European Geosciences Union General Assembly 2017
Vienna, Austria, 23-28 April 2017
ERE3.7/HS5.11 - Renewable energy and environmental systems: modelling, control and management for a sustainable future

Creating the electric energy mix of a non-connected Aegean island

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ABSTRACT

As the electric energy in the non-connected islands is mainly produced by oil-fueled power plants, the unit cost is extremely high. In this paper the various energy resources are examined in order to create the appropriate electric energy mix for a non-connected Aegean island. All energy resources (renewable and fossil fuels) are examined and each one is evaluated using technical, environmental and economic criteria. Finally the most appropriate energy resources are simulated considering the corresponding energy works. Special emphasis is given to the use of biomass and the possibility of replacing (even partially) the existing oil-fueled power plant. Finally, a synthesis of various energy resources is presented that satisfies the electric energy demand considering the base and peak electric loads of the island.

WARNING. Astypalaia is a beautiful and peaceful Aegean island. Today the electric energy demand is satisfied by an oil-fueled thermal station. All situations that are examined in this research are **fictional** and serve only **educational** purposes. The data that are used are plausible but the proposed cases have not been evaluated in terms of financial, social, and geopolitical aspects.

1. STUDY AREA

Astypalaia island,
Aegean sea, Greece
Population: 1334
Area: 96.9 km²
Visitors per year: 20000

History

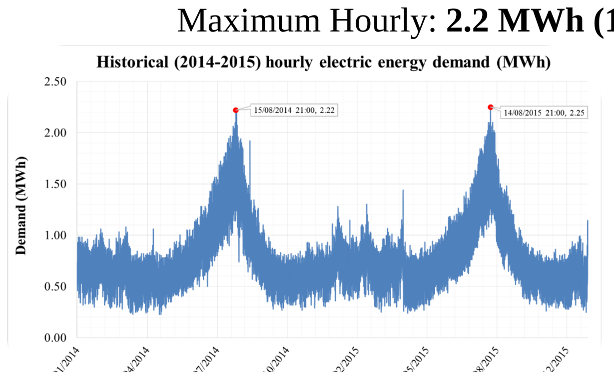
- The name Astypalaia in Greek means "old city" and is related to the fact that the settlement was located always at the same place.
- According to Thucydides, the island was inhabited by Carians (3rd millennium BC) and later by Minoans (2nd millennium BC).
- During the historical period (1st millennium BC), the island was inhabited by Megarians and Dorians. In that period it became an important member of the Athenian Confederacy.
- During the Roman period, Astypalaia had great autonomy (civitas foederata).
- In 1996, during the excavations in Kylindra, the largest child and infant cemetery in the world, was found. Cermic pots and skeletal remains reveal that the cemetery hosted infants from the Mediterranean area and it operated continuously from the Archaic to the Classical period.

Mean annual climatological values

Precipitation: **680 mm** Temperature: **19.2 °C** Wind Velocity: **5.6 m/s**
Solar Radiation: **203 W/m²** Relative Humidity: **70%**

Electric energy demand characteristics

[calculated from 2 years hourly data (2014-2015)]
Mean Annual: **6250 MWh** Minimum Hourly: **0.23 MWh**
Maximum Hourly: **2.2 MWh (14/8/2015 21.00)**

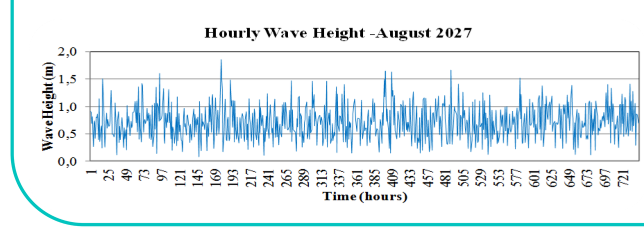


For the electric energy system simulation:
(a) Koskinas et al. (2017--this session) studied the cross correlations of several variables,
(b) Hadjimitsis et al. (2017--this session), generated and evaluated 100 years of synthetic hourly electric demand.

2. RENEWABLE ENERGY RESOURCES

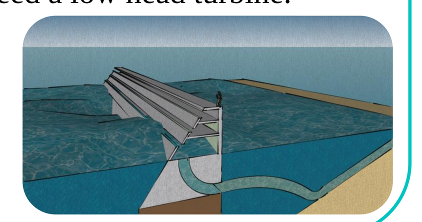
Marine

Moschos et al. (2017--this session) generated and evaluated 100 years of synthetic hourly wave height and produced electric energy. Below is the diagram for one month:



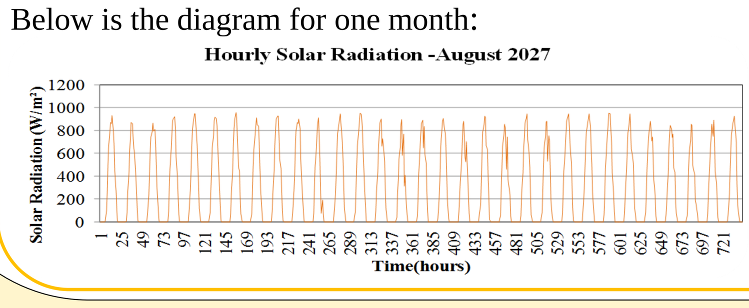
Overtopping Wave Energy Converters produce energy collecting the incoming waves through overtopping and wave run-up into deposit reservoirs, and using the water to feed a low head turbine.

A **0.3 MW** power machine is proposed:
Expected electric energy≈**0.835 GWh**
Capacity factor: **0.32**



Solar

Koudouris et al. (2017--this session) generated and evaluated 100 years of synthetic hourly solar radiation. Below is the diagram for one month:



The features of proposed photovoltaic plant are:
Power: 0.1 MW
Total area of panels: 754 m²
Total area of plant: 11000 m²
Panel efficiency: 13.4%

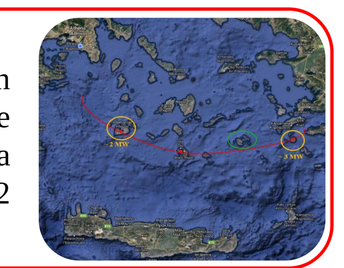
Expected electric energy per plant≈**162 MWh/y**
Capacity factor: **0.16**

Hydro

There is a dam located at Livadi area with the following features: Height: 32 m, Reservoir volume: 875.000 m³, Watershed area: 8 km², Mean annual inflow: 480 000 m³ (60 mm). According to *Papoulakos et al. (2017—this session)*, a turbine of **0.08 MW** is proposed on the existing dam to produce≈**25 MWh/y**.

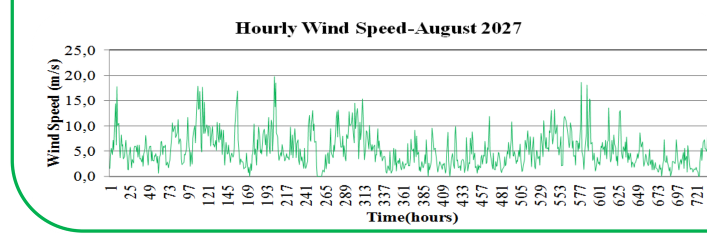
Geothermal

Astypalaia is located at the Volcanic Arc of southern Aegean Sea. Although no measurements have been implemented, we assume that there is an exploitable geothermal field with a minimum power of 0.5 MW. In Milos and Nisyros plants of 2 and 3 MW respectively have the potential to be installed.

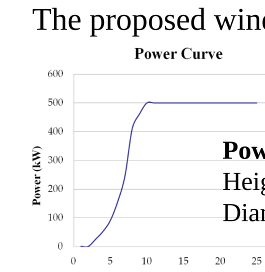


Wind

Moschos et al. (2017--this session) generated and evaluated 100 years of synthetic hourly wind speed. Below is the diagram for one month:



The proposed wind turbine:

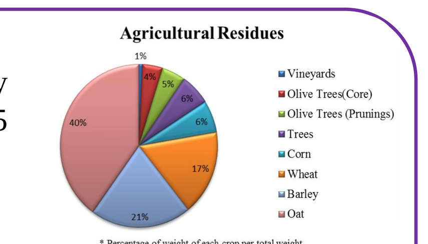


Power: 0.5 MW
Height: 75 m
Diameter: 54 m

Expected electric energy per turbine≈**2233 MWh/y**
Capacity factor: 0.5

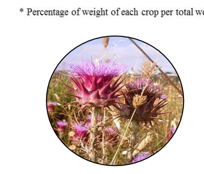
Biomass

Exploitation of **existing** 50 ha that produce 100 t/y agricultural residues with a mean calorific value 18.5 MJ/kg
Expected electric energy≈**190 MWh/y**



Exploitation of **cultivated** energy crops.
100 ha produce 1000 t/y with calorific value 18 MJ/kg
Expected electric energy per 100 ha≈**1750 MWh/y**

Biomass Power Stations of 1 MW are proposed considering efficiency of 0.35



Energy crops (Cynara Cardunculus)

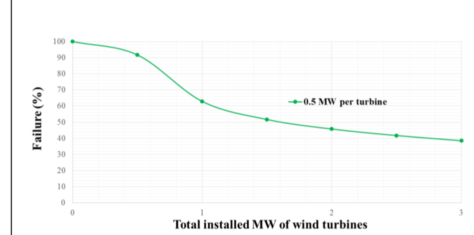
3. SIMULATION OF ENERGY SYSTEM

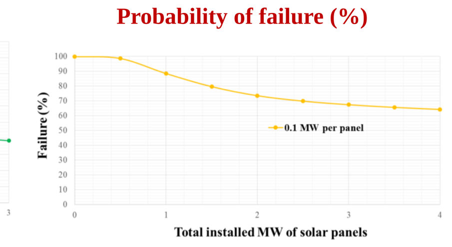
3.1. Exploration of weather related renewables

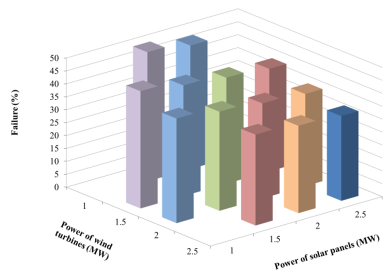
The energy system is simulated in hourly basis for a 100 years period. Several combinations of renewable resources are examined. For each electric energy mix the following are calculated : (a) probability of failure to satisfy the peak hourly energy demand, (b) mean annual deficit of energy, (c) mean annual surplus of energy

Wind **Solar** **Combination**

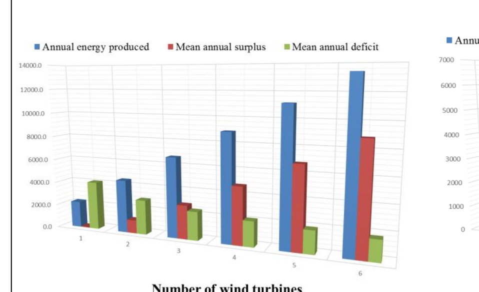
Probability of failure (%)

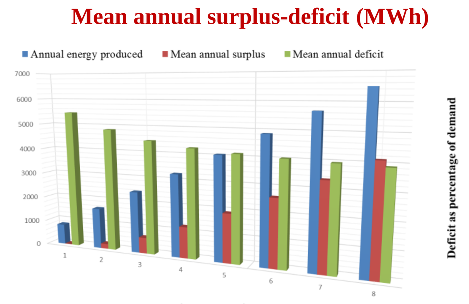




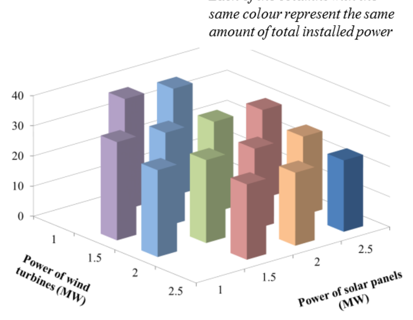


Mean annual surplus-deficit (MWh)

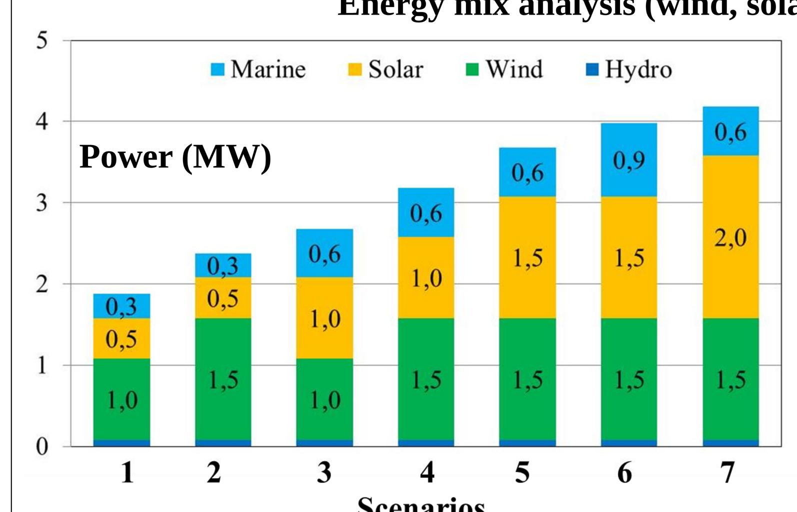


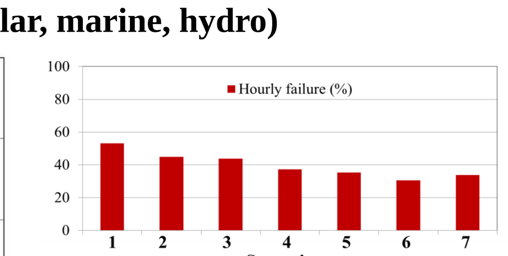


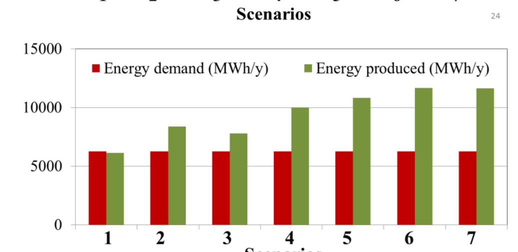
Each of the columns with the same colour represent the same amount of total installed power



Energy mix analysis (wind, solar, marine, hydro)





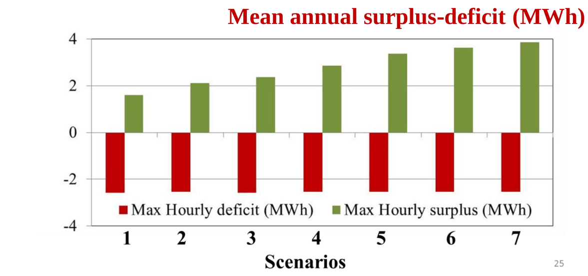


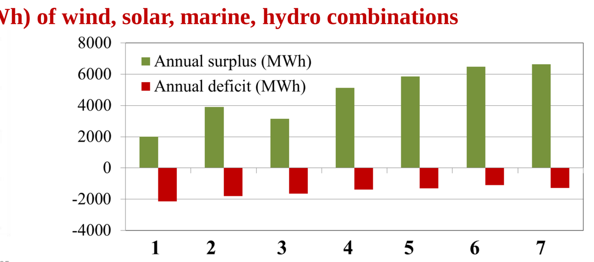
Comment 1: The use of weather related renewable resources results in high values of: (a) probability of failure, (b) mean annual deficit, (c) mean annual surplus

3.2. Adding controllable renewables

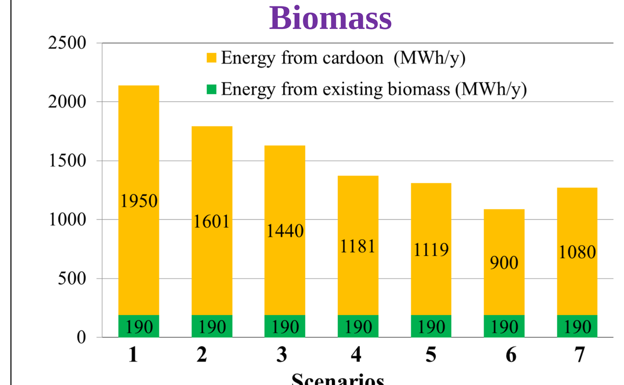
Controllable renewables (biomass, geothermal) are added to provide
(a) installed power (2.6 MW) in order to satisfy the peak hourly deficit,
(b) additional energy to cover the annual deficits (1-2 GWh) and
(c) management of surplus energy (2-6 GWh)

Mean annual surplus-deficit (MWh) of wind, solar, marine, hydro combinations

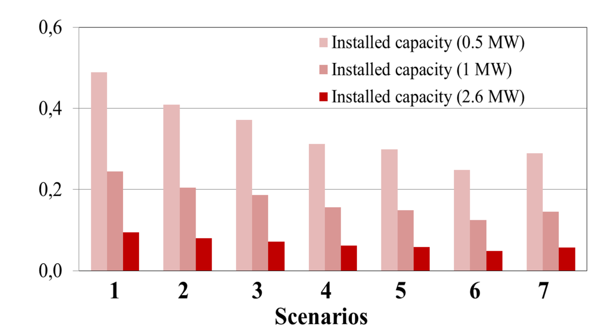




Biomass



Geothermal



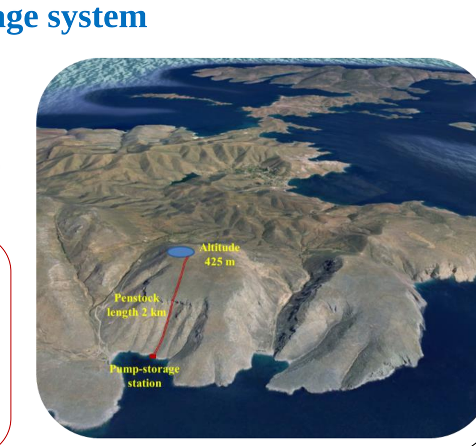
In all scenarios there is a requirement for cultivation of energy plants. The necessary cultivation area is about 50-110 ha.

In case that a geothermal field (capable of electric energy production) exists, it will operate with a small capacity factor.

Comment 2: The use of controllable renewable resources could satisfy the peak hourly and the annual deficit, but the amount of surplus energy is still a significant factor.

Sea water pumped-storage system

A pumped-storage system, that uses sea water to store energy, is considered. The available net head is 400 m and the efficiency of pumped-storage cycle is 75% . The reservoir volume and the installed power of hydro-turbine will be decided after optimization.



Comment 3: The use of pumped-storage is a convenient way to store electric energy surplus from other resources. The existence of a reservoir also contributes to the satisfaction of peak deficits.

3.3. Towards an energy mix

Case 1. There is a geothermal field that supports a power of 0.5 MW

1. Start with Geothermal: 0.5 MW

2. Add the energy mix of scenario 1
Marine: 0.3 MW Solar: 0.5 MW Wind: 1 MW Hydro: 0.08 MW

3. Simulation results Probability of failure: 19.7% Annual deficit: 487 MWh

4. Add Biomass: 2.1 MW Existing biomass: 190 MWh/y
Energy plant cultivations needed: 17 ha

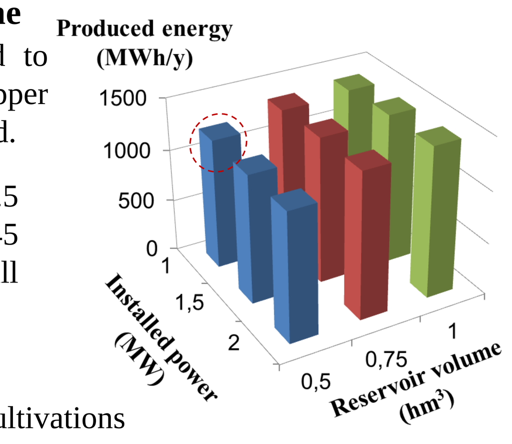
Total installed power: 4.5 MW

Case 2. There is no geothermal field

1. Start with the energy mix of scenario 1 plus a 0.3 MW marine project
Marine: 0.6 MW Solar: 0.5 MW Wind: 1 MW Hydro: 0.08 MW

2. Simulation results Probability of failure: 47.5%
Annual deficit: 1758 MWh Annual surplus: 2464 MWh

3. Considering a pumped-storage scheme
The pumped-storage system was simulated to calculate the energy production for various upper reservoir volumes and hydro turbines installed.



A scheme of 1 MW hydro-turbine and a 0.5 hm³ upper reservoir volume will produce 1245 MW/y (70% of the surplus) but there will still be a deficit of 513 MWh/y

4. Add Biomass: 1.6 MW
Existing biomass: 190 MWh/y
Energy plant cultivations required: 18 ha

Total installed power: 4.8 MW

Comment 4: Theoretically, the energy demand of the island could be satisfied using only renewable resources, but financial, environmental and sociological factors must thoroughly be examined.

4. DISCUSSION

In this research the **six renewable energy resources** were examined to create the electric energy mix of a non-connected small island. The common advantage is the **free and renewable fuel**. The energy production of **weather related resources** (wind, solar, marine, hydro) is completely **uncontrollable** and does not synchronize with demand. In the case of hydro energy, the use of reservoirs can control the production but also store the energy of other resources through pump-storage schemes. The other two resources (biomass, geothermal) are subject **to regulation** and therefore, capable of satisfying the peak electric energy demand. In the case of biomass, the fuel must be collected and transported before its use and in the case of geothermal the necessary high enthalpy geothermal fields are located at few places in the world.

	Case 1	Case 2	Estimated cost (M€/MW)
Source	Power (MW)	Power (MW)	
Wind turbine	1	1	1,5-2
Solar panels	0,5	0,5	2-3
Hydroelectric dam	0,08	0,08	1
Wave energy converters	0,3	0,6	3-4
Geothermal power station	0,5		1-2
Pumped-storage system		1	1,5-2
Biomass power station	2,1	1,6	2-3
Total	**4,5**	**4,8**	

Let's imagine the implementation of **Case 2** on the island. The plan includes **2 wind turbines** of 75 m height, **3800 m² of photovoltaic panels**, **2 wave converter** installations, **a small hydro turbine** on the existing dam, a **biomass installation** that must be fed with **180 t/y** of cultivated biomass, and a pumped-storage system that includes a **reservoir with a 0.5 hm³** volume, a **2 km penstock** and a hydro turbine installation. The total installed power of the system will be **4.8 MW and the total cost will be much more than 10 M€.**

On the other hand, the energy demand (peak and annual) of the island could be easily covered by a common **thermal station with installed power less than 3 MW.** The quantity of fossil fuel that must be burned to cover the annual electric energy demand is estimated to be about **1300 toe** (tons of oil equivalent) per year. In case that the fuel is oil, the estimated annual cost is about **0.5 M€. Let's imagine** that on the island there is a small **coal deposit** with the **volume of a small hill (200X200X50 m)**. In that case the specific deposit would feed the thermal station for about **1000 years**.

The decision of the energy mix must be taken after consideration of financial, environmental and sociological issues. The examined solutions have high demand of financial and organisational resources and therefore it is reasonable that thermal stations that are fed with oil, are broadly used on non-connected islands (*Roussis et al. (2017--this session)*.

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Acknowledgement: This research is conducted within the frame of the undergraduate course "Stochastic Methods in Water Resources" of the National Technical University of Athens. The School of Civil Engineering provided moral support for the participation of the students in the Assembly.