European Geosciences Union General Assembly 2017

ERE3.7/HS5.11: Renewable energy and environmental systems: modelling, control and management for a sustainable future

The uncertainty of atmospheric processes in planning a hybrid renewable energy system for a non-connected island

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Who is who

Twenty undergraduate students formed **eight groups** collaborating with each other to deal with the research challenges of a real-world energy management problem.

Research conducted **voluntarily** and out of scientific curiosity in the framework of the **Stochastic methods in Water Resources course.**

The instructors of the course, as well as other PhD students and staff members of the Itia research team were the advisors of the student groups (names shown in the title page).

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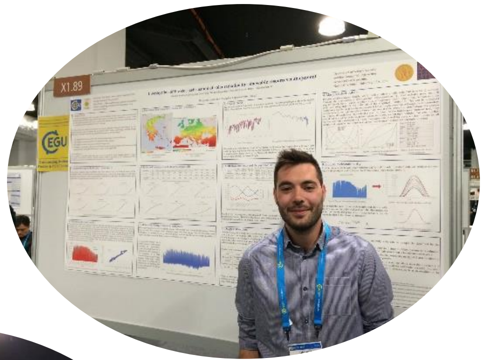
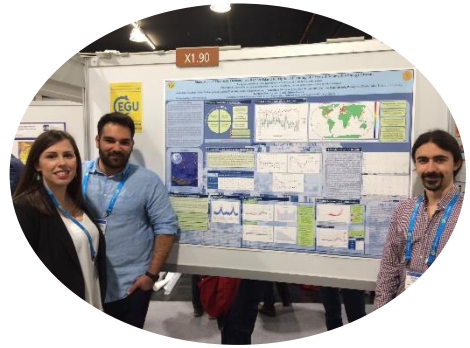
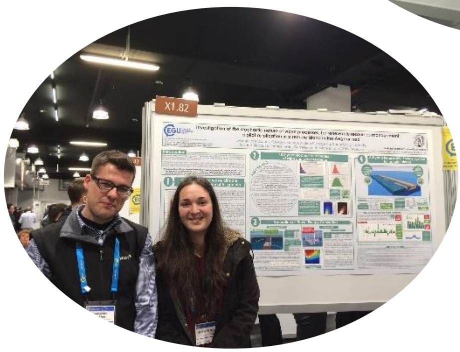
…the posters produced by the eight groups!

solar energy

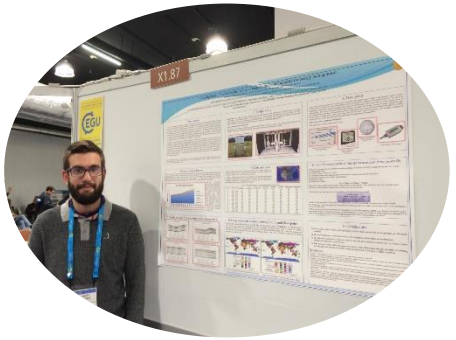




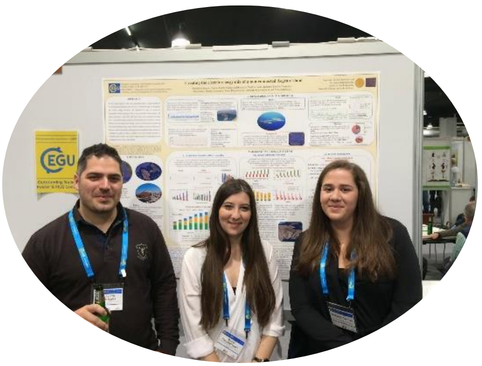
cross correlations ***and*** *energy demand*



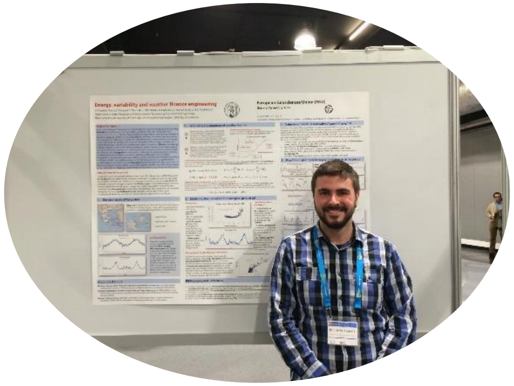
wave energy



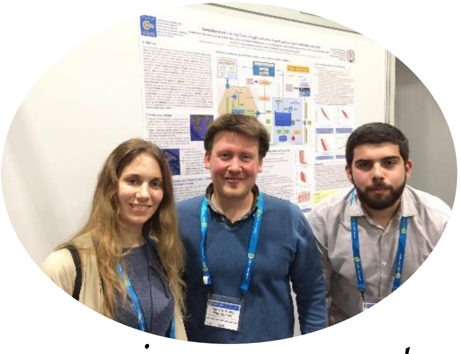
temperature and humidity



energy mix



weather derivatives



reservoir management

Motivation

- Uncertainty dominates natural processes and propagates into the management of weather-related Renewable Resources systems.
- Uncertainty is also present in energy demand, which is, in turn, also affected by hydrometeorological variability.
- Effective planning of a Renewable Energy Sources System under increased uncertainty and complexity of the processes involved requires a stochastic approach.
- Non-connected islands, such as remote Aegean islands, face energy deficit problems throughout the year and depend on costly shipping of fossil fuels.
- Is green energy autonomy in a small area a feasible goal in scientific and technological terms?

Case study area

Astypalaia island,

Aegean sea, Greece

Population: 1334

Area: 96.9 km^2

Visitors per year: 20 000

Mean annual hydroclimatic values

Precipitation: 680 mm

Temperature: 19.2 °C

Wind Velocity: 5.6 m/s

Solar Radiation: 203 W/m^2

Relative Humidity: 70%

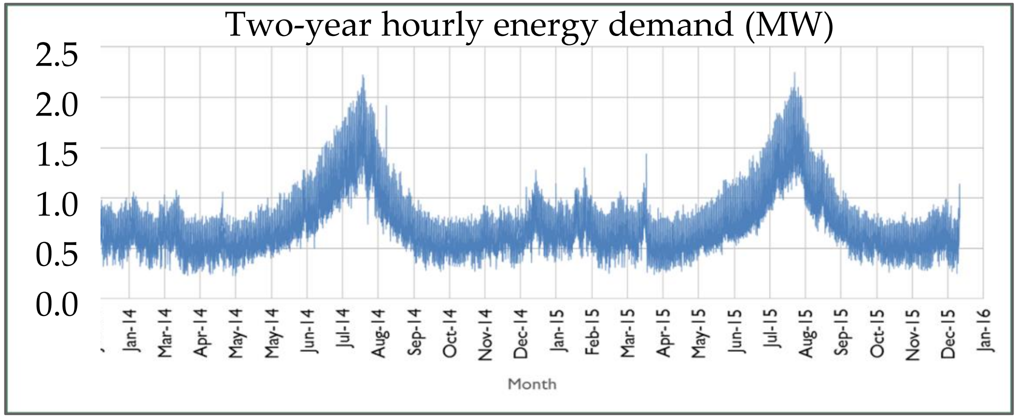
Stochastic modelling

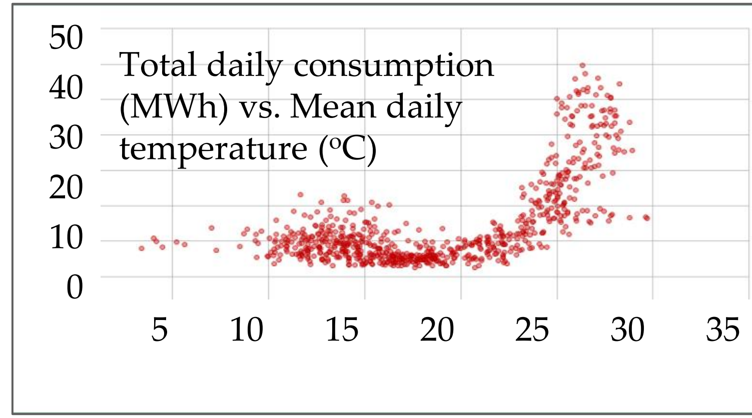
- Treating hydrometeorological variables **as stochastic processes** with deterministic components: **wind speed**, **solar irradiation**, **temperature** and **dew point** (for **energy demand**), **precipitation** and **rainfall-runoff** (for hydroelectric power plants to balance water-energy demand).
- Preservation of **cross-correlations** among hydrometeorological processes.
- Preservation of **double periodicity** (cyclostationarity).
- Preservation of **marginal distributions**.
- Preservation of **autocorrelation functions** (Hurst-Kolmogorov behaviour).
- Preservation of **intermittent behaviour** (such as probability of low/zero values).

Stochastic synthesis via **CASTALIA** open-software

www.itia.ntua.gr/en/softinfo/2/

Energy demand and cross-correlations among processes





Cross-correlations and validation via Monte Carlo analysis						
For more information see in [1]	**Rain-Temp**	**Rain-Wind**	**Rain-Dew**	**Temp-Wind**	**Temp-Dew**	**Wind-Dew**
Samos-Kos	0.5	-0.3	0.4	-0.2	0.6	-0.3
Heraklion-Santorini	0.0	0.3	0.1	-0.4	0.5	-0.5
Chania-Santorini	0.1	-0.3	-0.1	-0.3	0.5	-0.4

In the absence of meteorological stations at the exact location, we estimate the

(a) diurnal and seasonal periodicity of temperature and dew point

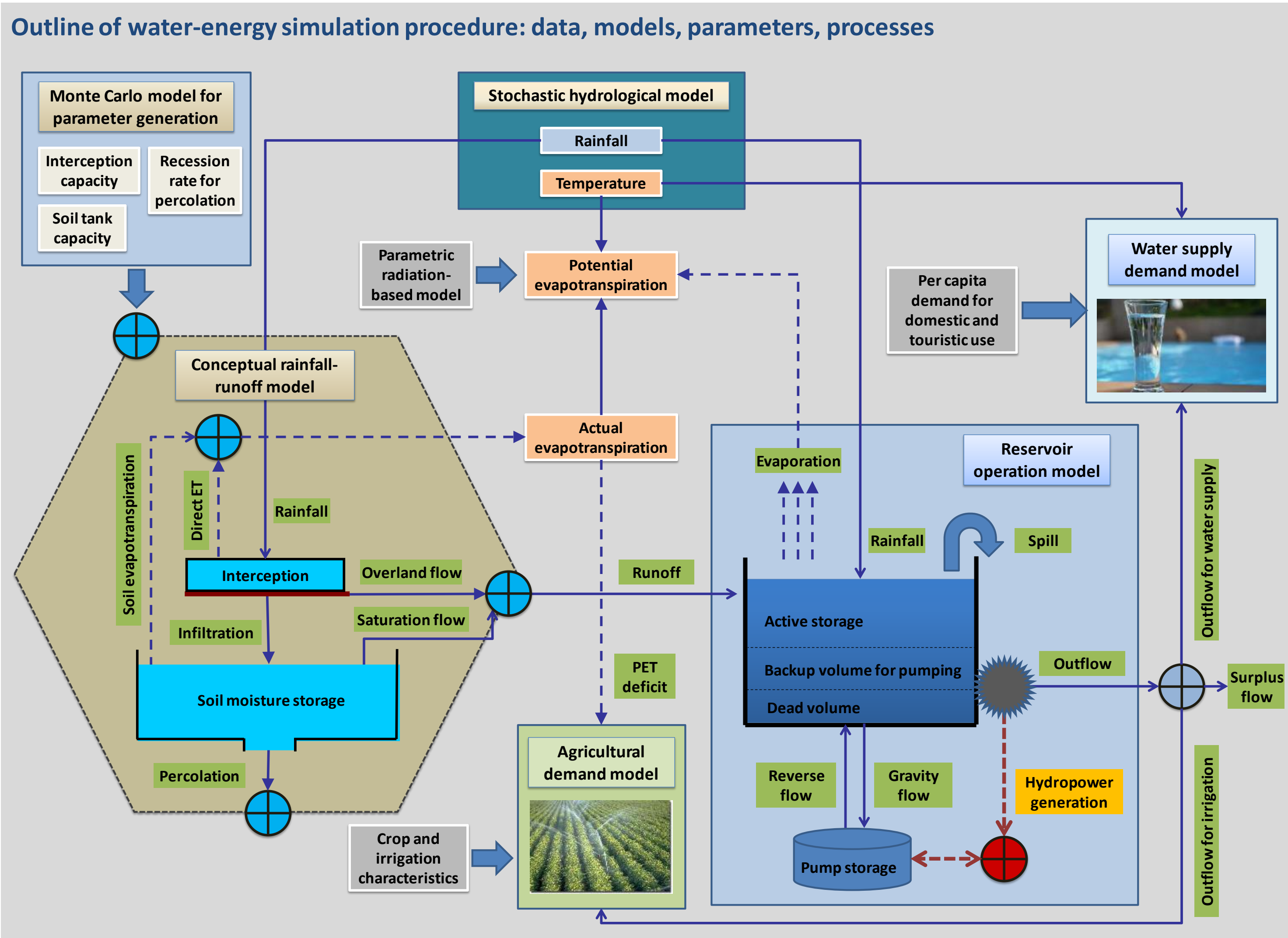
(b) energy demand

(c) cross-correlations among all processes, from nearby stations.

For more information see in [1] and [2].

Simulation of water-energy fluxes through small-scale reservoir systems

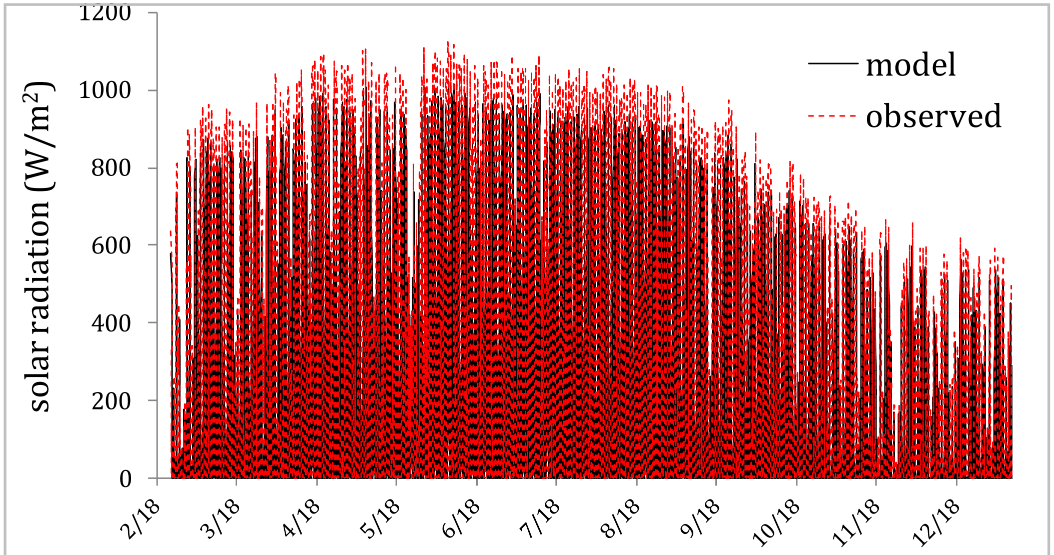
Simulation framework comprising: (a) synthetic rainfall and temperature; (b) rainfall-runoff model; (c) water supply and irrigation demands, and (d) daily operation model of the reservoir system. For more information see in [3].

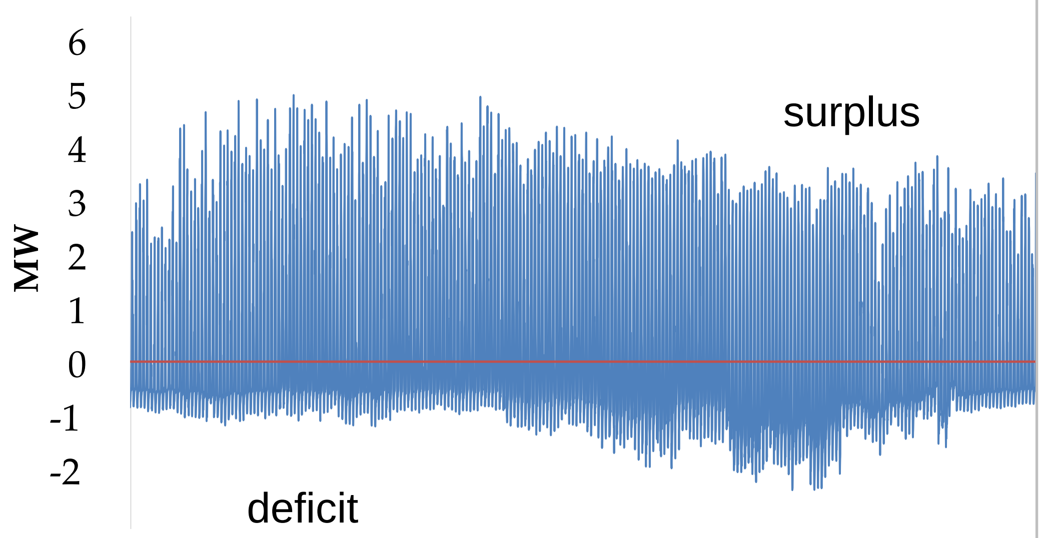


Solar power

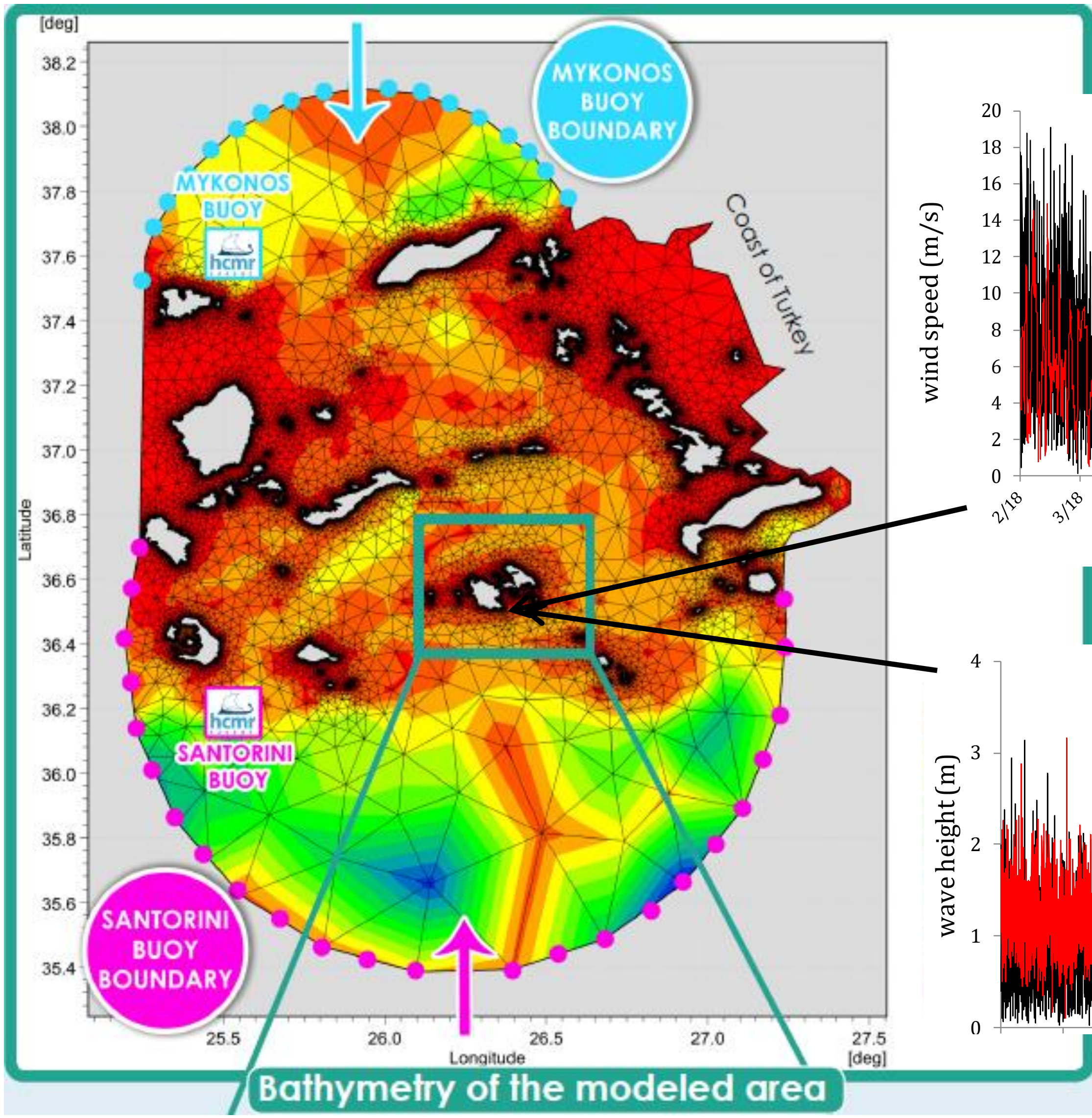
A popular solution could be to install various solar panels but this **is considered very expensive**. For example, a 5 MW installed solar energy system requires more than 23 800 solar panels of 210 W each and is expected to **fail meeting the energy demand 62.2% per year**.

For the energy surplus, we may install a **PV-Reverse osmosis (RO)** facility during autumn, winter and spring. We analyze the suggested installed capacity using 100 years hourly synthetic timeseries of solar radiance and the overall suggested system **can be paid in full after 8 years, providing more than 510 998 m³ of drinkable water per year**. For more information see in [4].

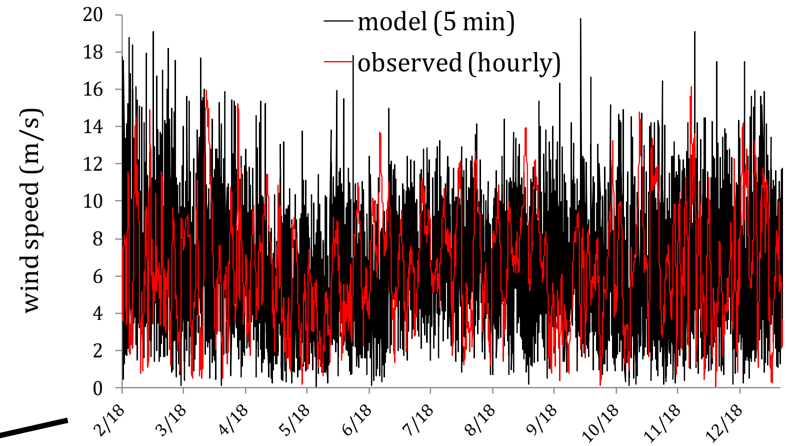


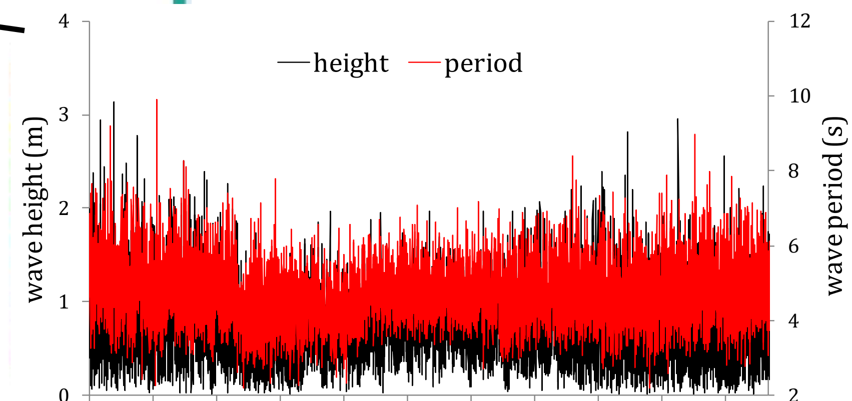


Wind and Wave power (I)



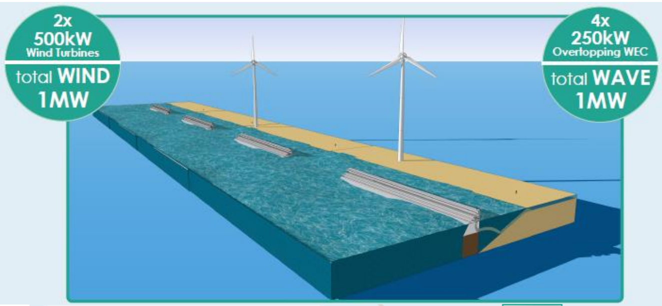
Assessment of the wave climate in Astypalaia through spectral wave numerical model MIKE 21 SW.





Observations of wind and wave height and period are obtained from nearby stations. For more information see in [5].

Wind and Wave power (II)



Brief Cost Analysis

	Wind	Wave
INSTALATION	115,000	375,000
TURBINE	840,000	180,000
FOUNDATION	50,000	40,000
GRID CONNECTION	120,000	50,000
total per item	**1,125,000** x2	**645,000** x4
PUMP		
TOTAL	**4,830,000 EURO**	

Today the island is power through a small fossil-fuel plant.

Alternatively it could be powered by a HRES, consisting of two wind-turbines and four OWECs.

Characteristics

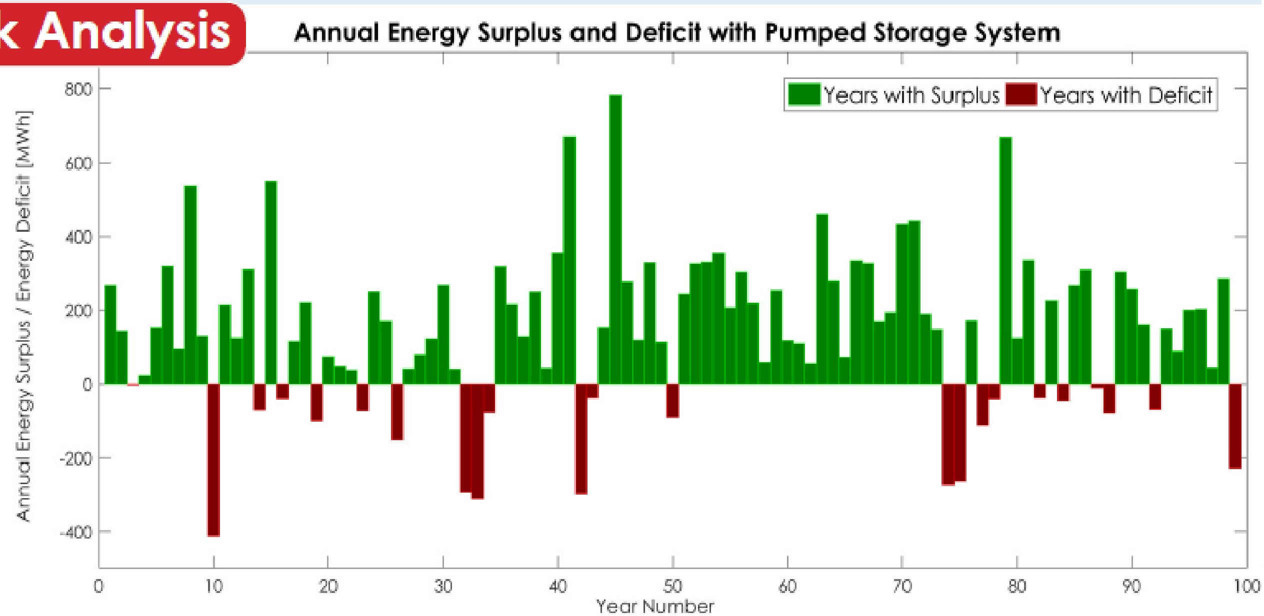
	Wind	Wave
INSTALLED CAPACITY	500kW	250kW *
HEIGHT or LENGTH	75m	125m
can store surplus	NO	YES

*One OWEC consists of five 50kW Kaplan Turbines distributed through the reservoirs

55% of days in 100 years are covered fully

A basic disadvantage of renewable sources is that they do not operate on-demand.

Risk Analysis



To cover the daily energy deficit and peak demands, surplus wave energy is collected through OWEC and is stored through a pumped storage system. For more info see in [5].

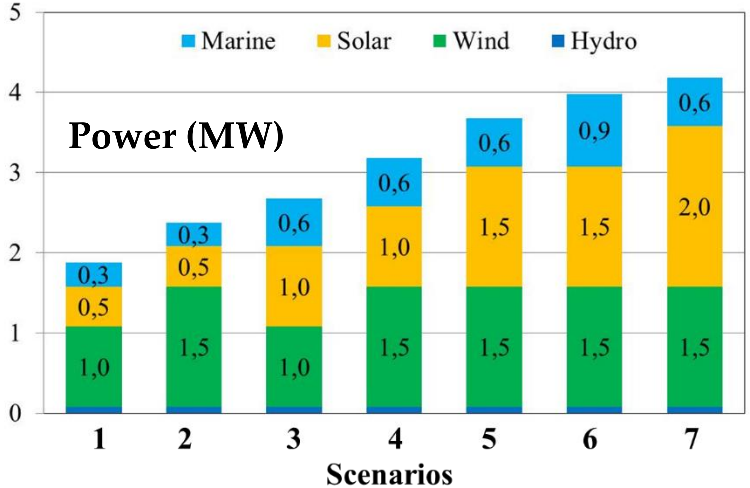
Simulation of energy system (I)

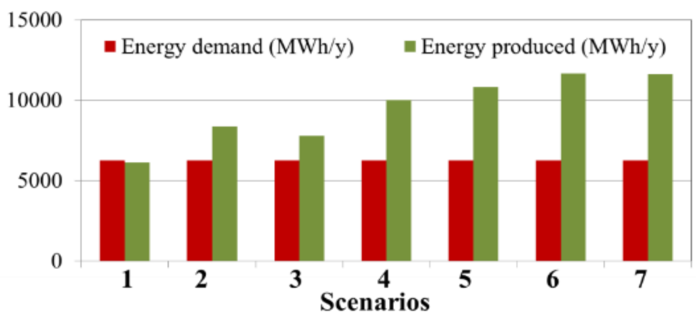
Exploration of weather related renewables

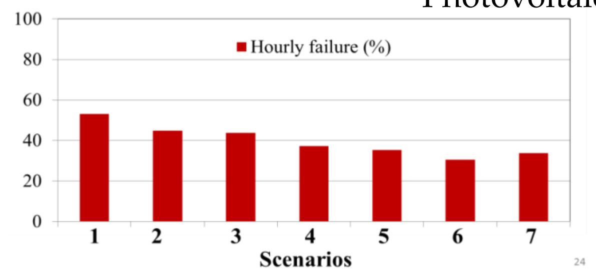
Wind, solar, marine and hydro resources are considered
Seven scenarios of energy mix are examined

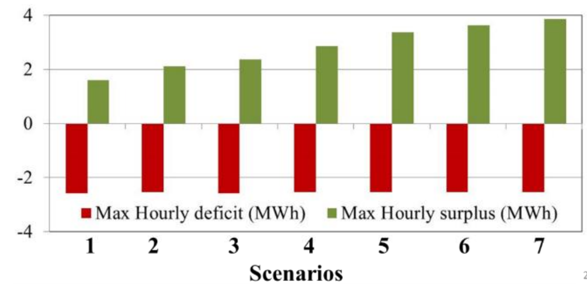
Electric energy demand
Mean Annual: 6250 MWh
Maximum Hourly: 2.6 MWh

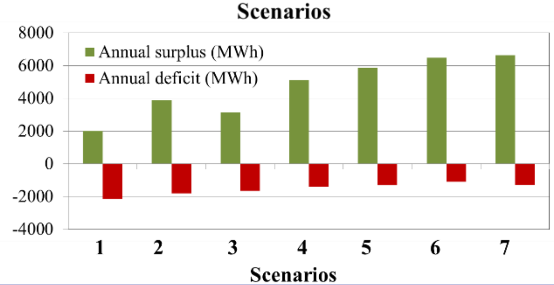
Suggested Equipment
OWEC: 0.3 MW
Wind turbine: 0.5 MW
Hydro turbine: 0.08 MW
Photovoltaic plant: 0.1 MW











Weather related renewables result in high values of:

(a)mean annual deficit
(b) mean annual surplus
(c) probability of failure

Simulation of energy system (II)

Adding controllable renewables

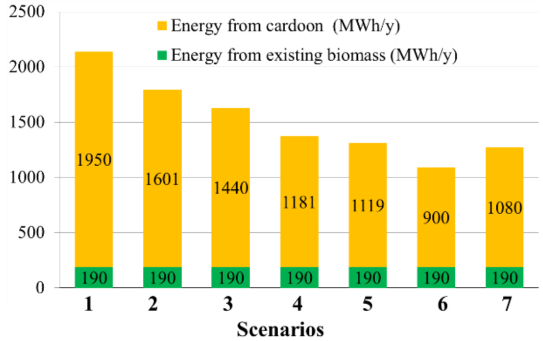
To provide **(a)** installed power (2.6 MW) covering the peak hourly demand,
(b) energy to cover the annual deficits (1-2 GWh)

Biomass

Cultivations area: 50 ha
Residues : 100 t/y
Electric energy ≈ 190 MWh/y

Cultivated energy crop (cardoon) area: 100 ha
Production: 1000 t/y per 100 ha
Mean calorific value: 18 MJ/kg
Electric energy≈ 1750 MWh/y

Power stations of 1 MW

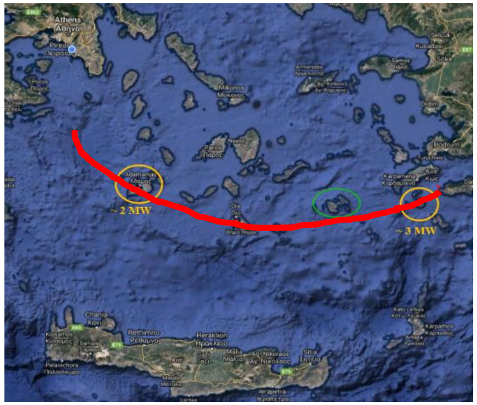


- Peak hourly and annual deficit coverage
- The amount of surplus energy still significant

Geothermal

Location of Astypalaia: Volcanic Arc of southern Aegean Sea

Measurements on nearby islands: exploitable geothermal energy field possible



Simulation of energy system (III)
Adding controllable renewables

To provide **(a)** installed power (2.6 MW) covering the peak hourly demand,
(b) energy to cover the annual deficits (1-2 GWh) and
(c) management of surplus energy (2-6 GWh)

Sea water pumped-storage system

Available net head: 400 m
Efficiency of pumped-storage cycle: 75%
Reservoir volume and hydro-turbine: after optimization

- ❖ Storage of electric energy surplus from renewable resources
- ❖ Satisfaction of peak deficits

Simulation of energy system (IV)

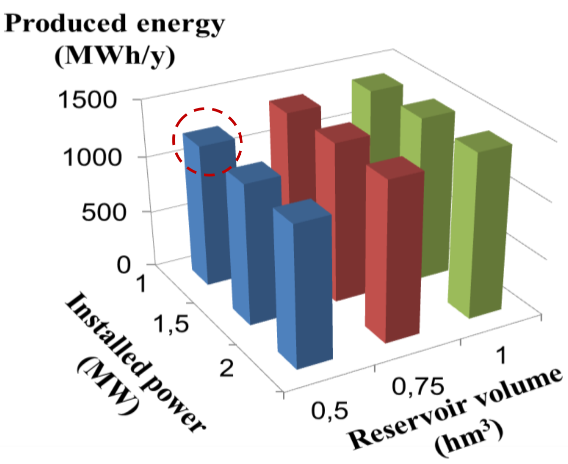
Towards an energy mix

Case 1. Weather related recourses plus geothermal and biomass

Case 2. Weather related recourses plus pumped-storage scheme and biomass

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

In both cases energy plant cultivations required: about 20 ha



In case 2:

- Pumped storage is used to manage the deficit and the surplus
- Annual deficit of 1 758 MWh and surplus of 2 464 MWh
- A scheme of 1 MW hydro-turbine and a 0.5 hm^3 upper reservoir volume will produce 1 245 MW/y (70% of the surplus) but there will still be a deficit of 513 MWh/y

Theoretically, the energy demand of the island could be satisfied using only renewable resources, but financial, environmental and sociological factors must thoroughly be examined. For example see in [6] for some ideas on weather derivatives.

Discussion

- **All six typical renewable energy resources** were examined to create the electric energy mix of a non-connected small island
  - Common advantage: **free** and **renewable**, no need for import
- The energy production of **weather related resources**: **uncontrollable** and does **not synchronize** with demand
  - The use of reservoirs can control the production but can also store the energy of other resources through pumped-storage schemes
- The **controllable resources** are subject to regulation and therefore, capable of satisfying the peak electric energy demand
- The **use of renewables** in the energy mix requires substantially increased installed power of the system and high installation cost.
  - For example in case 2:
    - The installed power of the system will be 4.8 MW (while 2.6 MW are needed).
    - The cost will be much more than 10 M€.
- The energy demand (peak and annual) of the island could be easily satisfied by a **common thermal station** with installed power less than 3 MW.
  - Disadvantage: **not renewable**, needs to be imported or mined.
- The **decision** of the energy mix must be taken after consideration of financial, environmental and societal issues.

For more information see in [7].

Thank you for your attention

Visit **www.itia.ntua.gr** for more details!

References

[1] A. Koskinas, E. Zacharopoulou, G. Pouliasis, I. Engonopoulos, K. Mavroyeoryos, E. Deligiannis, G. Karakatsanis, P. Dimitriadis, T. Iliopoulou, D. Koutsoyiannis, and H. Tyralis, Simulation of electricity demand in a remote island for optimal planning of a hybrid renewable energy system, *European Geosciences Union General Assembly 2017, Geophysical Research Abstracts, Vol. 19*, Vienna, 19, EGU2017-10495-4, European Geosciences Union, 2017.

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