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Distributed or centralised renewable energy systems? Meeting the demands of the Mediterranean islands.

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Abstract
The development of renewable energy technologies in an optimum way combined with energy efficiency technologies is investigated in the Greek island Ios. The energy consumption of the building and the transport sectors in the medium term have been estimated for a baseline and a sustainable future scenario. The transformation of the oil based transport to electricity powered one has been performed. Investigation on potential renewable energy systems based on solar and wind technologies and possible ways of their arrangement has been carried out. It is concluded that a viable combination of distributed and centralized RES systems with appropriate storage facilities constitutes the optimum solution. Ios island could then act as an exemplar of sustainable development for similar initiatives in other islands of the Mediterranean.

Keywords: island, RES, centralized, distributed, stand-alone

1. Aims and introduction

The energy sector is entering a new era towards sustainable energy systems. Renewable energy technologies through the exploitation of the local natural energy resources, combined with energy efficient technologies and other techniques, can contribute to the substantial reduction of greenhouse gas emissions and assure sustainable energy supply (EC 2009). Moreover, such systems help to hedge volatile energy prices and establish security of energy supply towards a stable and sustainable development.

The principal aim of the study is to assess the transformation of the conventional energy supply system of a Greek island to a sustainable system of zero emissions. Further objective to this end is the potential design of a complete energy system by renewable energy sources to cover the total energy demand in the buildings and transport sectors of the island with projection to the future.

The investigation is carried out for Ios island of the Cyclades complex, in Greece. The research work has produced a methodology that allows us to produce results suggesting the most efficient and advantageous renewable energy technologies, distributed or centralized, or a combination between them. The study is carried out in a way to be able to be used for implementation of a pilot or demonstration plant in a second stage, as well as in similar projects in the Mediterranean islands and other regions.

2. Methodology

The island system is assumed to include all the energy-related processes, interactions and activities that take place in the island within its sea boundaries. Two alternative futures or "scenarios" that may occur in the next 10 years are explored. In the first future, called "baseline" scenario, the "business as usual" approach is taken into consideration. The other scenario relates to a sustainable future. The building and the transport sectors of this future are powered by RES to meet their energy demands, while energy efficient techniques and technologies are integrated to buildings.

The first step of the research is to assess the energy demands for the building and the transport sectors of Ios in the next 10 years, transforming both oil-based sectors to RES based ones. Then, the potential renewable energy technologies to meet the demands are investigated and the most advantageous ones for each type of use are selected. The study carries on with the analysis of a RES energy system, indicating the share of each technology on the total energy demand. Finally, the sizing of the RES electricity system is provided and its arrangement on the island is elaborated. Storage techniques are also briefly discussed.

3. Energy demand in Ios in the next ten years

Electricity is currently the main energy carrier of Ios and is associated with buildings. It is followed by oil in the transport sector. Solar, wind and biomass, currently provide a small contribution to the island's energy needs. Although solar energy is abundant and well corresponding to the energy demands, only a small part of the domestic hot water (DHW) needs and heat demands are covered by solar thermal collectors and biomass correspondingly. A part of the electricity demand on the island, about 18% (1.16MW), is covered by wind energy at present, while no electricity is generated by solar PV.

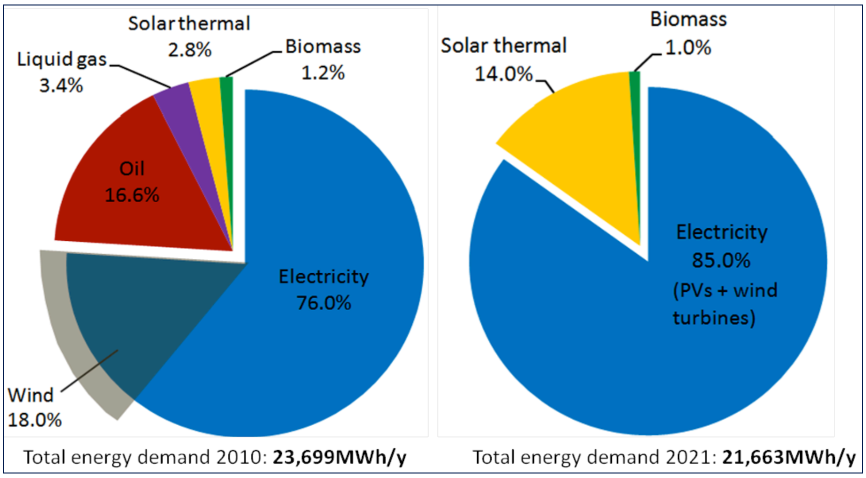

Figure 1: Energy consumption by energy carriers in 2010 and 2021 (100% RES) for the building sector in Ios island. In the baseline scenario the energy consumption is estimated to 30,457MWh/y with the same structure as in 2010.

Electricity presents high demands in summer for the building sector. The total annual demand for 2010 is 18,052MWh and the peak demand is about 7MW in the middle of August. Due to the high potential for improvement of energy efficiency in buildings, the methodology used in this paper assumes improvements in global energy efficiency of at least 25% in the medium term, while an increase in energy demand of about 26% above the figures of 2010 is assumed to occur over the 10-year period.

This increase is based on energy use projections taken from the island of Paros, which currently supplies Ios with diesel oil (Katsikeas and Dimeas 2011).

Space heating and cooling demands during the year are assumed to be covered by using electrically driven ground-coupled heat pumps (GSHP) or seawater-source heat pumps (WSHP) in 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 buildings are presented in Figure 1.

In the transport sector, for the baseline scenario, an increase of fuel consumption of about 30% above the figures of 2010 is assumed to occur over the 10-year period, according to the trends indicated by the National Energy Strategy Council (2008). In assessing the transformation of the oil based transport sector to an electricity powered one, the specific energy consumptions according to local conditions are introduced for the estimation of travel distances and electricity demands, as follows (Emandi 2011):

- For cars, fuel consumption 12lt/100km,
- For lorries, fuel consumption 20lt/100km,
- For electrical vehicles/cars 18kWh/100km, storage efficiency 95%,
- For electrical vehicles/lorries 40kWh/100km, storage efficiency 95%

On this basis, the electricity demand for the transport sector in the future sustainable scenario has been estimated. We can see that far less electrical energy in kWh is required to travel the same distance as by oil. For the transformation of fuel litres to kWh, the factors 10.35kWh/lt for diesel oil and 9.35kWh/lt for gasoline are used (Carbon Trust 2011). The results for the building and transport sectors for the baseline and future sustainable scenarios by 2021 are presented in Figure 2.

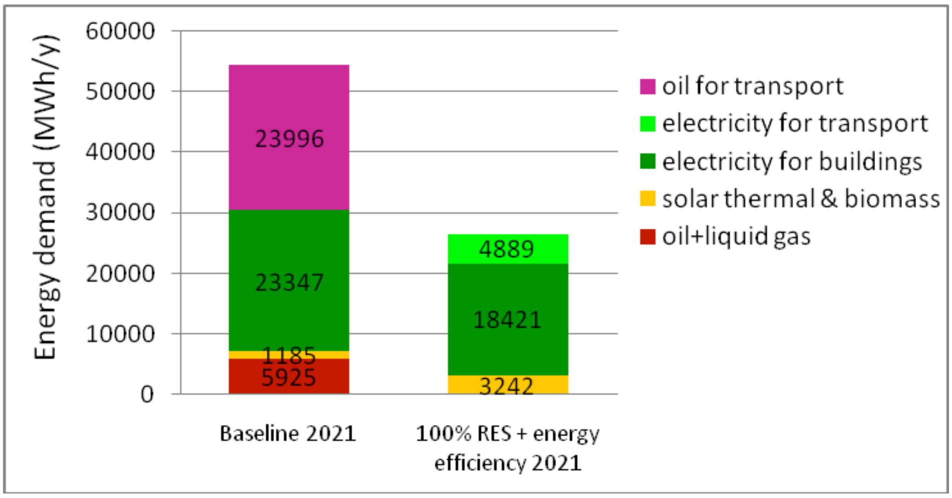

Figure 2: Energy demand by energy sources for the baseline scenario and the 100% RES and energy efficiency scenario by 2021 in Ios island.

Even though the overall energy consumption will have increased in ten years' time, the electricity demand profile for the 100% RES scenario is assumed to follow the energy profile presented in Figure 3, which is based on current consumption by month. The extremely high demand in August and July must be pointed out.

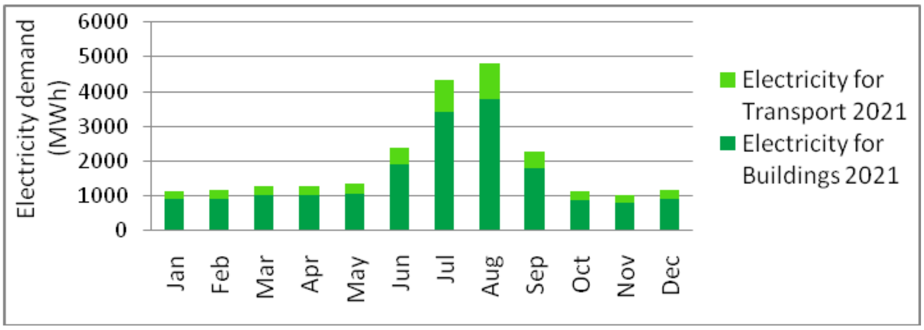

Figure 3: Monthly values of electricity demand by 2021 for buildings and transport for the 100% RES scenario and energy efficiency improvements (in total 23,310MWh/y)

4. Critical discussion on solar thermal, GSHP, wind and PV systems

The abundant solar radiation in Greece is a really motivating factor for solar power 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). Another advantage of such systems is the long lifetime of the equipment without O&M expenses. On the other hand, as this technology depends on the availability of the sun, supplementary heat production may be needed for some winter days.

With reference to the GSHP systems, they have relatively high total efficiency in winter, compared to the solar collectors. So, a concept would be to use only GSHP powered by PVs instead of installing solar collectors for the preparation of DHW all the year round. By adopting this solution, only one system is required to meet the space heating/cooling and DHW demands. However, more PVs would be needed to supply the GSHP with the extra load required for the DHW production in winter. Furthermore, the GSHP installation relates to high costs and O&M expenses. This also decreases the reliability of the system, as the building would depend on one system only to cover all the demands. It seems that the introduction of both solar collectors for DHW production and GSHP for space heating/cooling constitutes a more sustainable approach.

As regards electricity generation, solar energy, compared to wind energy, corresponds in a better way to the annual load profile of the island. Nonetheless, solar and wind are rather complementary energy sources (day and night), so a combination of the two seems to be beneficial in terms of generating electricity on a 24-hour basis.

5. Analysis of a sustainable energy system by RES and results

Based on the above, advanced GSHP or WSHP for coastal areas of high performance (COP>4) powered by RES electricity are assumed for space heating and cooling, and partially for DHW production in winter days. A small contribution from biomass will continue.

The ultimate target by 2021 is to cover nearly 100% of the energy demand for DHW by solar collectors, in the existing buildings and the new ones to be constructed by 2021. According to Weiss et. al (2007), the average annual energy yield for Greece is 525kWh$_{th}$/m^2 of collector area per year. For Ios, located in the southern part of the country, this value is assumed to be $550kWh_{th}/m^2/y$. For the residential sector, a solar collector area of $1,807m^2$ should be installed in addition to the existing $695m^2$ to cover the energy needs for DHW. In the commercial buildings, a collector area of $2,387m^2$ is found to be required in addition to the existing $425m^2$.

In the electricity sector, an exploration was performed using linear programming (Dantzig and Thapa 2003), with the aid of a software tool based on Excel (Chatzivasileiadi 2011). Considering the total minimum installed capacity and by introducing storage losses of 10%, the most preferable power system design solution was extracted. Monthly data for the electricity demand, solar PV power generation and wind power generation were taken into account. The tool indicated that, according to the given climatic conditions, the minimum installed capacity of the RES system is 20,442kW, while PVs should hold a share of about 33.4% of that capacity and about 66.6% should correspond to the wind installed capacity. In other words, 9.9GWh/y will be produced by solar PV applications, while 38.8GWh/y will be produced by wind turbines. This configuration results to a surplus of energy production of about 23GWh/y. In terms of system sizing, the above figures correspond to a horizontal flat solar PV area of approximately $82,000m^2$ or a sloped one of about $42,000m^2$ and 21 new wind turbines of nominal capacity of 600kW each. The exploration has actually improved this basic scenario and moved further on optimizing the electricity system based on solar PV and wind, by investigating alternative scenarios with different requirements and constraints. However, this notable progression is included in another paper, as it was not possible to fit all the relevant data in this paper.

6. Arrangement of the RES electricity systems (basic scenario)

The arrangement of the systems takes into account technical, social, economic, environmental and aesthetic parameters. 21 medium size wind turbines of advanced technology (variable speed, pitch control, power electronic system) have been selected for installation close to the existing one on the mountainous site called "Pyrgos". They should face towards the direction of the prevailing winds, due NNE-NE. The wind park is far from Chora and other settlements and no visual disturbance or noise is expected to be caused. Offshore or micro wind turbines are not suggested for technical, economic, environmental, legal and aesthetic reasons (EWEA 2011).

As regards the PV modules, they should be distributed in dispersed PV systems in the urban environment and three centralised PV systems on the ground. This will result to higher reliability and lower aesthetic impact. Considering the special conditions of the traditional settlements, a capacity of 1,440kWp in 360 households and 1,200kWp in 100 commercial buildings is estimated for integration by 2021. An additional capacity of about 300kWp is estimated for integration in Municipal buildings and facilities. The remaining PV capacity of 3,888kWp should be planted on sloped mountainous areas with south orientation in the southern part of the island. The PV plants require an area of about $23,500m^2$ and will be placed at a distance of about 1m from the ground, so that they serve stock-raising activities at the same time. 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.

Distributed storage with batteries in each household or using the battery pack of the electric cars (Emandi 2011), and a central storage of advanced technology - chemical or pump storage- seems to be the best combination for the electricity system. The flexibility of the demand and advanced control strategies for the management of the system are considered and the introduction of weather forecasting models as well.

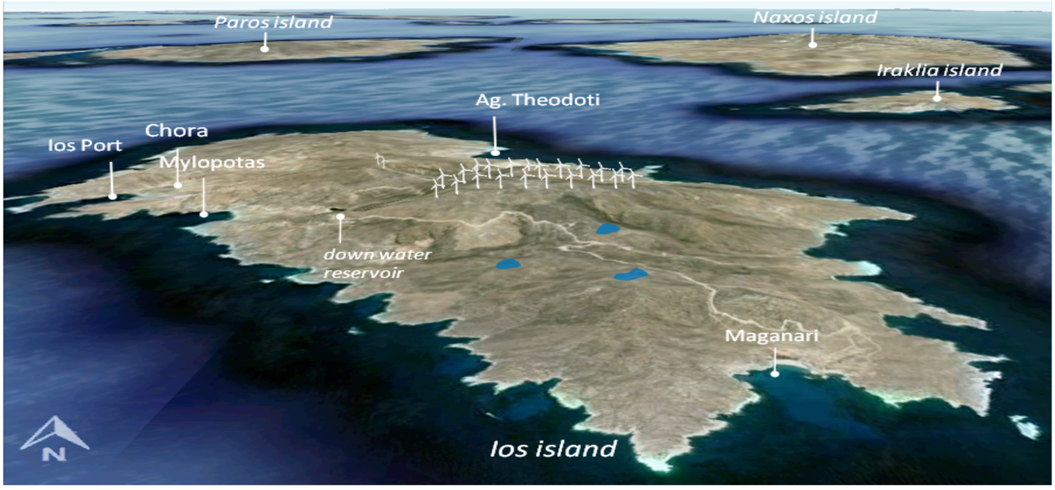

Figure 4: Overview of wind and solar PV (blue) applications in Ios island (basic scenario)

7. Conclusions

The proposed energy system by RES for Ios island differs substantially from its current energy supply scheme in terms of concept, but also from a social, economic and environmental perspective. The results show that the target of 100% RES in a Mediterranean island, so that it is rendered zero emission island, is by far realistic and can lead to huge benefits; local, regional and global. The results, as the study progresses on the next paper, are even more remarkable. Ios could absolutely be the pioneering island that would act as an exemplar for sustainable development.

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