Simulation model for autonomous energy planning for Milos island

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Abstract

A new project to generate electricity on a selected remote Greek island with a population of around 5,000 inhabitants has been developed, using only renewable energy sources (RES) and energy storage systems. This new energy plan was made taking into account the framework of the clean energy transition for islands, for the island of Milos in the Aegean Sea and compared with the current energy coverage. The electricity demand coverage needs on this island are met by using conventional fuels with the operation of diesel engines. Appropriate software was selected and used for the optimisation and creation of energy systems. For the energy study of the island, integrated simulation models were created both for the current total energy supply and for different scenarios of the newly developed energy planning.

Keywords: energy transition, clean energy, remote island, simulation model, renewable energy system (RES), storage system

1. Introduction

In Greece, there are a considerable number of remote islands, most of which are not interconnected with the mainland electricity grid of Greece. It is very common that such remote places with high potential for usage of renewable energy systems aren't being fully taken advantage of. On the contrary, the Public Power Corporation (PPC) uses autonomous thermal power plants to meet the needs of the Aegean islands (PPC 2020). These plants require large quantities of either light (diesel) or heavy (fuel oil) oil to operate, with correspondingly high carbon dioxide emissions.

A new project to generate electricity on the selected remote Greek island Milos with a population of around 5,000 inhabitants has been developed, using only renewable energy sources (RES) and energy storage systems. This article describes this new concept for an energy system for Milos island in Greece and the simulations which ran with an software application. The simulations results are then compared with the current supply of energy in the island.

2. Description of current situation

According to IPTO 2020 the majority of the island's energy is provided by diesel generators and imported electricity via underwater cables from Independent Power Transmission Operator (IPTO). The Public Power Corporation (PPC 2020) uses according to Kaldellis and Zafirakis 2007 autonomous thermal power plants (CHPs) to meet the needs of the Aegean and Ionian islands.

The majority of the island's energy is provided by PV panels, wind turbines, diesel generators and imported electricity via underwater cables from Independent Power Transmission Operator (IPTO 2020). However, out of these four sources, the main one being used are the diesel generators. The diesel generators on the island provide a consistent source of power, but they are costly to operate and maintain, and their emissions contribute to air pollution and climate change. Furthermore, the island's reliance on imported electricity exposes it to price fluctuation and supply problems (Mathew 2023).

Table 1 shows a list of the available and running diesel generators on Milos Island.

Selection and/or peer review under responsibility of Scientific Committee
10.18086/eurosun.2024.09.01 Available at http://proceedings.ises.org

Tab. 1: List of diesel generators on Milos Island as described in HEDNO 2022

No.	Generator	Capacity [MW]
1	G3	5.0
2	G4	5.0
3	G5	5.0
4	G7	1.5
5	G8	1.5

It is important to note that the five generators with a total capacity of 18 MW can produce more than the required demand of the island. These generators are switched on and off according to the real-time electricity demand.

Additionally there exist some small-scale PV systems and a wind turbine which are already installed on Milos Island, and are considered in order to prepare the current energy concept. The installed PV in the island according to HEDNO 2023 include PV arrays with a capacity of 0.5 MW, roof PV with an installed capacity of 74 kW and tracking PV systems of 120 kW. One wind turbine, with a rotor at a height of 50 m, is operating at the island with a total installed capacity of 2.6 MW.

Fig. 1 shows the current energy system model in Milos island.

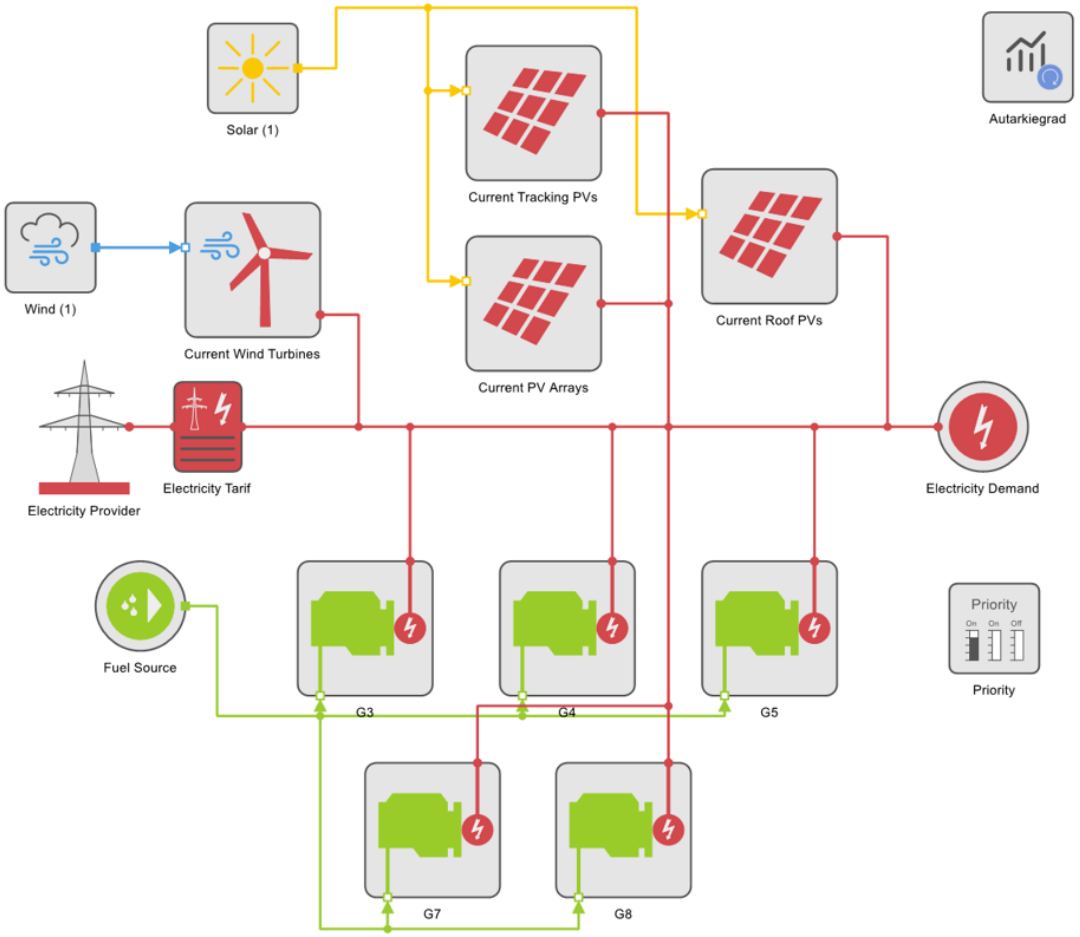

Fig. 1: Current energy system model in the island of Milos

This model was created by selecting the required components from the component library of the software tool and linking every input and output accordingly. Each of the components in the model can be configured with

the respective technical data. In Milos, most of the electricity comes from the diesel generators, a small percentage from the PVs and the wind turbine.

Also, an electricity grid provider, even though it is not used yet, is added to the concept since very soon the island will be connected to the main grid. The project, which concerns the interconnection of Milos with the mainland Electricity Transmission System, is part of the fourth and final phase of the interconnection of the Cyclades. The implementation of the project, including the installation of the 150 kV high voltage submarine cables, is expected to be completed in 2026.

Fig. 2 shows a typical summer electricity demand curve on Milos island. This is different to winter months as in these months the amount of tourists is decreasing.

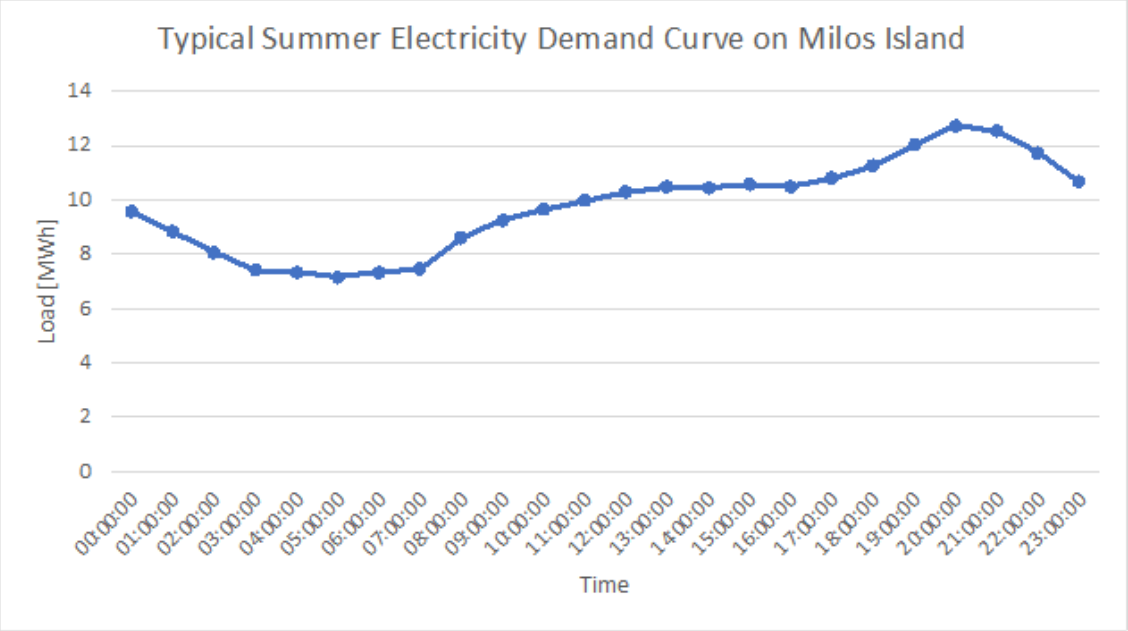

Fig. 2: Summer energy demand curve in Milos Island according to HEDNO 2022

In the winter time the energy demand for a characteristic day does not exceed 5 MWh and takes values between 2.5-5 MWh.

3. New concept for energy production in Milos

It is important to describe first the potential of renewable energy sources. This is followed by the new energy planning with the aim of 100% renewable energy use and modelling with appropriate software.

3.1. Renewable energy potential

It is a fact that the vast majority of the remote Aegean islands are characterised by a very high solar, but also a remarkable wind potential. The choice of renewable energy technologies is illustrated by a potential analysis which focuses on the location of the island and therefore the impact on the potential potential returns.

Regarding the solar potential Milos receives enough of sunlight throughout the year, making it an ideal location for the installation of solar panels (Greeka 2023). According to measurements of the National Meteorological Service (EMY), the Centre for Renewable Energy Sources (KAPE) and other services, the relative solar potential for the remote Aegean islands ranges according between 1500 and 1850 kWh/m^2 in the horizontal plane, while the average wind speed is between 7 and 9.5 m/s.

Fig. 3 shows according to Kaldellis 2021 the solar and wind energy potential for Greece. As can be derived from this figure the solar potential for Milos is the highest in Greece with annual solar radiation values of 1650 kWh/m² and annual mean wind speed at 30 m of more than 5.3 m/s. The average daily solar irradiance in Milos Island varies depending on the time of year, but it is generally around 5,5 kWh/m²/day during the winter months and 8 kWh/m²/day during the summer months (NASA 2018).

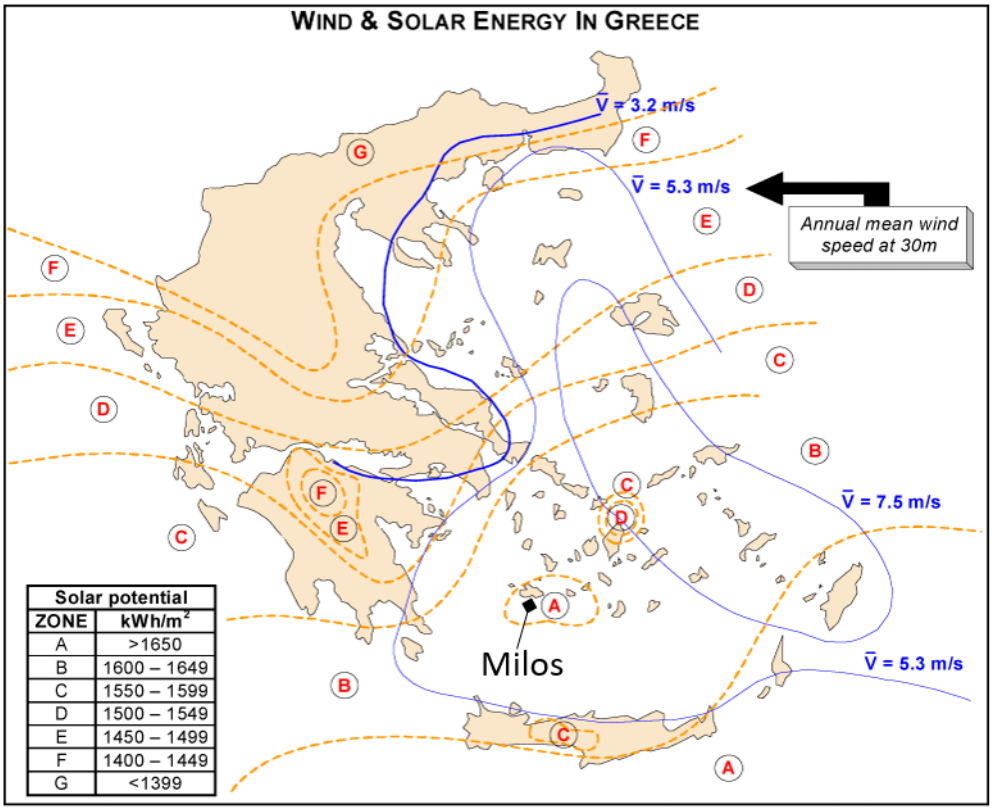

Fig. 3: Solar and wind energy potential for Greece, according to Kaldellis 2021

The average wind speed on Milos Island is around 6-7 m/s, with maximum wind speeds reaching up to 22 m/s at 10 m (NASA 2018). Milos also features a harsh and hilly terrain with several elevated locations that are exposed to the wind. These topography features generate high wind speeds and turbulence, making wind energy generation ideal.

3.2. New concept

Taking into account the pressing need to meet the island's energy needs without further use of conventional and therefore polluting fuels, the prospects for the development of a new energy system on the island, based mainly on the exploitation of the available solar and wind potential and the use of energy storage systems, are proposed and explored.

The main difficulty in drawing up an energy plan is that renewable energy production is always linked to storage, as it fluctuates throughout the day and the seasons. Generating electricity with photovoltaic and wind power systems is a way to make up for the use of conventional forms of energy in the long term.

The new concept envisages a combination of these two types of energy production technologies, as they work well together. In winter, wind speeds are high, so more electricity is produced than wind power, and in summer, solar power is high while wind power is lower, so the two are balanced throughout the year. For energy security, storage is also added to ensure that energy is available during the dark phase or in case of problems with the systems.

3.3 Simulation model development

Appropriate software was selected and used for the optimisation and creation of energy systems. For the energy study of the island, integrated simulation models were created both for the current total energy supply and for different scenarios of the newly developed energy planning.

The authors used the TOP Energy software, as it has a number of advanced features, which are mentioned in Schwarzkopf 2022:

- the possibility of carrying out economic and ecological evaluation
- the freedom to design and test new ideas
- the integration of solvers that help to find the right economic, ecological and energy optimum

Fig.4 shows the concept with new PV arrays, wind turbines and a battery for Milos island.

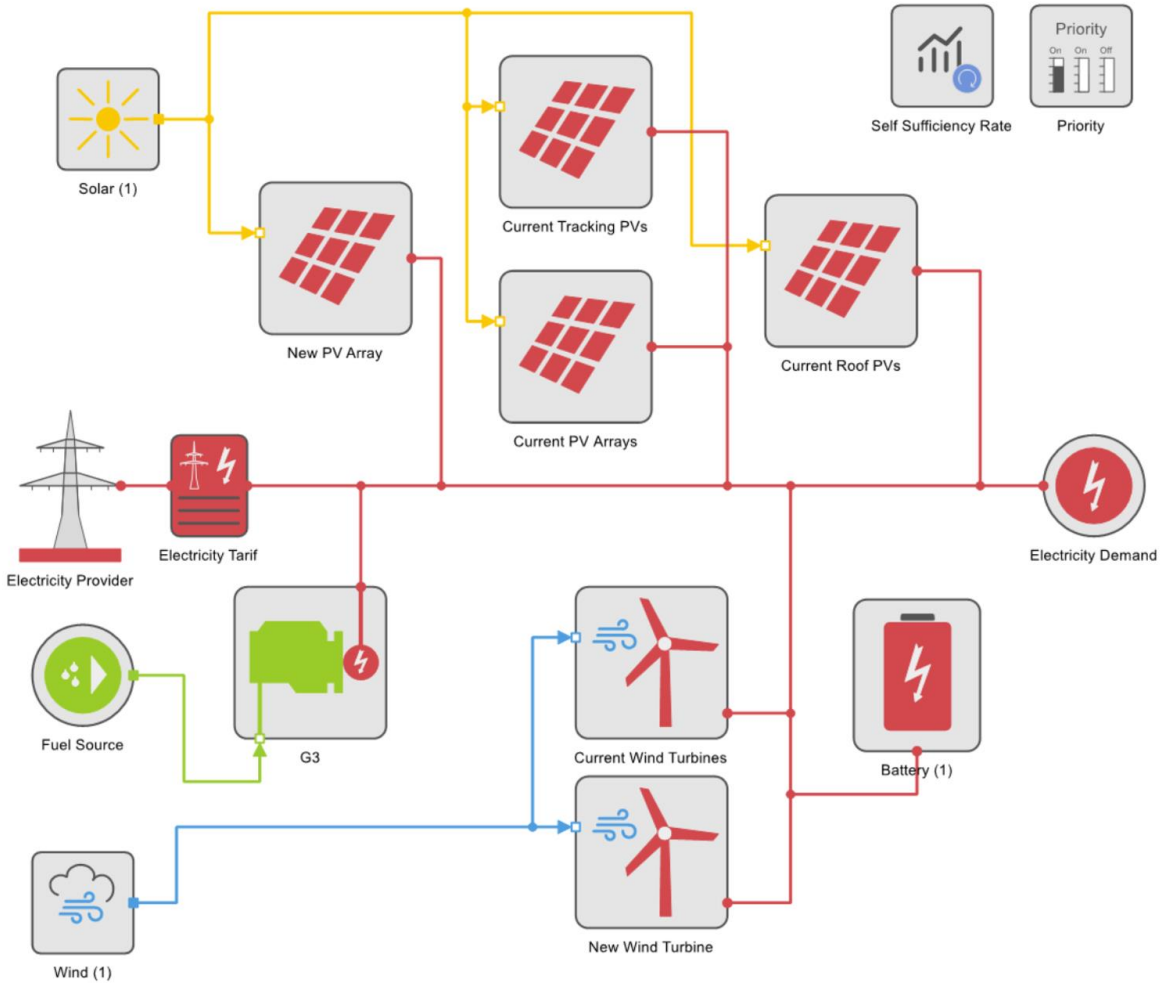

Fig. 4: Model of new energy concept for Milos Island

The new energy concept includes new PV arrays with an installed capacity of 17.5 MW and a wind turbine from Vestas with an installed capacity of 8 MW. For reasons of security of energy supply, the G3 diesel generator set of 5 MW is considered additionally but is only activated when no other sources and the battery are available. The battery was chosen to have a capacity of 433 MWh, which was not yet optimized. The priority is also configured so that the renewable energy sources are set as the main source of electricity.

The energy comparison is carried out using real data describing hourly step by hour the production of the renewable energy plants for a full year of operation. The climate impact is presented on the basis of a CO_2 balance and taking into account the reduction of fuel requirements.

4. Simulation results

Fig. 5 further shows the division of power production of the new energy concept. According to this pie chart most of the energy production comes from the new PV and wind turbine installation.

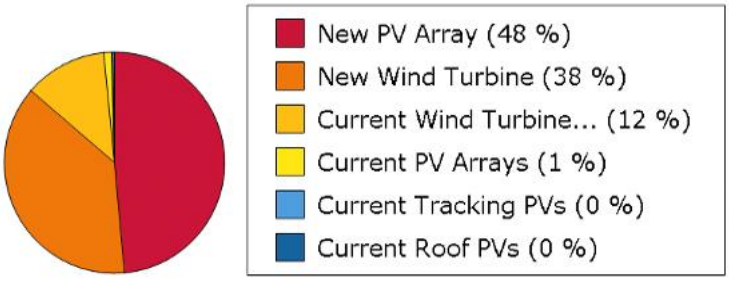

Fig. 5: Milos electricity production from different RES

To get a better overview of the results, Fig. 6 depicts the power output and compares it to the demand. The yearly electricity production was 59.3 GWh.

The stacked bars represent the energy being produced and the line represents the energy demand. It is noticeable here that the demand line is always lower than the sum of the bars, this means that enough energy is produced to cover the demand. The leftover energy will be stored in the battery and saved for usage in the next time period.

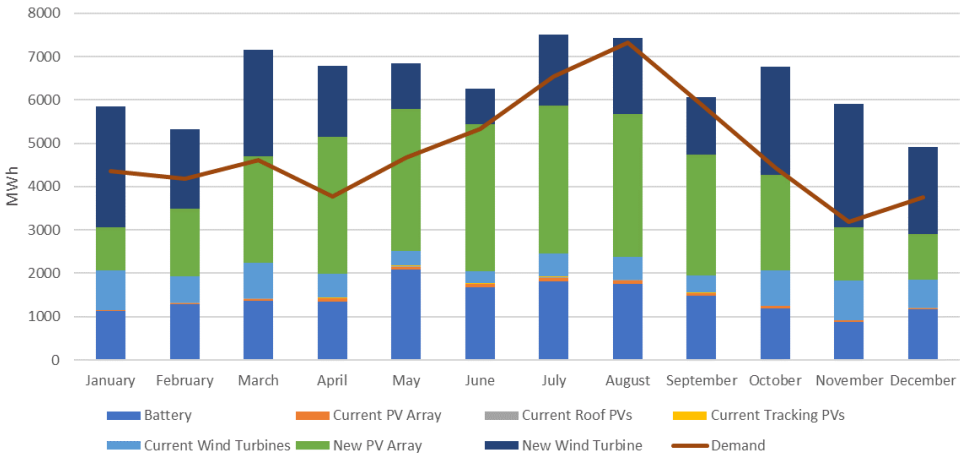

Fig. 6: Monthly production Milos concept

The main objective when implementing renewable energy sources is to lower the emissions of carbon dioxide. The currents sources of energy in Milos island still include diesel as a source, which has a high CO_2-emission factor of 1.1. With the simulations, it was possible to completely eliminate the usage of diesel and replace it with sustainable sources. The simulation results provided that an amount of 1,520 t CO_2/a can be saved, when the new concept is implemted.

The self-sufficiency rate for the new concept that was simulated is 100%. This means that the electricity demand for each island could be fully covered by the planned renewable energy sources.

5. Conclusion and future steps

A new project for the production of electricity on a selected remote Greek island with a population of less than 5,000 inhabitants has been developed for the island of Milos in the Cyclades, using only renewable energy sources (RES).

The electricity demand coverage needs on this island are so far covered by the use of conventional fuels with the operation of diesel engines. Taking into account the pressing need to meet the energy needs of the island without further use of these conventional and therefore polluting fuels, the prospects of developing a new energy system on the island, based mainly on the exploitation of the available solar and wind potential and the use of energy storage systems, were explored.

This article focused more on a small-scale location of an island, but it is generally also possible to implement the same techniques for larger scale locations or cities and ultimately lower CO_2-emissions. The energy planning is on a purely theoretical level and was done in the context of an undergraduate thesis. Next steps of optimization will be carried out in order to define a new energy planning for the island of Milos, which will be 100% based on RES.

In less than 2 years, in the year 2026, the island will be connected to the 150 kV HV submarine cable grid. Therefore the whole calculations will change and this should be considered in future energy concept analysis for the island of Milos.

6. Acknowledgments

The authors would like to thank at this point the TOP Energy team for their assistance and software support. The main author would like to thank Prof. J.K. Kaldellis for his scientific contributions in form of publications

in the field of remote island energy planning for Greece, which provided very useful basic informations about the RES potential and the energy concepts in this paper.

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