Energy Policy 102 (2017) 340–352

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Spatial analysis of the electrical energy demand in Greece

Hristos Tyralis[a,*], Nikos Mamassis[a], Yorgos N. Photis[b]

[a] *Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Iroon Polytechniou 5, 157 80, Zografou, Greece*

[b] *Department of Geography and Regional Planning, School of Rural and Surveying Engineering, National Technical University of Athens, Iroon Polytechniou 9, 157 72, Zografou, Greece*

ARTICLE INFO

Keywords:
Cluster and outlier analysis
Electrical Energy Demand
Gross Domestic Product
Grouping analysis
Hot Spot analysis
Spatial analysis

ABSTRACT

The Electrical Energy Demand (EED) of the agricultural, commercial and industrial sector in Greece, as well as its use for domestic activities, public and municipal authorities and street lighting are analysed spatially using Geographical Information System and spatial statistical methods. The analysis is performed on data which span from 2008 to 2012 and have annual temporal resolution and spatial resolution down to the NUTS (Nomenclature of Territorial Units for Statistics) level 3. The aim is to identify spatial patterns of the EED and its transformations such as the ratios of the EED to socioeconomic variables, i.e. the population, the total area, the population density and the Gross Domestic Product (GDP). Based on the analysis, Greece is divided in five regions, each one with a different development model, i.e. Attica and Thessaloniki which are two heavily populated major poles, Thessaly and Central Greece which form a connected geographical region with important agricultural and industrial sector, the islands and some coastal areas which are characterized by an important commercial sector and the rest Greek areas. The spatial patterns can provide additional information for policy decision about the electrical energy management and better representation of the regional socioeconomic conditions.

1. Introduction

A preliminary spatial analysis of the Electrical Energy Demand (EED) in Greece is presented in Tyralis et al. (2016). In this study the reader can find references concerning case studies in Greece in which spatial analysis of energy demand was applied. Recently Tyralis et al. (2017) analysed the EED in Greece in the time domain. A list of the most recent papers concerning the analysis of the EED in the time domain in Greece and a presentation of the Greek Interconnected Electric System (GIES) can also be found in Tyralis et al. (2017).

Many studies can be found in the scientific literature concerning the spatial analysis of energy demand mainly in China. These studies treat a variety of subjects while their primary theme is the investigation of the relationship between the energy demand and socioeconomic variables. E.g. Ito et al. (2010) estimated an upper limit of the energy demand, after analysing spatially the economic conditions, the industrial infrastructures and energy demand data. Liu et al. (2014) applied spatial clustering methods to industry energy efficiency data. Ma and Oxley (2012) analysed the behaviour of energy sectors and identified energy market spatial convergence clusters using price data. Sheng et al. (2014) examined the relationship between economic growth, regional disparities and energy demand - production. Wang et al. (2012) evaluated the efficient use of energy in the industrial sector. Zhang and Lahr (2014) revealed the regional disparities of energy consumption and correlated them to economic variables. Zhang et al. (2013) modelled the interprovincial flow of energy. Zhang et al. (2009a, 2009b) examined the spatial characteristics of energy consumption patterns in rural China and Zhang et al. (2011) repeated a similar study in the provincial capital cities.

Spatial statistical methods have been applied to energy data from the rest of the world however, to a lesser extent. To list a few studies, Ihara et al. (2008) and Schiesser and Bader (2005) investigated issues of energy demand in urban scale, while Arimah (1993), Kaijuka (2007), Khan and Ahmad (2008), Lee and Chang (2008) and Taylor et al. (2014) examined energy issues in country scale. Another interesting application concerning the spatial load forecasting was presented by Melo et al. (2015), while Yaylaci et al. (2011) used spatial statistical methods to investigate the spatial distribution of electrical energy generation and consumption in Turkey.

The aforementioned studies are based on statistical data for administrative units larger or equal to the county level. Lights time-series data obtained from satellites have higher spatial resolution

* Correponding author.
E-mail addresses: montchrister@gmail.com (H. Tyralis), nikos@itia.ntua.gr (N. Mamassis), yphotis@gmail.com (Y.N. Photis).

http://dx.doi.org/10.1016/j.enpol.2016.12.033
Received 7 August 2016; Received in revised form 6 December 2016; Accepted 19 December 2016
0301-4215/

therefore they offer accurate spatiotemporal information and a better understanding of the spatial distribution of the EED. In this context He et al. (2012) modelled the spatiotemporal dynamics of electrical energy consumption in China, while Shi et al. (2014) contributed, not only by estimating the electrical energy consumption, but also by using light data to estimate the Gross Domestic Product (GDP) in China. Yi et al. (2014) added another application of light data, i.e. the estimation of the urbanization process in Northeast China.

The paper of Francisco et al. (2007) who indicated that the electricity consumption could be an efficient predictor of income is of particular interest for the present study. Furthermore, Francisco et al. (2007) proposed the creation of a set of regional indicators of electricity consumption which would help in the examination of public and urban affairs.

As mentioned in most of the previous studies the spatial analysis of energy consumption, energy generation etc. provides information which can support the management of energy systems and the policy-making for their development. Furthermore, following the examples of Francisco et al. (2007) and Shi et al. (2014), it seems that the spatial analysis of the EED can provide additional indicators of the economic condition of a region, particularly when it is coupled with socioeconomic indicators.

The spatial analysis of the economic conditions in Greece using socioeconomic indicators is frequently met in the scientific literature. The examination of convergence and regional disparities is the main subject of economics studies which analyse spatially the economic conditions, e.g. see the recent papers from Benos and Karagiannis (2008), Caraveli and Tsionas (2012), Goletsis and Chletsos (2011), Ikonomou (2011), Liargovas and Fotopoulos (2009), Liontakis et al. (2010), Monastiriotis (2014), Petrakos and Saratsis (2000) and Tsionas et al. (2014). Other frequently met subjects are the allocation of capital and the investments, (e.g. see Benos et al. (2011), Lambrinidis et al. (2005), Liargovas and Daskalopoulou (2011), Lolos (2009), Monastiriotis and Psycharis (2014), Psycharis (2008), Rodríguez-Pose et al. (2015)), the economic crisis, (e.g. see Cuadrado-Roura et al. (2016), Karoulia and Gaki (2013), Monastiriotis (2011)), Monastiriotis and Martelli (2013), Petrakos and Psycharis (2016), Psycharis et al. (2014)), the sectoral economy, (e.g. see Christofakis and Gkouzos (2013), Vogiatzoglou and Tsekeris (2013)) and miscellaneous topics (e.g. see Artelaris and Kandylis (2014), Christofakis and Papadaskalopoulos (2011), Hlepas and Getimis (2011), Monastiriotis (2009)). In the aforementioned studies, statistical methods are applied to socioeconomic variables, while in some of them, the authors visualize the data spatially.

In the present study the EED of six sectors in Greece is analysed spatially: agricultural, commercial, industrial, domestic, public and municipal authorities and street lighting. Quite different inference could be made if the EED volume is analysed e.g. compared with the EED per capita for a given region. Consequently, ratios of specific electrical energy uses to the total EED and ratios of the EED to variables such as population, total area, population density and the Gross Domestic Product (GDP) are also examined. The analysis is performed on data from the years 2008–2012 and have annual temporal resolution and spatial resolution down to the NUTS (Nomenclature of Territorial Units for Statistics) level 3 of EUROSTAT. Some of the aforementioned variables were visualized in Tyralis et al. (2016), a spatial cluster and outlier analysis was performed and the results of the analysis were also visualized. The present study expands the Tyralis et al. (2016) paper by performing a hot spot analysis using the Getis-Ord Gi* statistic and a grouping analysis based on distances between the examined regions and the observed variables. Five years of data are examined, however only those from 2012 are presented here. Furthermore, the data and the code for cleaning the raw data and reproducing the visualizations of the present study as well as of the Tyralis et al. (2016) paper, additional analysis and Figures for the year 2012 associated with the Tyralis et al. (2016) and the present study, and a similar analysis on data which span from 2008 to 2011 but not included here for brevity, are available as supporting material (see Appendix A).

Greece is characterized by a diverse geographic and socioeconomic environment. The electrical energy consumption has already been used as a socioeconomic indicator in some studies. Furthermore, little research has been done in analysing the EED in Greece spatially. Hence, the aim of the paper is to define the spatial patterns of the EED variables and their transformations, in Greece using spatial statistical analysis methods in a GIS environment. The analysis can provide a better understanding of the regional development model of Greece and additional information for policy decision about the organization and management of the Greek Electric System.

2. Data and methods

The data and the methods which were used in Section 3 to perform the analysis are presented in Section 2. The socioeconomic condition in Greece, as it is reflected in the existing socioeconomic literature is also presented.

2.1. Data

Greece covers an area of 132 000 km^2 and has a population of approximately 11 million people. It is divided into 13 administrative regions, which correspond to the NUTS level 2 as illustrated in Fig. 1, and into 51 prefectures, which correspond to the NUTS level 3 as illustrated in Fig. 2. NUTS levels are European standards for the referencing of administrative divisions for statistical purposes. The mean prefecture area is approximately equal to 2 600 km^2, ranging from approximately 350–5 500 km^2. The mean prefecture population is approximately equal to 210 000 (2011 census) and has a high coefficient of variation approximately equal to 2.6. The capital region of Attica accommodates approximately 35% of the total population, while the second biggest region of Thessaloniki accommodates another 10% of the total population (Psycharis, 2008; Artelaris and Kandylis, 2014).

The raw data that were used in the analysis are presented in Table 1. The electricity data comprise the EED of three sectors (i.e. agricultural, industrial and commercial sector), as well as the EED used for domestic activities, public and municipal authorities and street lighting and the total EED. Three more socioeconomic variables, also presented in Table 1, were taken into account. From hereinafter each data case will be called variable. In total 9 variables were examined and

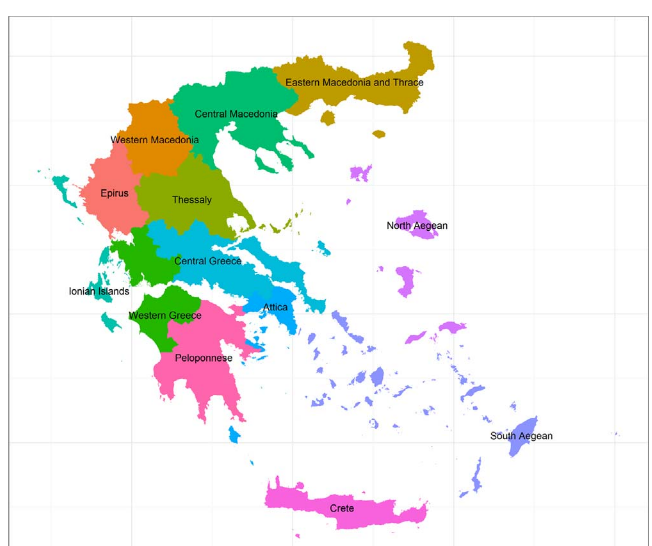

Fig. 1. NUTS (Nomenclature of Territorial Units for Statistics) level 2.