Simulation of Electricity Demand in a Remote Island for Optimal Planning of a Hybrid Renewable Energy System

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INTRODUCTION

The purpose of this study is to find correlations between the variables renewable energy systems depend on, in order to better simulate the electrical energy demand in the remote island of Astypalaia, Greece.

To this end, we first obtain information regarding the local socioeconomic conditions and energy demand needs. Secondly, the available hourly demand load data are analyzed at various time scales (hourly, daily, weekly, seasonal). The cross-correlations between the electrical energy demand load and the mean daily temperature as well as other climatic variables for the same time period are computed.

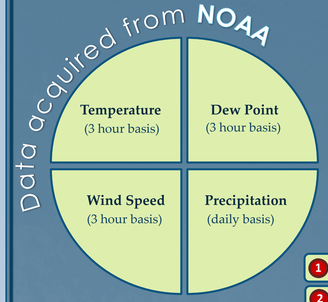
Also, we obtain data from numerous observations around the globe for various climatic variables, in order to investigate the cross-correlation between them, and assess the impact of each one on a hybrid renewable energy system. An exploratory data analysis including all variables is performed with the purpose to find hidden patterns on a yearly and monthly basis.

Finally, the demand is simulated, considering all the periodicities found in the analysis. This simulation will be used in the development of a framework for planning a hybrid renewable energy system in Astypalaia.

LOCATION

The island of Astypalaia
Aegean Sea, Greece

1.Climatic Variables Methodology



Create timeseries (annual and monthly basis)

Calculate cross-correlations

Ensure accuracy (with a data filter)

1. more than 20 years of data
2. more than 300 days/year
3. more than 25 days/month

Land Based Station Data
(https://www.ncdc.noaa.gov/data-access/land-based-station-data)

2.Global Cross-Correlations Analysis

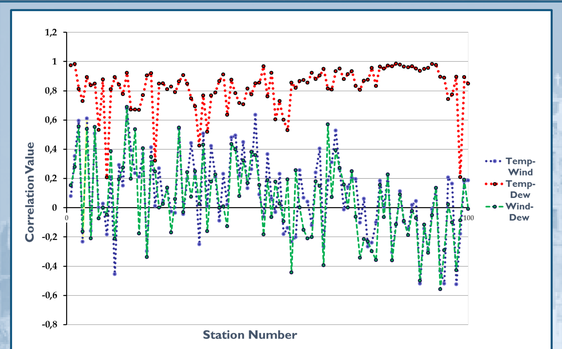
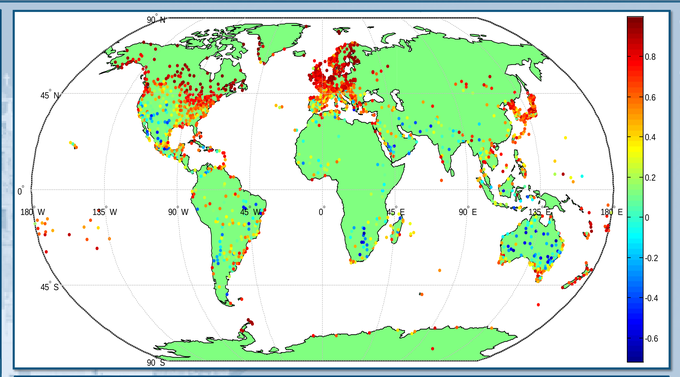


Figure 1: *Zero-lag Cross Correlations between Temperature, Wind Speed, and Dew Point (Annual basis, a sample of 100 stations)*



Map 2: *Zero-lag Cross Correlations between mean annual Temperature and Dew Point*

Strong positive correlation is the most consistent

Exception: certain areas with negative or close to zero correlation

These areas seem to be **arid** (large deviation between daily minimum and maximum temperatures)

We cross-correlated the **average temperature difference** between minimum and maximum values with their **temperature-dew point cross-correlation coefficient**. A negative relationship **(-0.4)** was calculated.

3.Astypalaia Cross-Correlations Methodology

For the example of the remote island of **Astypalaia**, in the absence of meteorological stations at the exact location, several nearby stations are analyzed. Specifically, precipitation measurements on a daily basis are taken from stations in **Samos**, **Heraklion**, and **Chania**, whereas temperature, wind speed, and dew point measurements on a three hourly basis are taken from **Santorini** and **Kos**.

Comparison of Cross Correlations						
	Rain-Temp	Rain-Wind	Rain-Dew	Temp-Wind	Temp-Dew	Wind-Dew
Samos-Kos	0,50	-0,30	0,36	-0,23	0,64	-0,28
Heraklion-Santorini	0,04	0,33	0,13	-0,35	0,54	-0,45
Chania-Santorini	0,11	-0,29	-0,10	-0,32	0,51	-0,40

Table 1: *Zero-lag cross-correlation coefficients of annual timeseries*

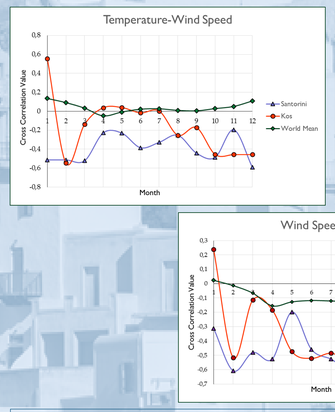


Figure 2*: Cross correlations of climatic variables from stations close to Astypalaia and the global mean on a monthly basis*

4.Validation of the Results

To examine the validity of the cross-correlations, a test is conducted using timeseries of normal random values.
Through **Monte Carlo analysis** and the **SMA** generation algorithm **[7]**, 1000 timeseries of 20 years each are generated, and their cross-correlations are calculated, for various values of the Hurst parameter. Next, using SMA, 10000 annual synthetic timeseries for each process with a 32-year length are generated based on the historical data from the Samos and Kos stations and with Hurst parameters as indicated in [8] and references therein.
As is shown in the upper box plot, even cross correlations between uncorrelated datasets follow the **Gaussian distribution**. Therefore, it is **proven** that a high cross-correlation value has a very low probability to occur randomly.
The actual historical cross-correlations are compared with the synthetic timeseries in the lower box plot (shown as points).

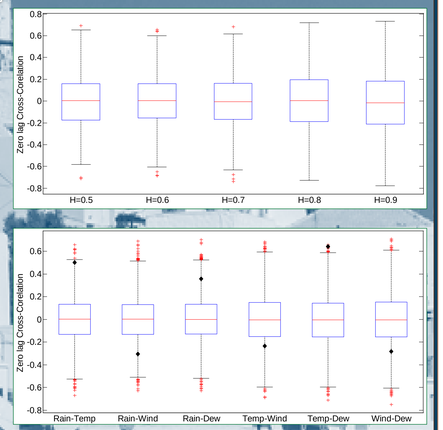


Fig. 3: *Box plots of cross-correlations among sets of normal random values (top) and annual Samos-Kos data (bottom)*

5.Demand Analysis Methodology

Goal: Analyze electricity demand data in Astypalaia in order to create a simulation with the use of synthetic timeseries, 100 years long, for future demand load.

Further Use: Design of a hybrid renewable energy system. Accurate forecasts will lead to substantial savings in operation and maintenance costs, increased reliability of the power supply, and will act as guidance for future development

Data: Hourly demand data from the years 2014-2015

1. Visualize and cluster the data in 2 time scales (hourly and daily) to better understand the behavior of electricity demand and phenomena that are directly related to it
2. Calculate the main statistical characteristics and search for hidden periodicities. If any recurrences are found, they will be taken into account in the simulation
3. Analyze temperature measurements and search for correlations between them and electricity demand
4. Fit a stochastic model to historical data to create a simulation, and confirm the appropriate behavior of statistical characteristics of the historic timeseries

6.Demand Data

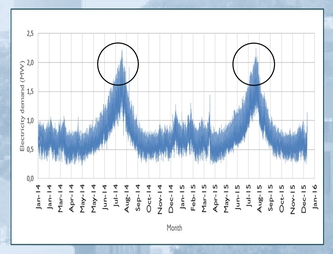
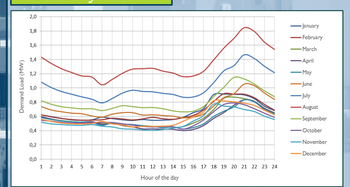


Fig. 4: *Variance of electricity demand load in years 2014-2015. The timeseries have an annual periodicity and a positive asymmetry (more values above the average)*

7.Clustering Data

Hourly basis

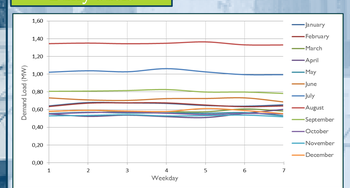


Demand load increase during **summer** due to *tourism* and *increased temperature* in both time scales

- Strong evidence of **daily periodicity**, on an hourly basis
- **No periodicities** on a daily basis **[1],[2]**

(Results confirmed from the autocorrelograms)

Daily basis



Hourly basis:
- Local **maximum** in the *evening*
- Local **minimum** around 07:00

Daily basis:
- Weak (50 KW) increases/decreases during the week
- No minimums or maximums

Figure 5,6,7,8: *Hourly (top) and daily (bottom) variance of electricity demand loads in the years 2014-2015, and their corresponding autocorrelograms*

8.Energy Demand and Temperature

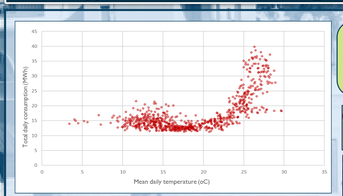


Figure 9: *Total day consumption related to mean daily temperature data from the island of Kos, Greece*

Energy demand peaks **follow** temperature peaks **[1],[3]**

1. Use of air conditioning systems
2. Temperature peaks during population peaks

Simulation

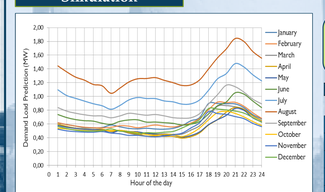


Figure 10: *Simulation of demand in the first 10 years (2016-2025)*

Simulation with the ***tsboot function*** of the ***software R*** **[1],[4-6]**

Marginal Characteristics In Hourly Scale	Historical Data (MW)	Synthetic Data (MW)
Average	0.715	0.715
St. Deviation	0.297	0.297
Skewness	1.488	1.498
Maximum	2.250	2.721
Minimum	0,23	0.00

CONCLUSIONS

- Concerning the cross-correlations of climatic variables around the globe, the only strong and consistent pattern is a positive correlation between mean temperature and dew point.
- Comparisons among other climatic variables show a mild cross-correlation consistency on a global scale (the average global mean is close to zero for both annual and monthly scales),
- Due to the relatively short lengths of the sample timeseries, any small correlation values could be statistically non-significant.
- In the example of Astypalaia, on an annual scale, a moderately positive correlation is found between two processes: precipitation and mean temperature (approx. +0.5), and mean temperature and dew point (approx. +0.6).
- By examining the nearby Samos and Kos stations on a monthly scale, observed annual cross-correlations become more prominent during the winter, and less during the summer.
- Through Monte Carlo analysis, it is evident that high cross-correlation values have a very low probability of random occurrence (<5%). Thus, the cross-correlation between precipitation-temperature and temperature-dew point as estimated from the meteorological stations close to Astypalaia can be considered statistically significant.
- The historic electricity demand timeseries includes periodicities derived in part from the earth's rotation around the sun, but mostly occur due to consumer habits. Those periodicities should be taken into account for the simulation.
- Significant demand peaks in the evening are observed. The designed system must have the capability to cover these needs.
- Increased demand during the summer due to tourism.
- Significant positive correlation between energy consumption and temperature.

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The poster will be uploaded to www.itia.ntua.gr

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