegean. The permanent residents are 1400 and the majority live in the capital village, Fournoi. During the tourist season, the population reaches 4000 people. Today, drinking water is supplied from a public spring in the central square of the island and by extensive use of bottled water. Irrigation water is supplied from private wells and their agricultural produce is mainly available for private and non-commercial use outside the island's boundaries. The monthly drinking water requirements are estimated to be around 5000 m^3 during the winter months and up to 16000 m^3 during the tourist season. The data is collected after personal communication with the engineer of the Municipality of the island. The irrigation season extends from April to September with demand ranging from 1000 to 30000 m^3. To find the required irrigation water quantities, agricultural crop data is collected from Hellenic Statistical Authority and then the evapotranspiration is calculated using the Blaney-Criddle (1962) method, taking into account the precipitation and the temperature. The maximum demand for domestic water is observed in August and for irrigation water in July. However, cumulatively the highest demand occurs in August and the lowest in the winter months when water is not used for agricultural activities and there is no tourist traffic. Meteorological data (wind speeds, temperature and precipitation) are collected from the Fournoi station of the National Observatory of Athens (Lagouvardos et al., 2017).

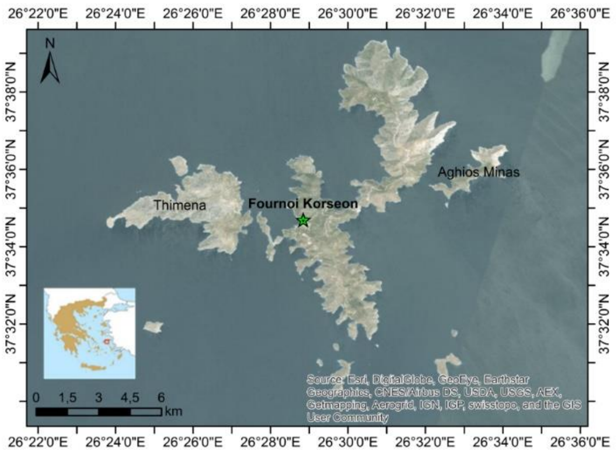

Figure 1. Study area-Fournoi Korseon

3. Methodology

3.1 Wind turbines

Enercon E-44's 900 kW power curve is employed in this study. The power coefficient for this model is provided by the manufacturer and ranges from 0.00 to 0.50 depending on the wind speed at the hub height. The nominal power of the wind turbine and the wind speed u determine its output. For this model u_{cut-in} is equal to 2 m/sec, u_{rated} is equal to 17 m/sec and $u_{cut-out}$ is equal to 25 m/sec. For 25 ≤u<2 the power output is equal to zero. For 17 ≤u<25 the power output has its maximum value equal to 900 kW and for 2<u<17 the power output is calculated according to the power curve. A 5th degree polynomial trendline with an R-squared value greater than 0.99 is derived by the power curve for estimating power production based on wind speed. The number of required wind turbines, z, is based on the total energy demands, E_y, the maximum power output, N_o, and the load factor, CF. The number is calculated for the case where there is a complete agreement between wind potential and demand, i.e. without considering wind stochasticity, and for the case where there is a complete mismatch between wind potential and demand.

$$E_y/(N_o \cdot CF \cdot 8760) \leq z \leq E_y/(N_o \cdot CF \cdot 8760 \cdot 0.6)$$

Synthetic time series of 10 years of wind data is produced, based on the historical data which are obtained by the National Observatory of Athens and using the first-order autoregressive model, AR (1).

3.2 Batteries

The storage capacity of the batteries is estimated for a two-day autonomy of the HRES (Bhandari et al., 2015). If there is surplus RES, E_s, after the fulfillment of the demands, the battery is charging according to:

$$SOC(t) = SOC(t-1) \cdot (1-\sigma) + E_s \cdot n_{bat}$$

$SOC(t)$: state of charge at time t (kWh)
$SOC(t-1)$: state of charge at time t-1 (kWh)
σ: self-discharge rate (%)
n_{bat}: efficiency of the battery (%)

If there is an energy deficit, E_d, the battery is discharging according to:

$$SOC(t) = SOC(t-1) \cdot (1-\sigma) - E_d \cdot n_{bat}$$

3.3 Desalination unit

Energy for desalination is assumed equal to 5.85 kWh/m^3 for reverse osmosis desalination and the desalination plant is assumed to be able to meet the average daily demand.

3.4 Energy management

The proposed HRES consists of a wind park of 3.6 MW, a battery of 60 MWh and a desalination unit of 1,400 m3/day. The input data are entered, meteorological data and the demand data of the island. The energy produced by the WTs is calculated and priority is given to the domestic water. The produced RES is calculated for each step and each demand is checked if it can be fulfilled. Once the check for each of the three demands is made, it is then checked if there is surplus energy. If there is surplus energy, it is checked if there is available stored energy in the batteries. If not, then this energy is rejected, otherwise, the new state of charge of the batteries is calculated, and the met and unmet demands for one hour are estimated, before approaching the next step. In case there is no surplus energy, but there is still demand that has not been fulfilled, it is checked if there is available stored energy in the batteries, the new state of charge is calculated and at the end, the met and unmet demands for one hour are estimated again. For each year the reliability of the HRES is estimated, as the fulfillment of water and energy demands and the loss of load expectation,i.e. the number of hours in one year that load loss occured.

4. Results

In Fig. 2, the different energy sources that participate yearly in the energy mix of the island are presented for each demand, electrical load, domestic water and irrigation water. The fulfillment of each demand is based on the direct penetration of RES from the WTs (ELwt for the electrical load, DWwt for the domestic water and IRWwt for the water for agricultural use), the penetration of the batteries (ELbt, DWbt, IRWbt). The unmet demands are also depicted (ELunmet, DWunmet, IRWunmet). Fluctuations are presented for the 10-year wind data, while the demands are considered to remain stable for the decade. The percentage of unmet demand for household consumption ranges between 8% and 13.5%, the corresponding value for domestic water ranges from 3% to 6%, while for irrigation water ranges from 6.3% to 14.5%.

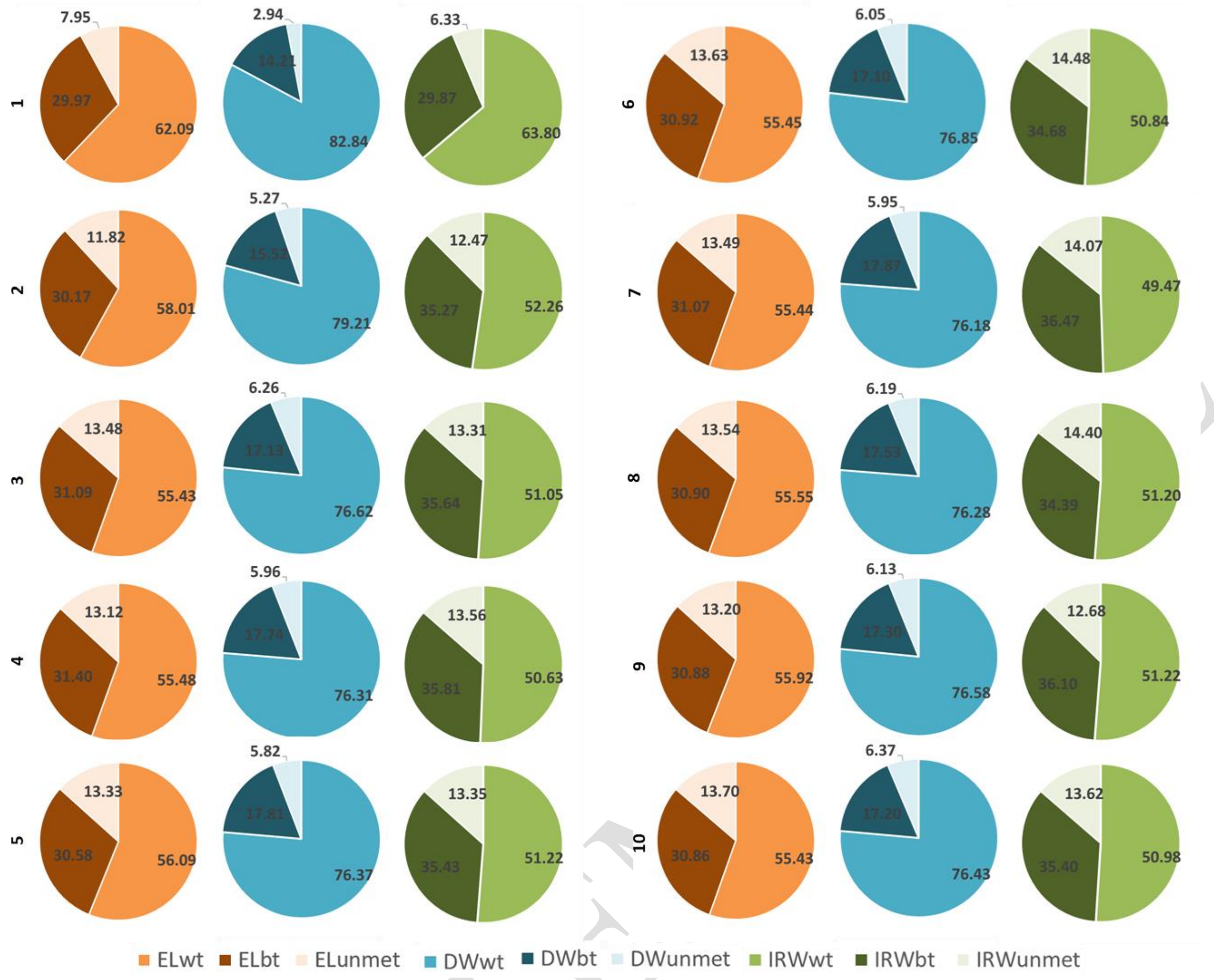

Figure 2. Ten-year reliability analysis for household consumption, domestic and irrigation water

In Fig. 3 the load loss for each demand for ten years is presented. There are consistently more hours of load loss for electricity demand, as it is the last demand in the priorities. Demand irrigation water has a lower chance of load loss, as irrigation is carried out only during the irrigation season from September to April. There is a relative variation in load loss hours over the 10 years.

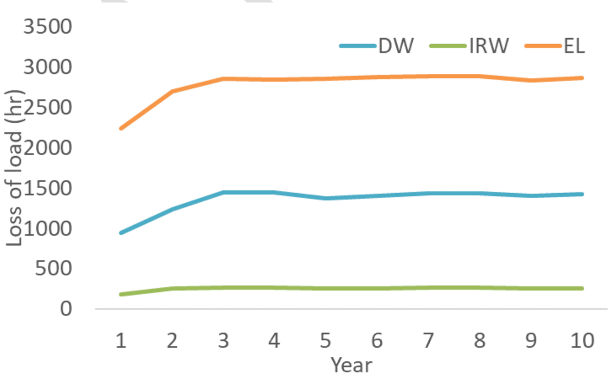

Figure 3. Number of hours of load loss for each demand and for ten-year simulations

5. Conclusions

Simulation results show a satisfactory coverage of the demands by the HRES. However, the probability of load loss and unmet demands vary significantly from year to year, indicating the need for multi-year data collection to fully evaluate the introduction of an HRES to meet the needs of a remote area. Further research is suggested in the direction of stochastic generation of synthetic time series for the demand data to evaluate the performance of the HRES not only based on the energy produced but also based on the demand variations.

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