Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 125 (2017) 435–442

Energy Procedia

www.elsevier.com/locate/procedia

European Geosciences Union General Assembly 2017, EGU
Division Energy, Resources & Environment, ERE

Simulation of electricity demand in a remote island for optimal planning of a hybrid renewable energy system

Konstantinos Mavroyeoryos[a], Ioannis Engonopoulos[a,]*, Hristos Tyralis[a], Panayiotis Dimitriadis[a] and Demetris Koutsoyiannis[a]

[a]*School of Civil Engineering, National Technical University of Athens, Heroon Polytechniou 9, Zografou 15780, Greece*

Abstract

Here we simulate the electrical energy demand in the remote island of Astypalaia. To this end we obtain information regarding the local socioeconomic conditions and energy demand needs. The available hourly demand load data are analyzed at various time scales (hourly, weekly, daily, seasonal). The cross-correlations between the electricity demand load and the mean daily temperature are computed. An exploratory data analysis including all variables is performed to find hidden relationships. Finally, the demand is simulated. The simulation time series will be used in the development of a framework for planning of a hybrid renewable energy system in Astypalaia.

Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).

Keywords: energy demand; stochastic simulation; hybrid reneable energy system

1. Introduction

Electric load and demand forecasting involves the projection of peak demand levels and overall energy consumption patterns to support an electric utility's future system and business operations. Electricity demand's behavior is very complex due to the deregulation of energy markets. Therefore, finding an appropriate model has many hard aspects. Here we analyze and simulate the electricity demand in the Greek island of Astypalaia. The

* Corresponding author. Tel.: +306981556481
E-mail address: johny_3ngo@hotmail.com

Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).
10.1016/j.egypro.2017.08.095

simulated time series will be used in the design of a hypothetical hybrid renewable energy system [1]. The required length of the synthetic time series is 100 years. Accurate forecasts will lead to substantial savings in operating and maintenance costs, increased reliability of power supply and delivery system, and sustainable decisions for future development. The energy system will make use of all potential renewable energy resources, i.e., sunlight, wind, waves and biomass and will include a pumped-storage reservoir serving multiple water uses. The analysis is based on data from the period 2014-2015 with one-hour temporal resolution. Firstly, we visualize the data in two time scales (hourly and daily) for better understanding the behavior of electricity demand and the phenomena that have direct relationship with it. Secondly, we identify the main statistical characteristics and seek for internal periodicities. If any recurrences are found, they will be taken into account in the simulation. Based on the above, synthetic time series will be generated using time series bootstrap, which reproduce the autocorrelation and the marginal characteristics of the observed data. Finally, a comparison is made between temperature data and electricity demand [2].

2. Exploratory Data Analysis

2.1 Study area

Astypalaia is a perfect example of a non-connected island where the electric energy is mainly produced by oil-fueled power plants, the unit cost of which is extremely high [3]. Astypalaia is the fourth largest and westernmost island of the Dodecanese. It is located, as shown below (Fig. 1), west of Nisyros and east of Anafi (Cyclades). It acts as a “bridge” that connects Cyclades and Dodecanese, since it administratively belongs to the Dodecanese but geographically and culturally stands between Dodecanese and Cyclades, combining elements from both island groups. The island covers an area of 97 km^2, a coastline of 110 km and has 1 334 inhabitants. Astypalaia took its name after the daughter of Phoenix and Perimidis, who was also Europe’s sister. The island kept the same name for centuries [4].

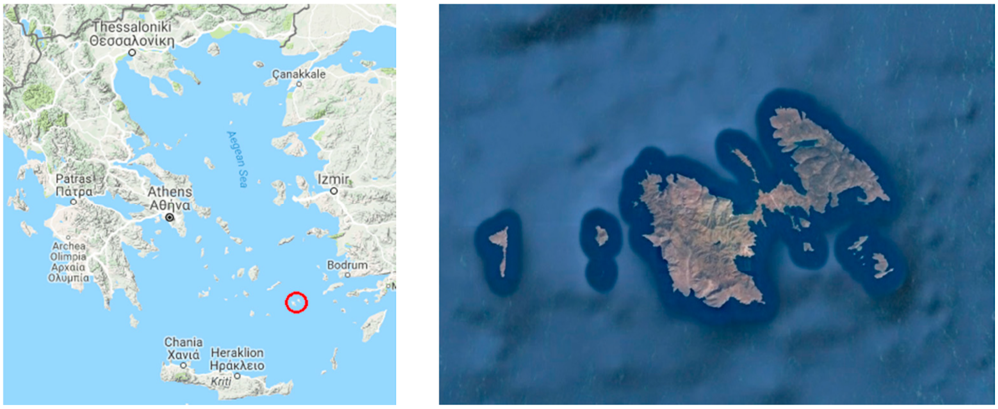


Fig. 1. Location of Astypalaia (satellite images from Status Meteo and Google Earth).

2.2 Original data

From the data analysis we obtain information about significant values. Specifically, an hourly maximum value of 2.25 MWh and an hourly minimum value of 0.23 MWh are extracted from the data, whereas we calculate an annual mean value of 6.26 GWh. In Fig. 2, we observe particularly high values during the summer, which are expected due to tourism. Also we can see the existence of annual periodicity.

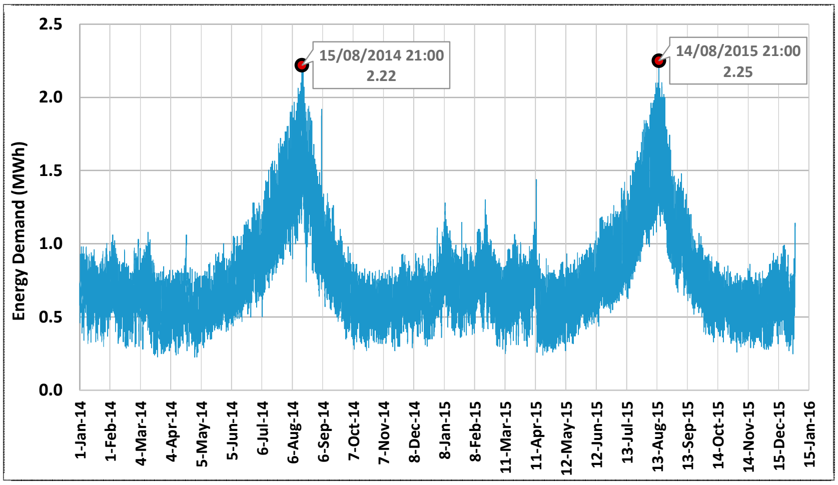


Fig. 2. Historical data in hourly scale for years 2014-15.

2.3 *Visualization in the hourly scale*

In Fig. 3, we observe a local maximum in the evening (around 21:00) that shifts to the left on winter months approximately 2 to 3 hours. A local minimum is formed around 07:00 in the morning that is most noticeable on summer rather than on winter. A local minimum - lighter than the previous - is formed at noon (14:00 – 16:00). During the summer months demand load is increased, as expected, due to tourism and increased temperature.

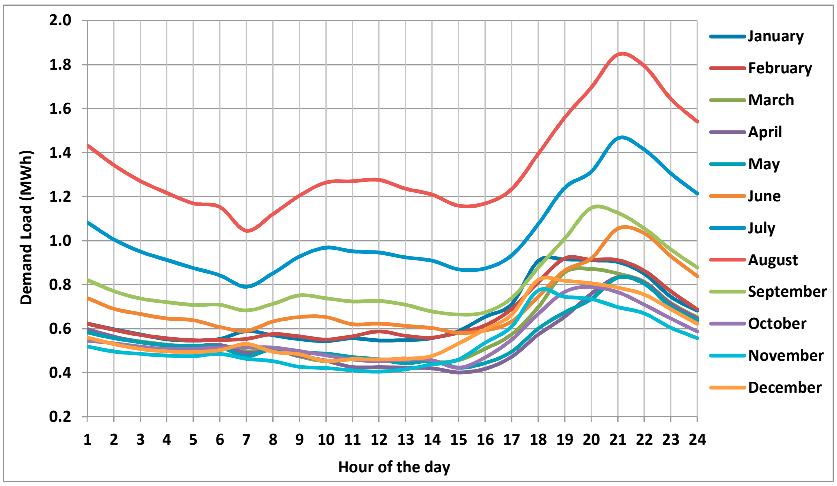


Fig. 3. Hourly-monthly mean electricity demand.

There is strong evidence of diurnal periodicity which is confirmed from the autocorrelation function below.

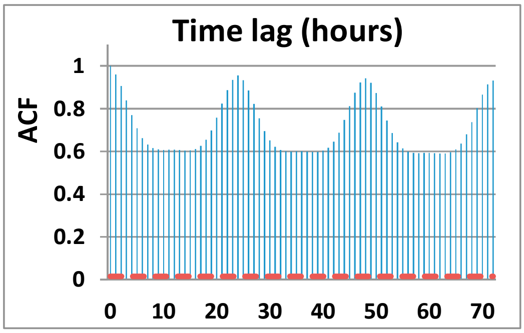


Fig. 4. Autocorrelation function of time series in the hourly scale.

2.4 *Visualization in the daily time scale*

On the other hand, in a daily scale, the data does not form any particular pattern and there aren't any local maxima or minima, as shown in Fig. 5. As it turns out, there are low fluctuations during the week with a maximum of 50 kW. We do not observe weekly periodicity, in contrast to the total energy demand in Greece [5], [6]. The autocorrelation function (Fig. 6) confirms this finding.

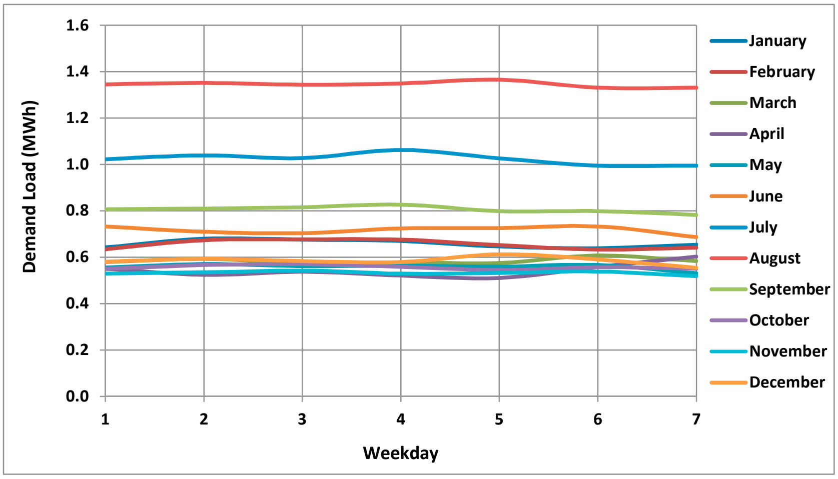


Fig. 5. Daily-monthly mean electricity demand.

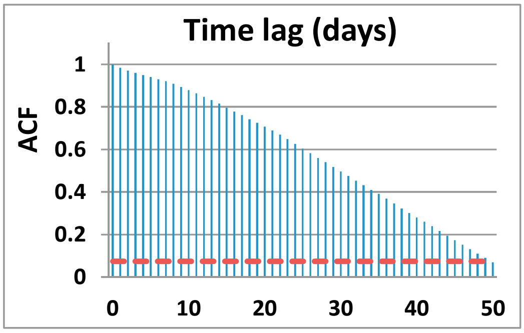


Fig. 6. Autocorrelation function of time series in the daily scale.

3. Relationship between temperature and electricity demand

To examine the cross-correlation between the two variables, temperature data acquired from NOAA were analysed on two time scales (hourly and daily). Due to the absence of a meteorological station on the island, several nearby stations in Kos, Santorini, Amorgos and Kalymnos were examined. The data analysis showed that all the aforementioned stations presented similar results. That is why the station on the neighbouring island of Kos was chosen. On the hourly scale, the correlation coefficient is maximized for a 9 hour lag at about 0.634. This value is greater than what we would expect given the shape of the two variables as shown in the diagram below. On a daily scale, the correlation coefficient gets 0.64 as expected for 0 to 10 days lag. In Fig. 7, between the average daily temperature and the total daily energy consumption, we can observe that high values of temperature correspond to high values of energy demand. That is reasonable due to the use of air-conditioning systems but also because high temperatures correspond to summer (Fig. 8) where the population of the island increases.

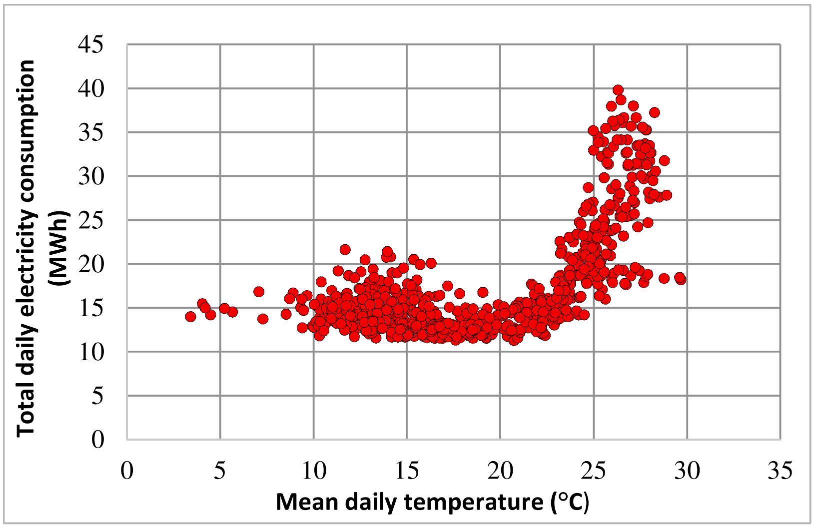


Fig. 7. Daily electricity consumption vs mean daily temperature.

The demand is stabilized for temperatures lower than 22° C which is dissimilar with what we observe in Greece [5-7]. Energy demand minimizes for average temperatures around 15°-20° C. However, an inconsistency is shown for some values between 25° - 30° C, which happens when the temperature suddenly rises for 4 to 5 days in June and then stabilizes to normal levels. During these days, energy demand does not seem to follow an according behavior.

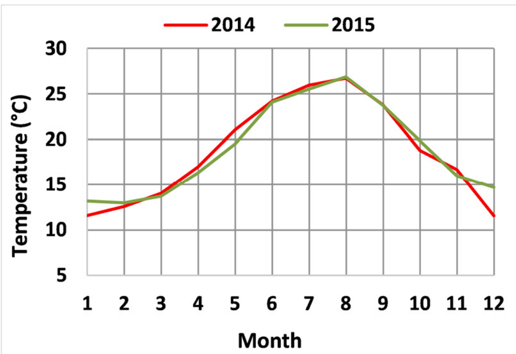


Fig. 8. Mean monthly temperature.

4. Simulation

4.1 Methodology

The periodicities found through the investigation of data on the three scales must be taken into consideration in the simulation. In this particular case study, firstly we deseasonalized the time series. To this end we computed for a given hour and month their corresponding means and standard deviations. For instance we obtained 62 values corresponding to the first hour of January from the years 2014 and 2015. We calculated the mean and standard deviation of the sample of 62 values and then we used this value to deseasonalize the time series. This removes the periodic factor of the time series which can now be simulated. The simulation was done with block bootstrap. By using the deseasonalized time series, a block of data with a certain length is randomly chosen and reshaped in order to extract the synthetic data. This process is repeated numerous times so that each time a different block is chosen and finally the desired length of the synthetic time series is generated. Two key features are that the length of the block follows a geometric distribution with an average value equal to the optimal length [5, 8-10] resulting from the b.star function of the R software, which was equal to 336 elements and that the simulation was made on the basis of maintaining the mean value, the standard deviation, and the first 25 autocorrelations of the remainder of the time series. Then, to preserve the observed periodicities, we added the same values obtained by the deseasonalization procedure, firstly by multiplying each hourly value for a particular month with the standard deviation and then by adding the mean value. The resulting time series is the one used in the simulations.

4.2 Validation of the results

As shown in Fig. 9, demand behavior has been reproduced quite well and the method has succeeded in maintaining local maxima and local minima. Marginal characteristics have remained unchanged. In addition, by comparing Figure 10 to Figure 4, we come to the conclusion that the autocorrelation of the series has been preserved quite well.

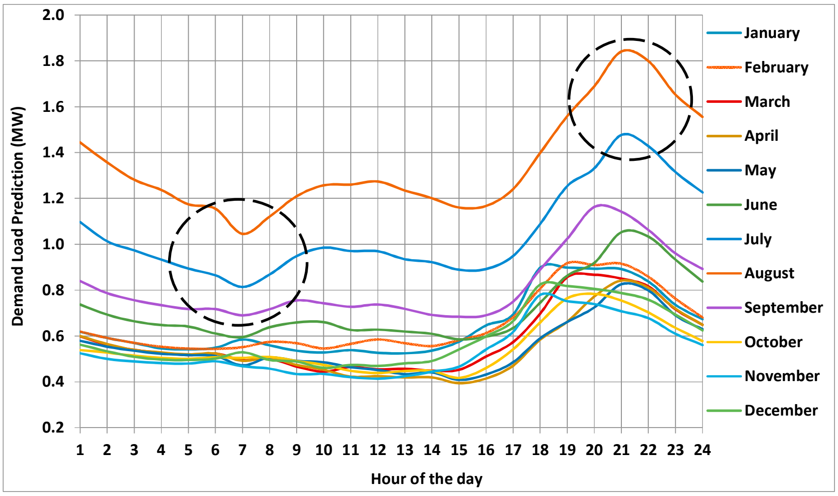


Fig. 9. Hourly-monthly mean electricity demand for simulated data.

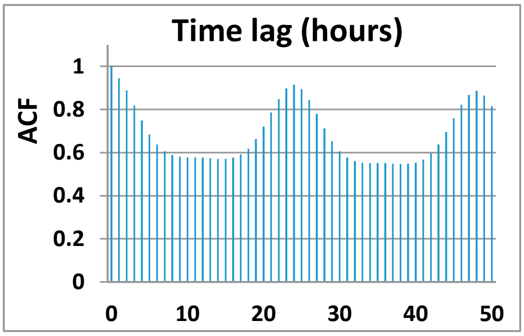
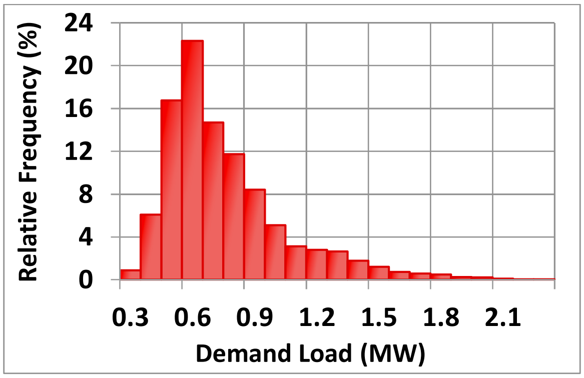


Fig. 10. Autocorrelation function of synthetic time series in the hourly scale.

Table 1. Marginal characterictics of the observed and simulated electricity demand in the hourly time scale

	Historic data (MW)	Synthetic data (MW)
Mean	0.715	0.715
Standard deviation	0.297	0.297
Skewness	1.488	1.498
Maximum value	2.25	2.721
Minimum value	0.23	≈ 0

(a)


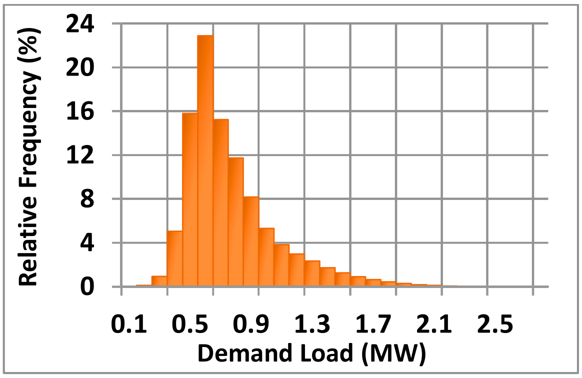
(b)


Fig. 11. Histograms of historic (a) and simulated (b) data.

5. Conclusions

In this study, we investigated the electricity demand in the remote island of Astypalaia. We examined the data at various time scales (hourly, daily, weekly and seasonal) and found the existence of double cyclostationarity (hourly, due to the people's habits) & monthly (due to earth's rotation around the sun and tourism in summer months). Those periodicities must be taken into account to the simulation. In a daily scale, we observed local maxima (in the evening) and local minima (in the early morning). The designed energy system must be credible to cover the above mentioned peaks. For this purpose, a representative synthetic time series must be generated, with the ability to reproduce the autocorrelation and the marginal characteristics of the historical data. With these criteria, the historical time series was simulated and the synthetic was produced to be used in the work [1] which is the purpose of the present. Finally, irrespective of the above, we also found a significant correlation between energy consumption and temperature, especially in the area of high values of the two variables.

References

[1] Stamou, Paraskevi, Sophia Karali, Maria Chalakatevaki, Vasiliki Daniil, Katerina Tzouka, Panayiotis Dimitriadis, Theano Iliopoulou, Panos Papanicolaou, Demetris Koutsoyiannis, and Nikos Mamassis. (2017) "Creating the electric energy mix of a non-connected Aegean island." *European Geosciences Union General Assembly 2017, Geophysical Research Abstracts, Vol. 19, Vienna, EGU2017-10130-10, 2017.*

[2] Koskinas, Aristotelis, Eleni Zacharopoulou, George Pouliasis, Ioannis Engonopoulos, Konstantinos Mavroyeoryos, Ilias Deligiannis, Georgios Karakatsanis, Panayiotis Dimitriadis, Theano Iliopoulou, Demetris Koutsoyiannis, and Hristos Tyralis. (2017) "Simulation of electricity demand in the remote island for optimal planning of a hybrid renewable energy system." *European Geosciences Union General Assembly 2017, Geophysical Research Abstracts, Vol. 19, Vienna, EGU2017-10495-4, 2017.*

[3] Friedrich, Daniel, and George Lavidas. (2015) "Combining offshore and onshore renewables with energy storage and diesel generators in the stand-alone Hybrid Energy System." *Offshore Energy & Storage Symposium 2015,* Edinburgh.

[4] Astypalaia-Island: History [Internet]

[5] Tyralis, Hristos (2016) "Spatio-temporal analysis of the electrical energy demand in Greece." *MSc thesis, 95 pages,* (2016)

[6] Tyralis, Hristos, Georgios Karakatsanis, Katerina Tzouka, and Nikos Mamassis. (2015) "Analysis of the electricity demand of Greece for optimal planning of a large-scale hybrid renewable energy system." *European Geosciences Union General Assembly 2015, Geophysical Research Abstracts, Vol. 17, Vienna, EGU2015-5643* (2015)

[7] Tyralis, Hristos, Georgios Karakatsanis, Katerina Tzouka, and Nikos Mamassis. (2017) "Exploratory data analysis of the electrical energy demand in the time domain in Greece." *Energy* 134 (2017): 902-918.

[8] Davison, C. Anthony, and Hinkley V. David. (1997) “Bootstrap methods and their application”, Cambridge University Press, Cambridge

[9] Canty, Angelo, and Ripley D. Brian. (2015) "boot: Bootstrap R (S-Plus) Functions." R package version 1.3-17.

[10] Hayfield, Tristen, and Racine S. Jeffrey. (2008) "Nonparametric Econometrics: The np Package." *Journal of Statistical Software* 27 (5) (2008)