Towards a zero carbon energy system strategy for remote communities

Case study: Optimization of a sustainable electricity supply system for the Mediterranean islands

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

Energy remoteness is defined both by its causes, which include being disconnected from central infrastructure, and by its symptoms, such as reliance on liquid fuels, lower quality of energy supply and high cost of energy (IEA-RETD 2012). This study presents a case study of establishing sustainability in a Mediterranean island, which currently relies on liquid fuels, by reducing CO_2 emissions to zero through the robust design of a sustainable energy system.

Fig. 1: Ios island within the Cyclades complex, Greece

Aim of study

Transformation of the conventional energy supply system of the building and the transport sectors of a Greek island to a sustainable system of zero emissions

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Design of a complete energy system based on RES (Renewable Energy Sources)

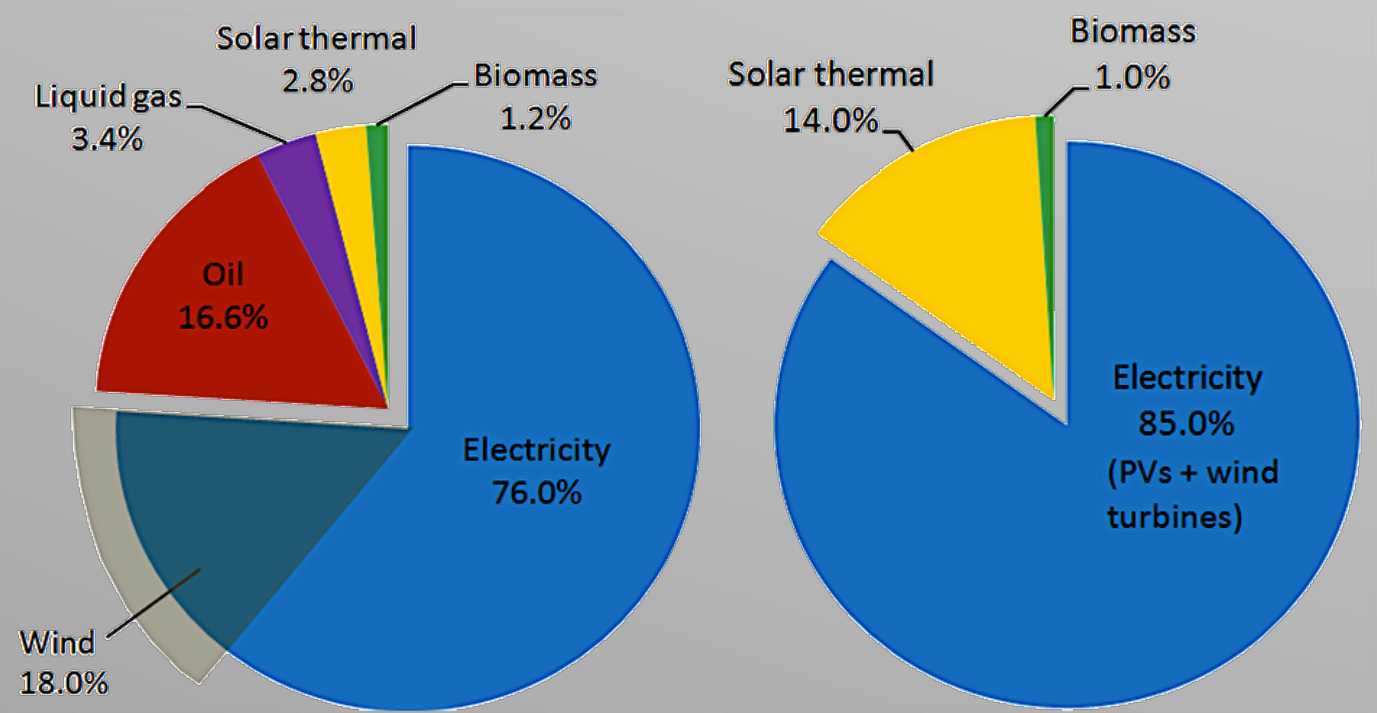
Methodology

The investigation is carried out for Ios island in the Cyclades complex (Figure 1). Electricity demand, space heating and cooling loads and domestic hot water needs are estimated for a baseline (BS) and a sustainable future scenario (SS) in the medium term. Then Ios' RES potential is explored and the investigation of efficient technologies based on RES is performed. Through the use of linear programming an optimal RES energy system is designed and finally the arrangement of the RES electricity systems is suggested.

Assumptions_building sector

Due to the high potential for energy savings in buildings, the methodology used in this research study assumes energy savings in buildings of at least 25% in the medium term. This figure relates to measures applied to the buildings' envelope, the introduction of energy efficient appliances and the adoption of a sustainable behaviour by the locals. In addition, an increase in energy demand of about 26% above the figures of 2010 is assumed to occur over the 10-year period (Katsikeas and Dimeas 2011).

Space heating and cooling demands during the year are assumed to be covered by using electrically driven GSHP or WSHP in the coastal areas with COP>4 (IEA 2011), instead of oil. Solar collectors will be used for the preparation of DHW with a small contribution by heat pumps for some days in winter. The estimated figures for energy demand in the household sector are presented in Figure 2. The monthly values of electricity demand in the medium term are presented in Figure 3.



Total energy demand 2010 **23,699 MWh/y**

Total energy demand 2021 (SS) **21,663 MWh/y**

Fig. 2: Current and projected energy consumption by energy carriers

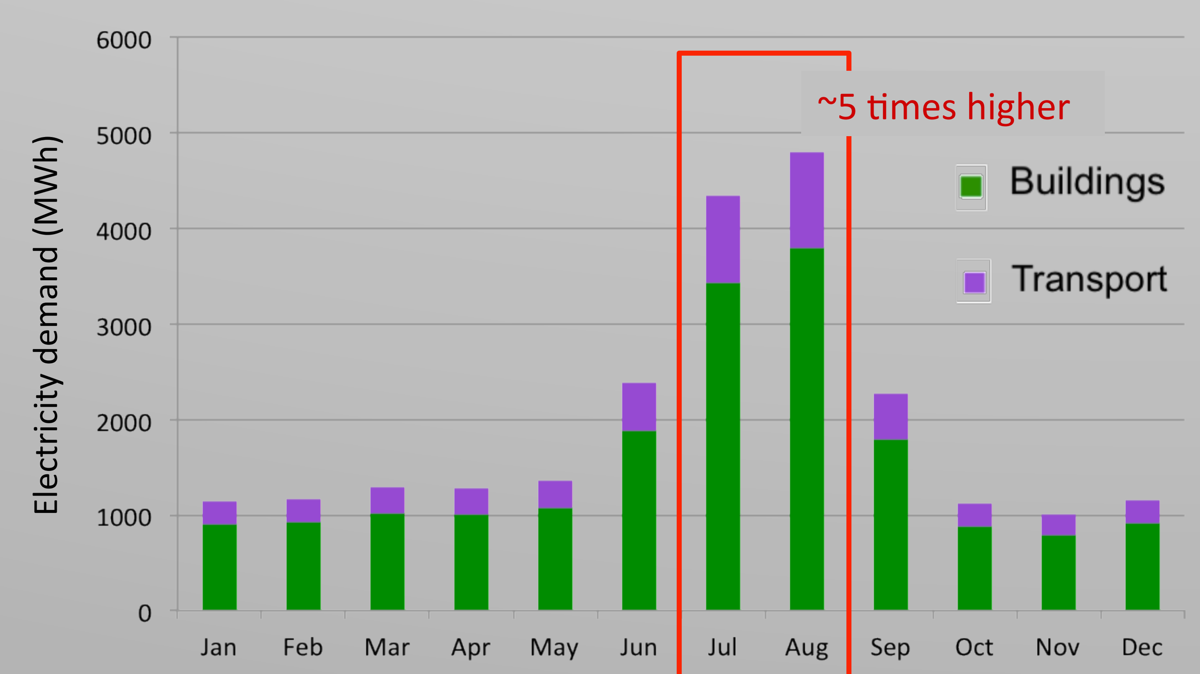


Fig. 3: Monthly values of electricity demand in the medium term (in total 23,310MWh/y, peak demand 7.5MW)

Space heating/ cooling, DHW

The abundant solar radiation in Greece is a really motivating factor for solar energy exploitation through solar thermal collectors and solar PV. Solar thermal collectors constitute a simple, direct and inexpensive technology for DHW production, providing high efficiency, reliability and a rather rational use of the energy source (IEA 2011). Regarding GSHP, their introduction for space heating and cooling constitutes a highly sustainable approach. GSHP could also contribute in supplementary heat production during some cloudy winter days for DHW production. As regards electricity generation, solar and wind are rather complementary energy sources, so a combination of both seems to be beneficial in terms of generating electricity on a 24-hour basis over the year.

Based on the above, advanced GSHP or WSHP powered by RES electricity are assumed to be used for residences' space heating and cooling, while solar thermal collectors are assumed to be covering nearly 100% of the energy demand for DHW. The introduction of such systems will result to a significant reduction of the energy consumption, without affecting the comfort level of the users. A small contribution from biomass will continue.

Electricity sector

In the electricity sector, the exploration was performed considering the overall building and transport sectors through the use of linear programming (Dantzig and Thapa 2003), with the aid of a software tool developed in Excel. The criteria under which the optimization was performed are the total minimum installed capacity, storage losses of 10%, the minimum surplus energy, the annual capacity factor of the system and the specific power generation per kW installed. The optimization was a three-stage process and the final results suggested that the solar PV installed capacity should be 12,114kWp (77%), while the wind installed capacity should be 3,628kW (23%). The optimal solution also suggested that 40% of the load during July and August should be supplied by Paros power station, while the surplus zero-emission energy from Ios RES system should be supplied to the neighbouring islands during the rest 10 months of the year. In this way, a net zero energy requirement from the grid for Ios is achieved over the year. Figure 4 presents an overview of the monthly values for energy demand, the solar PV and wind energy production, and the imported and exported energy for Ios Island. It is concluded that solar energy, compared to wind energy, corresponds in a better way to the load profile of the island.

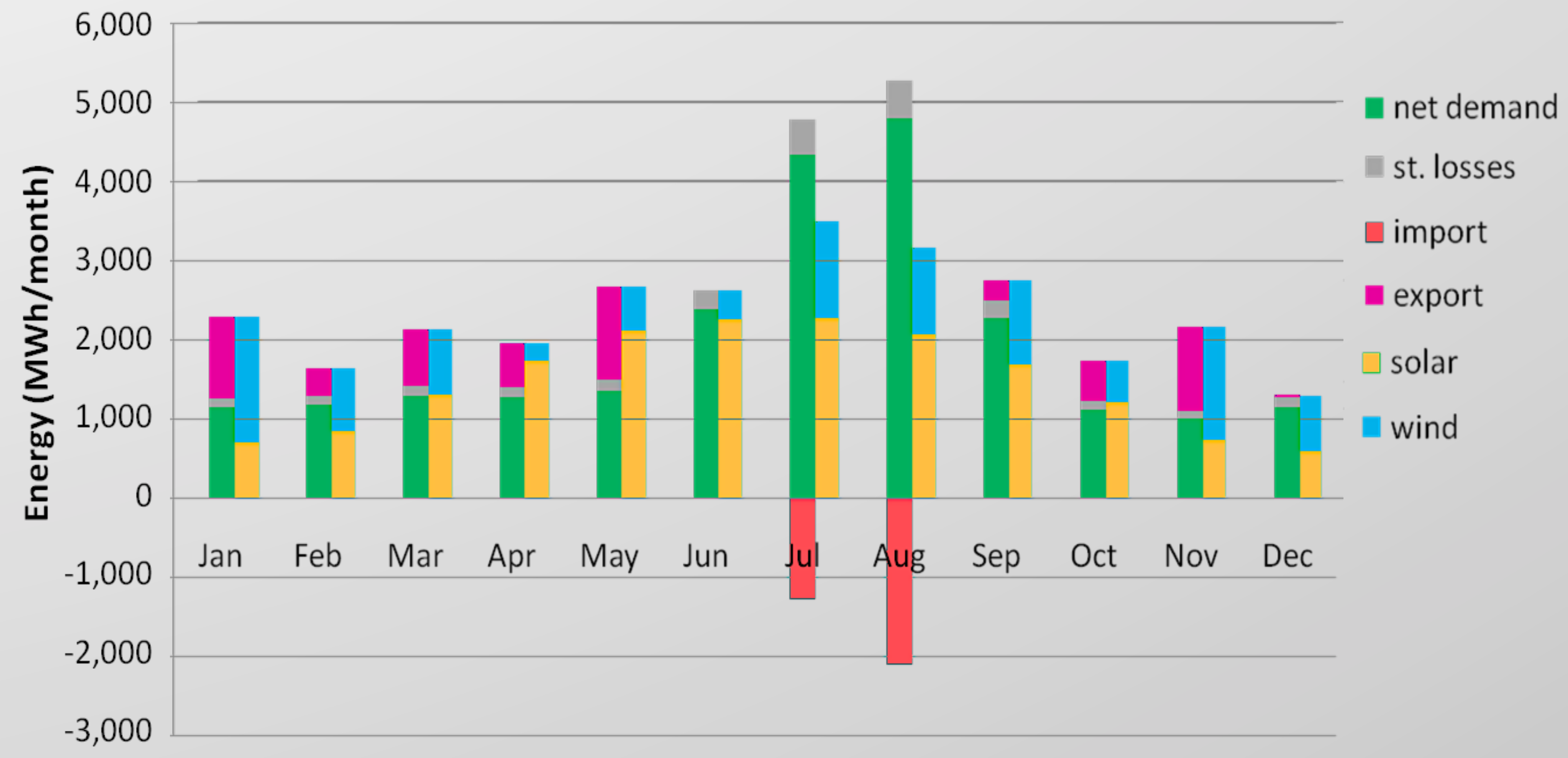


Fig. 4: Monthly data of energy demand, production by solar PV and wind, imports and exports

Arrangement of the RES electricity systems

The arrangement of the systems takes into account technical, social, economic, environmental and aesthetic parameters. The PV modules are distributed in dispersed PV systems in the urban environment and three centralised plants. This will result to higher reliability and lower aesthetic impact. The special conditions of the traditional settlements and the percentage of the owners who would be interested in installing RES systems on their houses have been taken into account for the residential buildings.

- Dispersed PVs: 3MWp (50% in residential buildings)
- PV plants: 9MWp
- PV plants' area: 0.05% of total area of Ios
- PV plants + wind turbines < 0.1% of total area of Ios
- PV plants raised 1m from the ground → not cancelling existing land use
- RES potential is not over-exploited → minimal effect on Ios' ecosystem

Fig. 5: Size and arrangement of the RES electricity systems on the island

The color of the PV modules and the supporting structures is suggested to be cobalt blue, like the color of the window frames, the shutters, the doors of the buildings and the sea. Thus, polycrystalline silicon PV modules are suggested.

Electrical energy storage

A central storage facility of advanced technology –that is chemical or pump storage- and distributed storage systems with batteries in each household or by using the battery pack of the electric cars seems to be the best combination for the electricity system. Both types of distributed storage systems can be managed by advanced control strategies based on Smart Grids, which are expected to be playing a more and more important role in the future. The flexibility of the demand and forecasting weather models are also necessary for an efficient system management. A daily load curve for a summer day in the middle of August is illustrated in Figure 6.

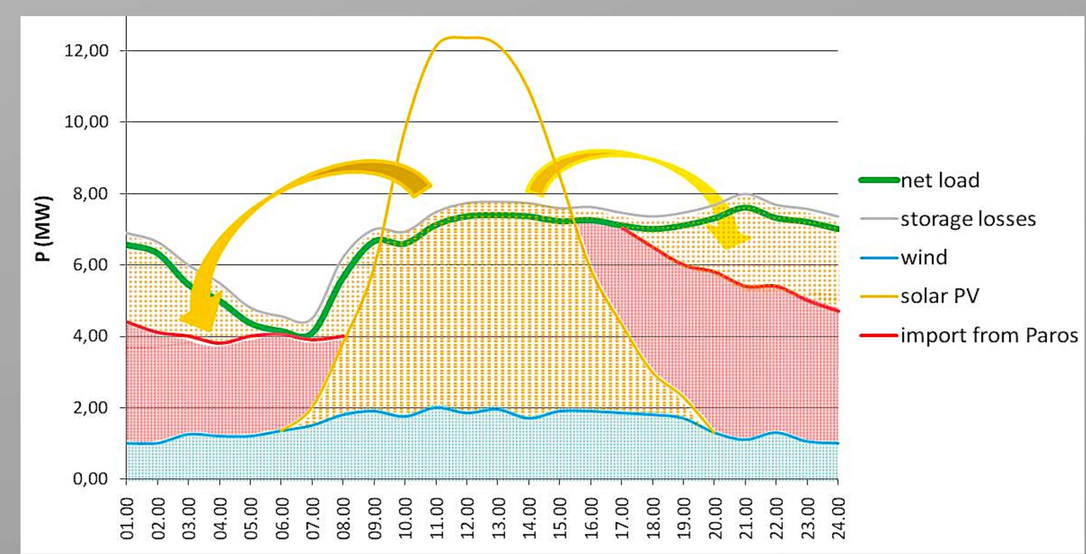


Fig. 6: Concept of solar energy storage

Katerina Chatzivasileiadi
e-mail: ChatzivasileiadiA@cardiff.ac.uk
Welsh School of Architecture, Cardiff University

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