Spatial analysis of the electrical energy demand in Greece

Hristos Tyralis[1], Nikos Mamassis[2] and Yorgos N. Photis[3]

[1] Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Iroon Polytechniou 5, 157 80 Zografou, Greece, (montchrister@gmail.com)

[2] Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Iroon Polytechniou 5, 157 80 Zografou, Greece (nikos@itia.ntua.gr)

[3] Department of Geography and Regional Planning, School of Rural and Surveying Engineering, National Technical University of Athens, Iroon Polytechniou 9, 157 72 Zografou, Greece (yphotis@gmail.com)

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.

Keywords: cluster and outlier analysis; electrical energy demand; Gross Domestic Product; Grouping analysis; Hot Spot analysis; spatial analysis

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, b) 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 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 Figure 1, and into 51 prefectures, which correspond to the NUTS level 3 as illustrated in Figure 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 km^2 to 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 they are presented in Table 1. The variables have annual temporal resolution and cover the time period 2008-2012. They also have spatial resolution down to the level of prefecture.

Moreover, several transformations of the variables of Table 1 which resulted from operations performed on them were examined. The transformed variables are presented in Table 2. In particular, they are scaled over the population, the area, the GDP etc. In total 45 variables were examined and visualized, i.e. the sum of the examined cases in Table 1 and Table 2 (cases column). The visualizations can be found in Appendix A. The number of Figures in Appendix A for all examined variables, for the time period 2008-2012 is 225 (i.e. 45 variables by five years).

2.2 Methods

In Tyralis et al. (2016) specific variables for the year 2012 were visualized and a spatial inference was made after applying to them a cluster and outlier analysis using the Anselin Local Moran's I statistic. As explained in Tyralis et al. (2016) visualization is not sufficient for making a complete inference. Thus in this study a hot spot analysis using the Getis-Ord Gi* statistic and a grouping analysis using spatial statistics are additionally performed. Moreover, and as a side result the spatial centroid is found. An overview of the methods that were used is presented in Table 3. The relevant tools of Esri (2015) were used to apply the methods, while the parameters of the tools were set according to Table 3. Table 3 also contains the documentation of the tools.

Briefly, spatial clusters of similar high or low values or spatial outliers (high/low outliers surrounded by features with low/high values) can be located using the cluster and outlier analysis. The possible outcome of this analysis is presented in Table 4 and is depicted as legend in the Figures. Statistically significant hot spots and cold spots, given a set of weighted features, can be identified using the hot spot analysis. A region with a high value is interesting, but may not be a statistically significant hot (or cold) spot. To be a statistically significant hot (or cold) spot, a region will have a high (or low) value and be surrounded by other regions with high (or low) values as well. Using the grouping analysis, regions can be grouped and patterns are revealed based on variable values and spatial constraints. The outcome of the grouping analysis is a set of groups with high similarity within-them and high differences between them. The four tools of Table 3 were applied to all 225 cases and the results are illustrated in 900 Figures of Appendix A.

2.3 Socioeconomic condition in Greece

In Goletsis and Chletsos (2011) and Monastiriotis (2009) a detailed representation of the regional development model of Greece can be found. To summarize their results, that are of interest for the present study, it is first noted that Goletsis and Chletsos (2011) clustered Greece, using multivariate clustering into five groups, i.e. Western Macedonia, South Aegean islands, Attica, Central Greece and Peloponnese and finally the remaining regions (see Figure 1). The main feature of Western Macedonia is the high secondary section and low tourist development. In contrast, the South Aegean islands are characterized by high tourist development and low primary sector. Attica, is a totally different case with high GDP per capita and low primary sector. Central Greece and

Peloponnese are described by the high secondary and low services sectors. The remaining regions are characterised by low GDP per capita and an average sectoral structure.

The conclusions of Monastiriotis (2009) are not quite different as he claims that Greece's economic geography is heterogeneous, and simultaneously a few and rather weak high–high clusters appear, which implies a fragmented socio-economic space. This low number of high-high clusters is also confirmed by Tyralis et al. (2016). When examining specific economic sectors, Monastiriotis (2009) concludes that the industry is mainly concentrated in and around Attica, Thessaloniki, Kozani (power generation) and Eastern Macedonia. Central Greece and southwest Peloponnese specialise in agriculture, and services are concentrated in the major cities and in the islands.

3. Results

The data, the code and the results of the application of the methods of Section 2.2 to the data of Section 2.1 are presented in Appendix A. Details concerning the cleaning of the raw data can also be found in Appendix A. The data cover the time period 2008-2012 and concern various uses of the EED and socioeconomic variables, therefore the presentation of all results here would require a huge amount of space. Hence we decided to present some important results for the year 2012 regarding selected variables. The interested reader is referred to Appendix A, for additional results of his interest.

The use of EED in the agricultural, commercial and industrial section, its domestic use and the total EED are examined in Section 3. The aforementioned EED variables coupled with socioeconomic variables such as the GDP and the population are also examined. Before analysing the data, all the variables are visualized. For brevity, just a few visualizations are presented here. Appendix A contains all the visualizations while some of them have already been presented in Tyralis et al. (2016).

Data visualization helps understanding the data and indicates appropriate methods for their analysis, however it is not possible to capture all aspects of the problem at hand. Spatial analysis algorithms must be applied to identify spatial patterns of the variables of interest. In Sections 3.1-3.5 results from the cluster and outlier analysis, the hot spot analysis and the grouping analysis are presented. Each Figure of these Sections simultaneously contains the hot spot analysis for a specific variable and the corresponding grouping analysis. For brevity, a limited number of Figures with the results of the cluster and outlier analysis are also presented, while the rest of them can be found in Tyralis et al. (2016) and in Appendix A.

3.1 Agricultural sector

The visualization of the EED in the agricultural sector in Figure 3 indicates that Larissa and Boeotia are high consumers. A cluster of high values including Larissa, Phthiotis, Boeotia and Euboea is also observed, while the adjacent Phocis is an outlier of low values. It is observed in Figure 4 that Larissa and Boeotia are hot spots for EED in the agricultural sector. It is also observed that Larissa (no. 1) consists a group, while Boeotia belongs to a group with Phthiotis and Karditsa (no. 2). Another group (no. 3) consists of Argolis and Laconia in Peloponnese. Groups 4-6 divide Greece almost equally into three regions.

The EED in the agricultural section per capita is of importance, because this scaled variable can be a reliable indicator of the percentage of people being employed in the agricultural sector. In Figure 5 three more hot spots compared to Figure 4 are observed, i.e. Karditsa, Argolis and Laconia. It is also observed in Figure 5 that Larissa and Boeotia now belong to the same group 1, with Karditsa, Phthiotis and Arta. Group 3 of Figure 4 is group 2 of Figure 5, while two new distinct groups appear, i.e. 3 and 5.

Another useful variable is the ratio of the EED in the agricultural section to the prefecture area. This variable is presented in Figure 6 and can be an indicator of the percentage of area of a prefecture which is used in agriculture. Three hot spots are observed, i.e. Larissa, Boeotia and Argolis. This is a similar pattern to that of Figure 4 and Figure 5. However, two new groups are observed, i.e. the group 2 in Central Macedonia and the group 5 which includes prefectures which were hot spots in Figure 4 and Figure 5 (i.e. Phthiotis and Laconia), but not in Figure 6. It is also observed that group 4 extends to almost all Greece.

3.2 Commercial sector

It seems that a high volume of the activity is concentrated in Attica and Thessaloniki (Figure 7) regarding the EED in the commercial sector while Attica is also a spatial data outlier with high value. It is observed in Figure 8 that Attica is a hot spot for the EED in the commercial sector. Groups 1, 2 (Thessaloniki), 3, 5, 6 form a region with high EED in the commercial sector (see also Appendix A).

Figure 9 presents the EED in the commercial sector per capita. This variable could be an indicator of the commercial character of a region. Several hot spots dispersed in Greece are observed, i.e. Chalkidiki, Kerkyra, Lefkada, Zakynthos and Dodecanese. Groups 1 and 2 coincide with their respective hot spots in Figure 9, while group 4 includes the other dispersed hot spots, as well as the administrative region of Crete and the Cyclades prefecture. Group 3 is a subset of the administrative region of Epirus, while groups 5 and 6 divide equally the rest of Greece.

3.3 Domestic use

Similarly to Figure 7 and Figure 8, it is observed in Figure 10 and Figure 11 that Attica and Thessaloniki are high consumers of EED for domestic use while Attica is a hot spot. Attica in group 1, Thessaloniki in group 2 and Achaea (group 4) are high domestic users of EED as also shown in Appendix A.

Whereas hot spots were found solely in Sections 3.1 and 3.2, when examining the EED for domestic use per capita in Figure 12 both hot and cold spots are found. Three hot spots, i.e. Lefkada, Corinthia and Argolis and two cold spots, i.e. Preveza and Evrytania appear in Figure 12. Groups 1 and 2 coincide with their respective spots, while the group 3 includes the other two hot spots.

3.4 Industrial sector

The EED in the industrial sector is examined in Section 3.4. Figure 13 indicates that Magnesia, Phthiotis, Boeotia and Attica form a cluster of high values of the EED in the industrial sector, while high values are also observed in Thessaloniki. It is observed in Figure 14 that Phthiotis, Boeotia and Attica are hot spots. The latter prefectures are simultaneously two groups, while Phthiotis with Magnesia form group 3, Thessaloniki is group 2 and Euboea is group 4. The rest prefectures belong to group 6. Combined with the visualization results in Appendix A, it seems that the industrial activity is concentrated in groups 1-5.

Figure 15 presents the analysis for the EED in the industrial sector per capita. This variable is an interesting indicator of people being employed in industry. Phthiotis and Boeotia are hot spots, while it is observed that groups 1-4, each one includes a single prefecture, while the rest two groups divide Greece almost equally. This result, coupled with the visualization of the variable in Appendix A indicates that groups 1-4 form a region with high values of the variable. Figure 16 examines the ratio of the EED for industrial use to the GDP. The exact same patterns are observed in Figure 15 and Figure 16.

3.5 Total EED

Figure 17 presents the total EED for each prefecture. Attica and Thessaloniki are two prefectures with high total EED, while Attica and Boeotia form a cluster of high values. It is again observed in Figure 18 that Attica and Thessaloniki are two total EED hot spots, while groups 1, 2, 4, 5 (with the latter being industrial areas) form a group of high total EED.

The total EED per capita of the Greek prefectures is presented in Figure 19. Phthiotis and Boeotia are two hot spots, similarly to Figure 15, while it is observed in Appendix A that groups 1-5 are described by high values of the ratio. Groups 1-3 and 5 of Figure 19 almost coincide with groups 1-4 of Figure 15, indicating that the differences between regions of the EED for all uses primarily depend on the quantity of EED in the industrial sector.

4. Discussion

The results of Section 3 are summarized in Section 4. A first result which confirms the conclusions of previous papers (e.g. see Caraveli and Tsionas, 2012), regarding the uneven geographic development in Greece and the regional imbalances between Attica, Thessaloniki and the rest regions is that Attica and Thessaloniki, which are by far the most populated Greek prefectures, also exhibit the highest total EED, and the highest EED for each sector, excluding the agricultural. Therefore, the economic activity is primarily concentrated in these two areas. However, some prefectures specialize in specific sectors, in which the respective EED is also high.

A different state is observed when examining the scaled variables. Indeed, Attica and Thessaloniki do not yet seem to be high electrical energy consumers, while different and rather dispersed patterns are revealed. Firstly, regarding the agricultural sector, the production is mainly concentrated in Thessaly, Central Greece and Peloponnese. The pattern does not change significantly, even when examining the scaled variables, i.e. the agricultural production seems to be independent of the total people being employed in this sector and the areas of the prefectures.

Regarding the commercial sector, it seems that the islands and regions considered as touristic exhibit high EED per capita. Therefore, this variable could be a good indicator of the touristic nature of a region. Furthermore, it seems that the touristic regions are dispersed in Greece. Regarding the EED for domestic use, a rather clustered pattern is observed, while no certain inference could be made by the investigation of this pattern. The industrial sector is primarily concentrated in Central Greece, confirming the high level of agglomeration, associated with the location of the industries. High consumers of electrical energy are the industrial prefectures in Central Greece, which indicates that the EED in the industrial sector is the main factor affecting the quantity of the EED.

In general, beyond the two major poles, Attica and Thessaloniki, it seems that the economic activity is concentrated in the adjacent administrative regions of Thessaly and Central Greece, which are the main consumers of EED in the agricultural and industrial sector. A few other regions, dispersed in Greece, also exhibit a specialization in agriculture and industry. On the other hand, the islands and coastal prefectures are commercial regions.

Figure 20 is a heatmap of the standardized values of the variables examined in Section 3. The prefectures in the y-axis where clustered according to the standardized values of the variables, while variables associated with the EED in the agricultural sector, the commercial sector, the EED for domestic use, the EED in the industrial sector and the total EED are presented from left to right. A cluster of high values in the top-right corner of Figure 20 is again observed when examining the industrial and total EED related variables. This cluster consists of Attica, Thessaloniki, prefectures in Central Greece and the adjacent Magnesia (The top six prefectures). Prefectures with high values in several variables are also Dodecanese (commerce related variables), Larissa and Argolis (agriculture related variables). A rather dispersed pattern is observed When examining the agriculture and commerce related variables (in the left of Figure 20).

Therefore, it can be concluded that Greece is divided into 5 regions, according to the spatial analysis of the EED. Firstly, Attica and Thessaloniki are two distinct major poles. The third region includes Thessaly and Central Greece, where the agricultural and industrial production is concentrated. The islands and some coastal regions have a touristic character. Finally, the rest Greek prefectures are similar in terms of various uses of the EED, without any specialization.

5. Conclusions and policy implications

In this study the electrical energy demand of the agricultural, commercial and industrial sector in Greece, as well as its use for domestic activities, public and municipal authorities and street lighting was analysed. Ratios of specific electrical energy uses to the total electrical energy demand and ratios of the electrical energy demand to variables such as population, total area, population density and the Gross Domestic Product were also examined. The data span from 2008 to 2012 and have annual temporal resolution and spatial resolution down to the NUTS level 3.

All variables were visualized, a spatial cluster and outlier analysis, a hot spot analysis and a grouping analysis on all variables were performed and the results of the analysis were visualized. Five years of data were examined, however only those from 2012 are presented here, while the full analysis is presented in Appendix A.

Based on the analysis Greece is divided in five regions, each one with a different development model. Attica and secondary Thessaloniki are two major poles, i.e. two regions highly populated, thus the absolute volumes of electrical energy demand are likewise high. Thessaly and Central Greece form a united region with important agricultural and industrial sector, while the islands and some coastal areas are characterized by an important commercial sector. The rest Greek areas could form a region with similar characteristics.

The novelty of the present study is the application of various spatial statistical methods, to various uses of the electrical energy demand, to infer about the development model of a country. It was shown that the electrical energy demand and its variants could serve as substitutes of socioeconomic variables, or could be used, coupled with them, since the results of the analysis are equivalent to results of papers published in economic journals. Therefore, the use of such indexes is proposed, especially when taking into account that such data are automatically available from the local electricity companies.

The results of the analysis could also be used in the planning of the Greek electrical system, providing directions for a specialized energy supply infrastructure development, considering the unique characteristics of each region. Attica and Thessaloniki are two major electrical energy consumers. Boeotia, Euboea, Magnesia and Phthiotis with their important industrial sector can also be added to the latter regions, since the industrial activities are the cause of high electrical energy consumption. The distribution of the electrical energy demand of the industrial section in the time domain has some interesting properties. E.g. the industries are closed down in the summer due to summer holidays or in the weekends, resulting in an uneven distribution of the electrical energy demand, whose bulk is concentrated in smaller time periods. Thus higher picks of electrical energy demand should be satisfied in certain time periods, mainly in winter months and working days. However, the high level of agglomeration, associated with the location of the industries which are primarily concentrated in Central Greece helps in the implementation of target specific mechanisms during the planning procedure.

The agricultural sector in Greece is dispersed, especially when compared to the industrial sector. Regions with agricultural orientation can be found in Central Greece, but also in Central Macedonia Peloponnese and Thessaly. The electrical energy demand of the industrial section is also unevenly distributed in the time domain. However, unlike the distribution of the industrial sector, the electrical energy demand of the agricultural sector is concentrated in the summer, thus requiring a respective planning.

Regions with high electrical energy demand for commercial use are also spatially dispersed in Greece. Of great importance is that most of these regions are islands, e.g. Kerkyra, Lefkada, Zakynthos and Dodecanese. The islands in Greece are not connected to the Greek Interconnected Electric System. Furthermore, the commercial activities are primarily correlated to the touristic character of these regions, hence the bulk of the electrical energy demand is concentrated in the summer.

In concluding it is recommended that the developers of the Greek electrical system must consider the peculiarities of the spatial distribution of the electrical energy demand of each sector for its optimal planning.

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Appendix A Supplementary material

Supplementary data and the code for cleaning the raw data and reproducing the visualizations of the present study as well as 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 are available as online supplementary material in Appendix A.

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Tables

Table 1. Examined variables for every Greek prefecture for the time period 2008-2012. Data are annual. The cases column includes the number of variables that are presented in the supplementary material (data source: Hellenic Statistical Authority).

Variable	Unit of measurement	Cases
EED (agricultural use, industrial use, commercial use, domestic use, public and municipal authorities, street lighting, total use)	MWh	7
GDP	10^6 €	1
Area	m^2	-
Population	people	1

Table 2. Examined combinations of variables, occurring after the transformation of the variables of Table 1. The cases column includes the number of variables, which are illustrated in the supplementary material.

Variable	Unit of measurement	Cases
Population density	population / km^2	1
GDP / capita	€ / capita	1
EED per use / total EED		6
EED per use / GDP	MWh / 10^6 €	7
EED per use / capita	MWh / capita	7
EED per use / area	MWh / km^2	7
EED per use / population density	MWh / (population / km^2)	7

Table 3. Esri (2015) tools which were used in the study and parameters. In all cases we used the inverse distance to denote the spatial relationship and the Euclidean distance to calculate distances.

Method	Parameters	References
Cluster and Outlier Analysis (Anselin Local Moran's I)	p-value = 0.05	Anselin (1995)
Hot Spot Analysis (Getis-Ord Gi*)		Getis and Ord (1992), Ord and Getis (1995)
Grouping Analysis	Delaunay triangulation, six classes	Duque et al. (2007), Assunção et al. (2006), Jain (2010)
Central Feature		

Table 4. Output Feature Class of the Cluster and Outlier Analysis (Esri 2015, reproduced from Tyralis, 2016).

Attribute	Indication
high-high	statistically significant cluster of high values
low-low	statistically significant cluster of low values
high-low	statistically significant spatial data outlier with high value and surrounded by features with low values
low-high	statistically significant spatial data outlier with low value and surrounded by features with high values

Figures

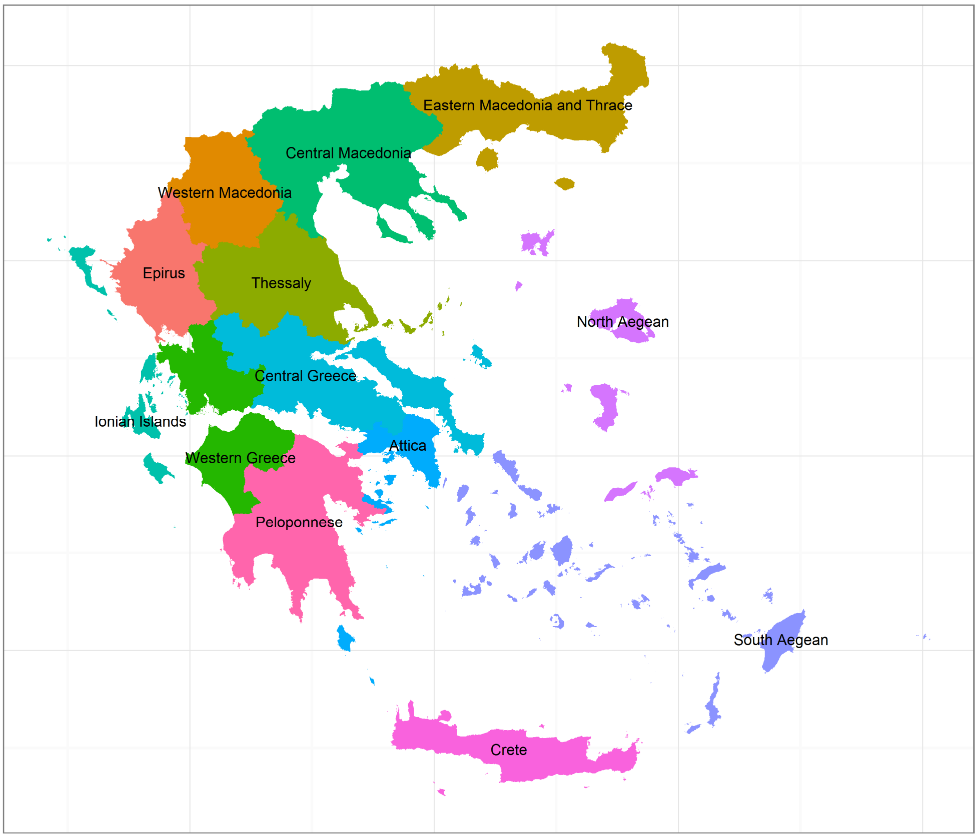

Figure 1. NUTS (Nomenclature of Territorial Units for Statistics) level 2.

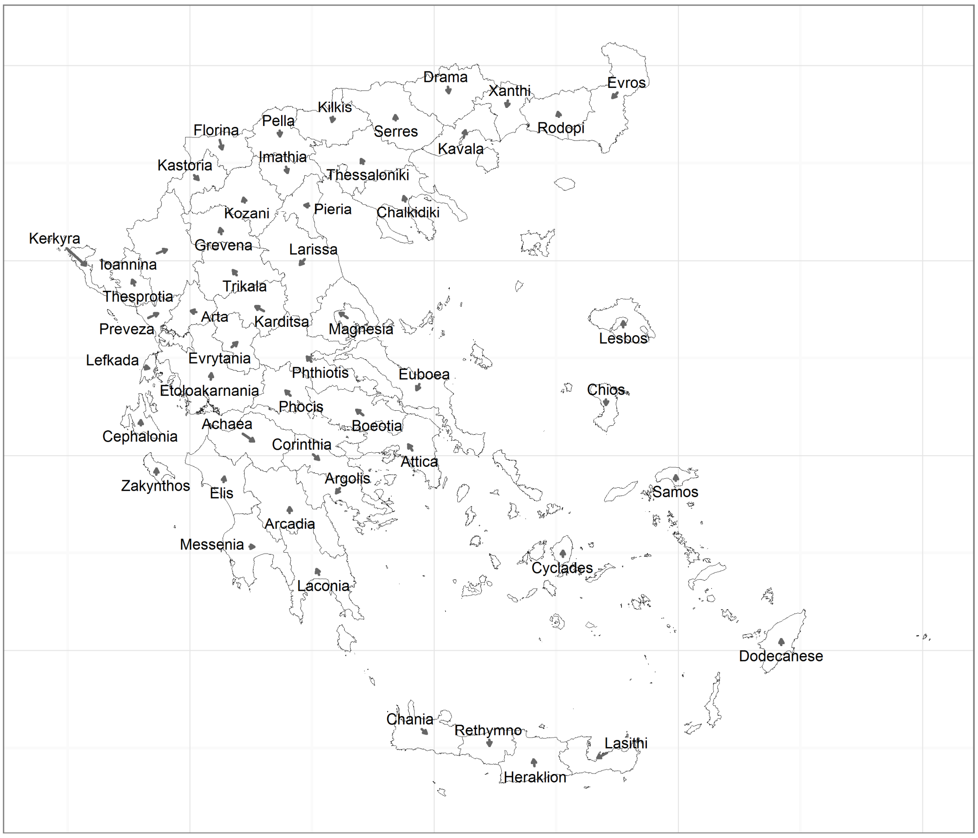

Figure 2. NUTS (Nomenclature of Territorial Units for Statistics) level 3.

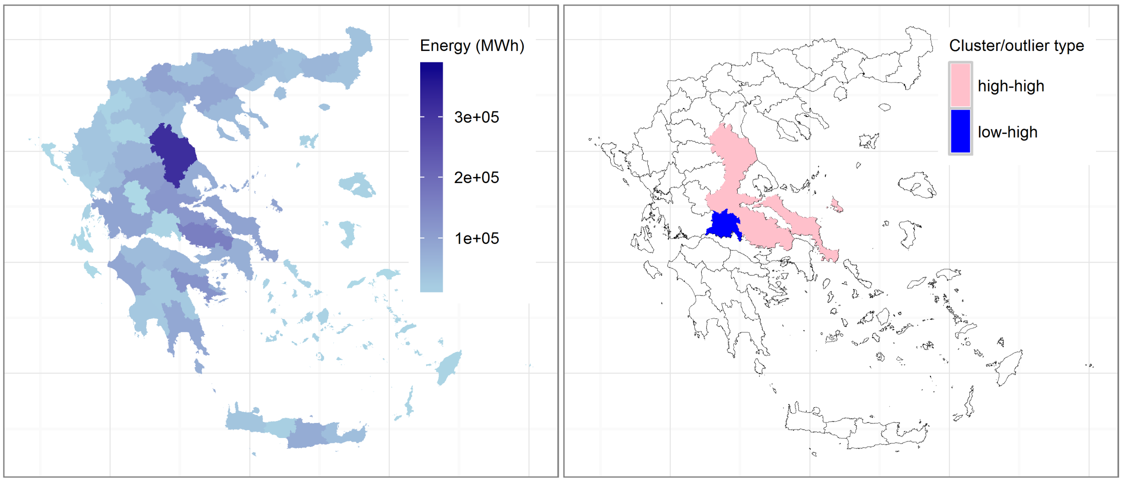

Figure 3. EED for agricultural use of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

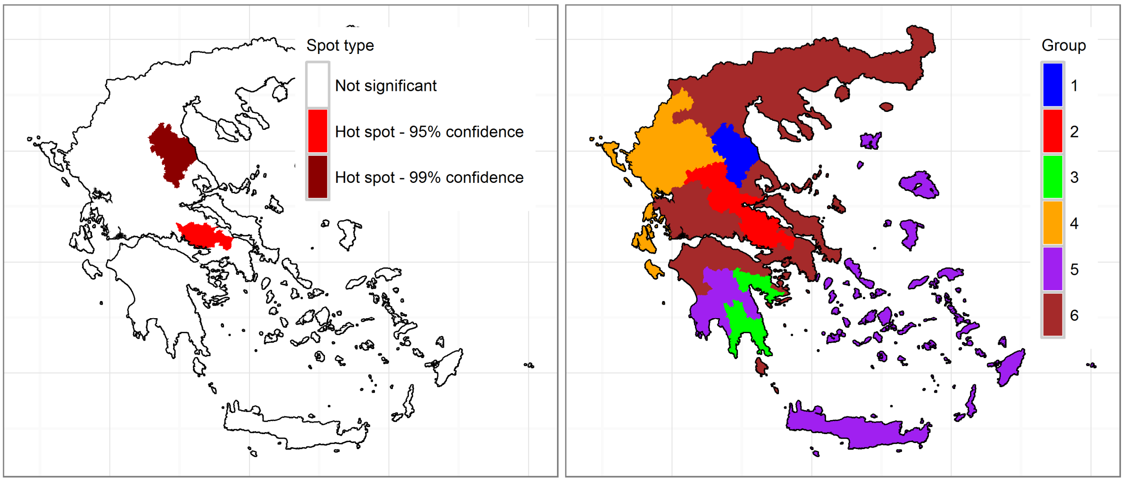

Figure 4. Hot spot analysis of the EED for agricultural use of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

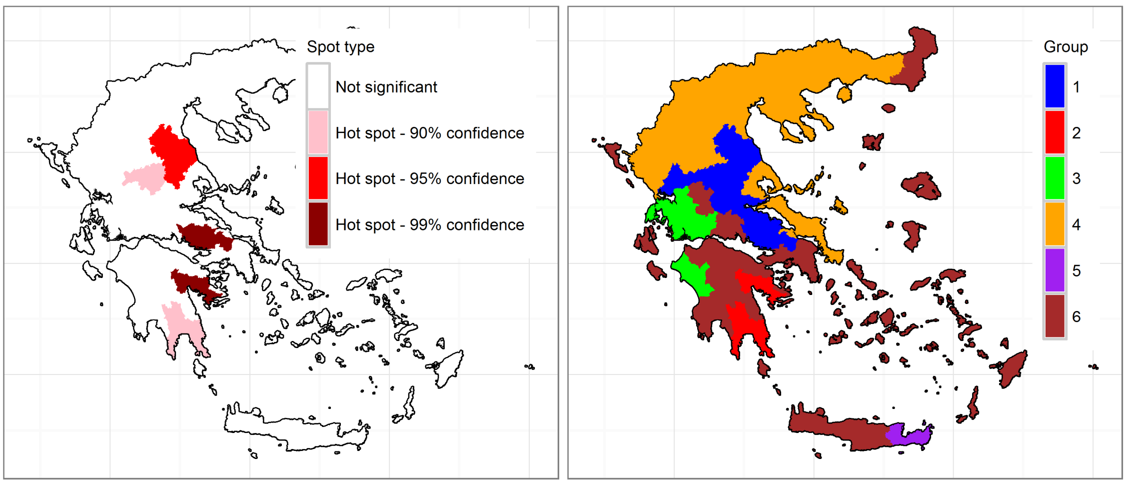

Figure 5. Hot spot analysis of the EED for agricultural use per capita of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

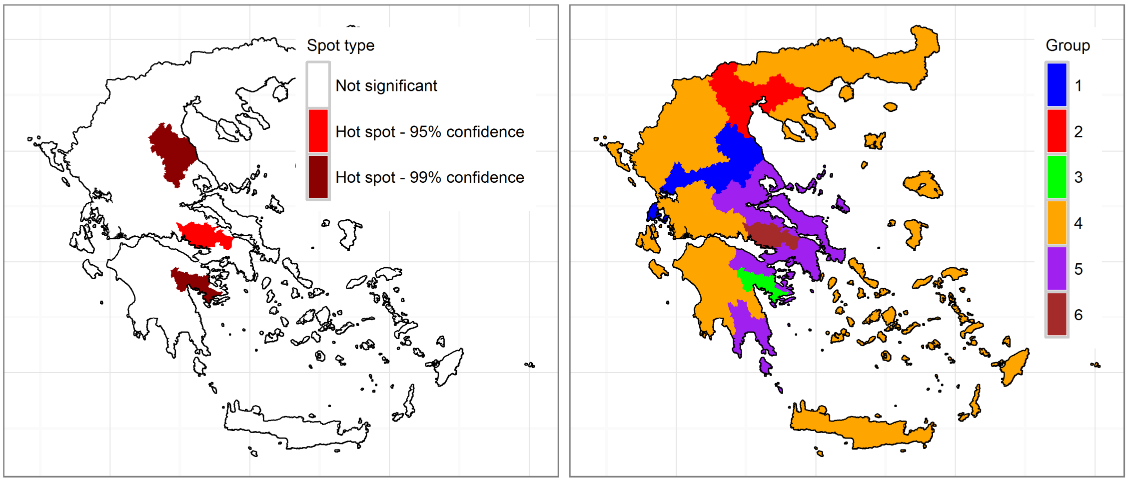

Figure 6. Hot spot analysis of the ratio of the EED for agricultural use to the prefecture area of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

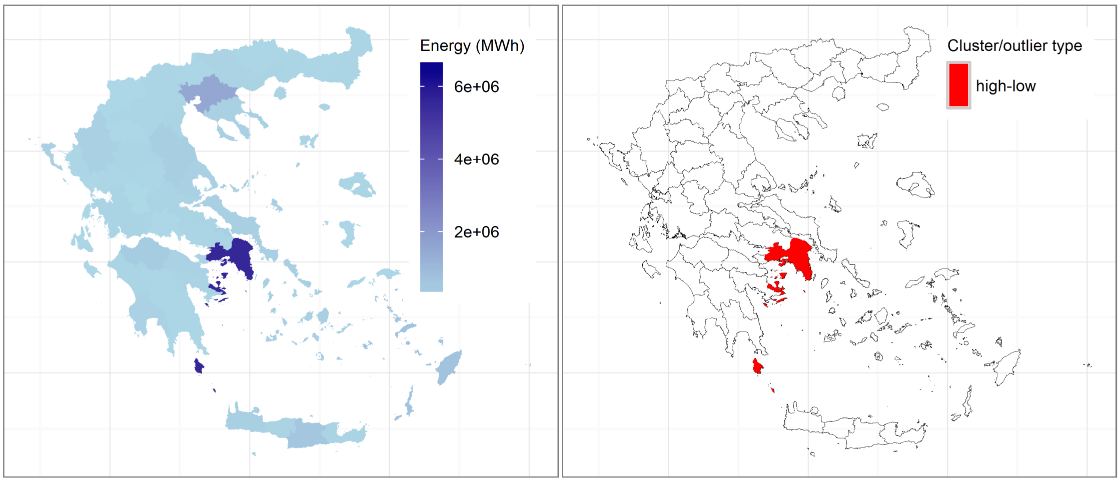

Figure 7. EED for commercial use of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

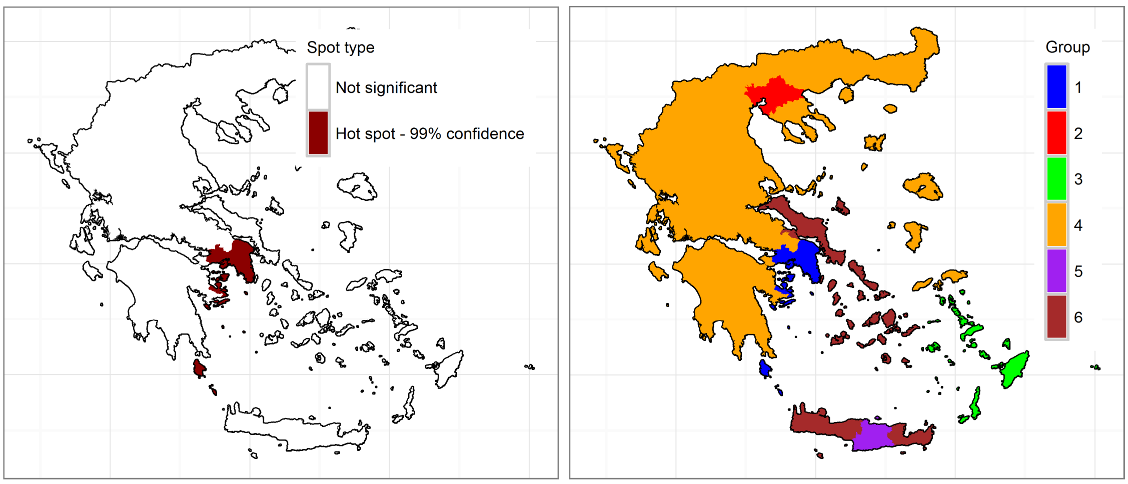

Figure 8. Hot spot analysis of the EED for commercial use of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

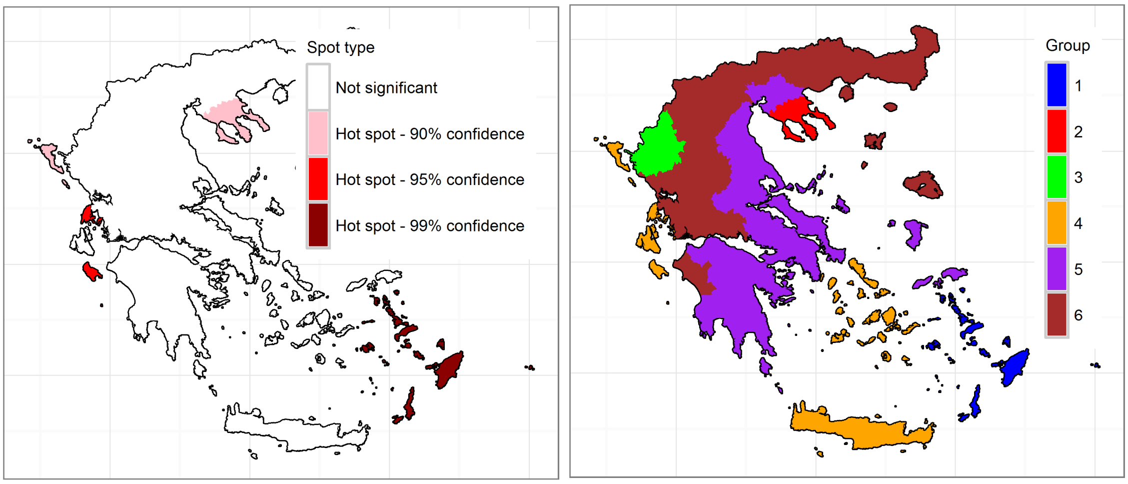

Figure 9. Hot spot analysis of the EED for commercial use per capita of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

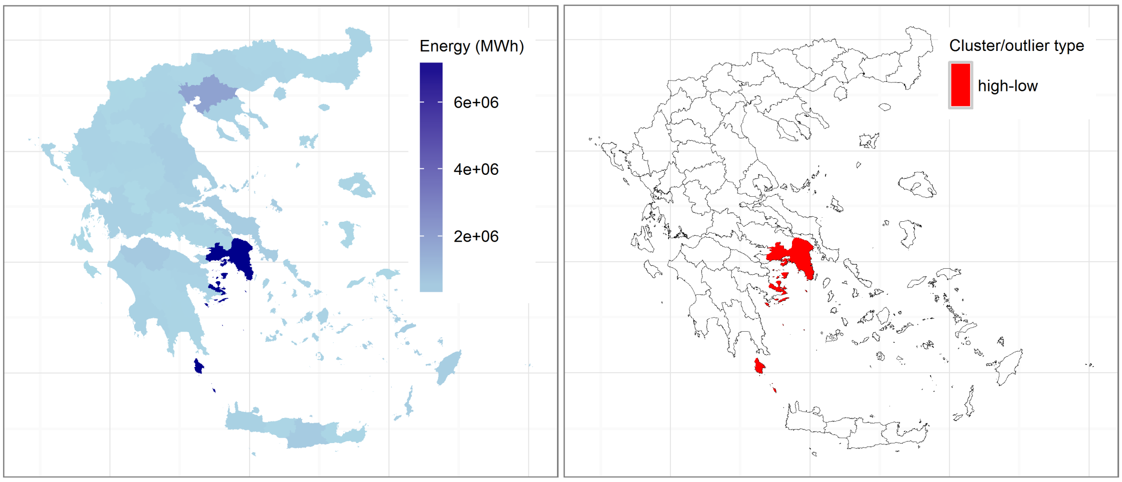

Figure 10. EED for domestic use of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

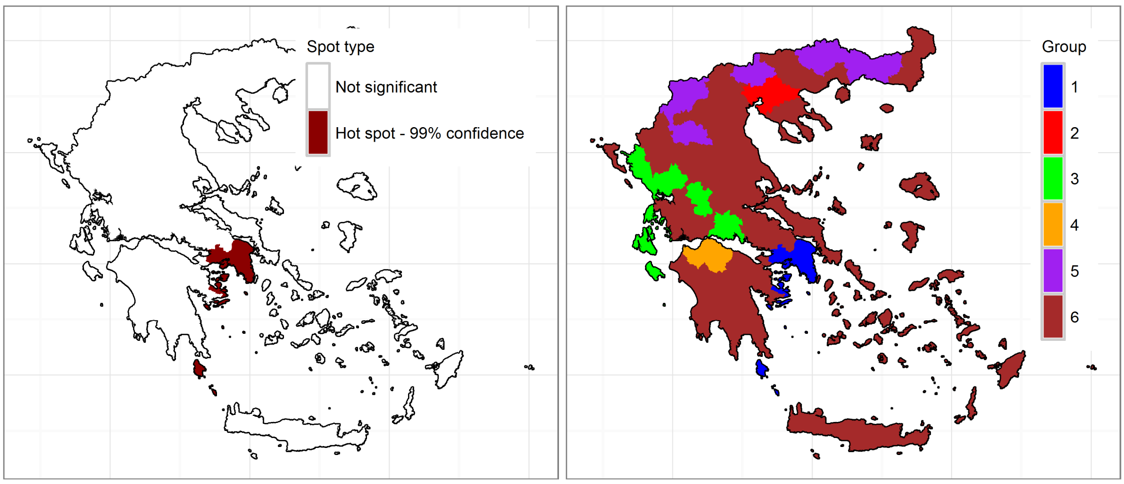

Figure 11. Hot spot analysis of the EED for domestic use of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

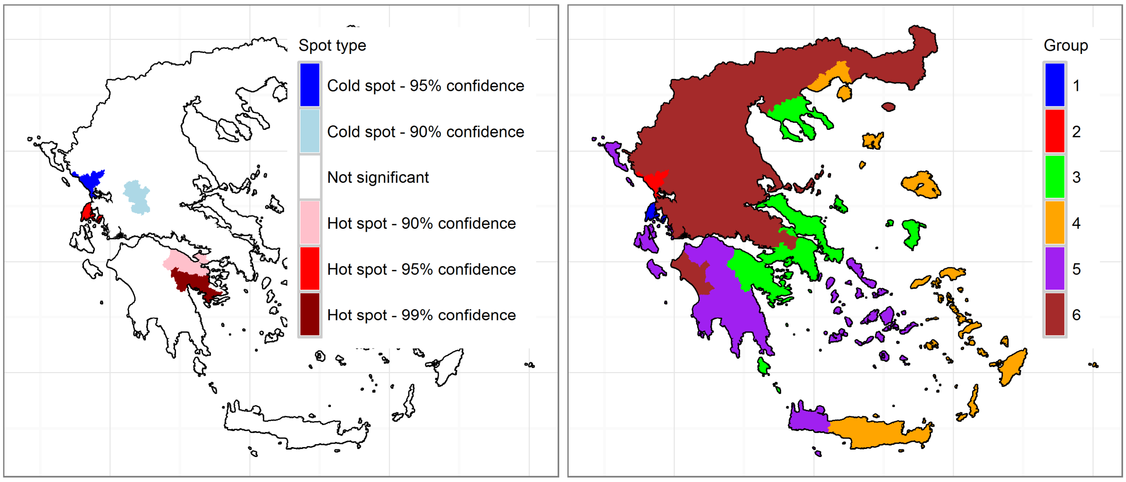

Figure 12. Hot spot analysis of the EED for domestic use per capita of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

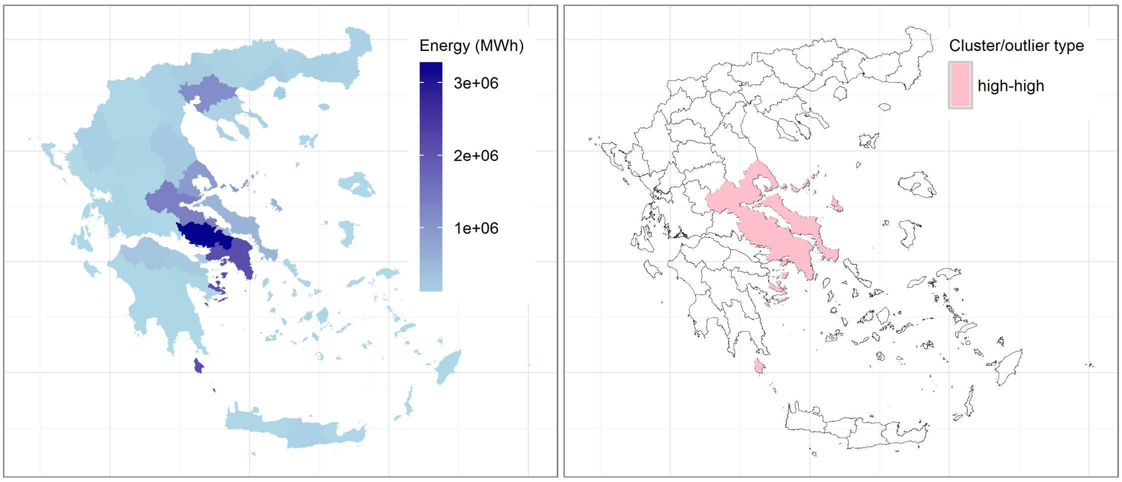

Figure 13. EED for industrial use of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

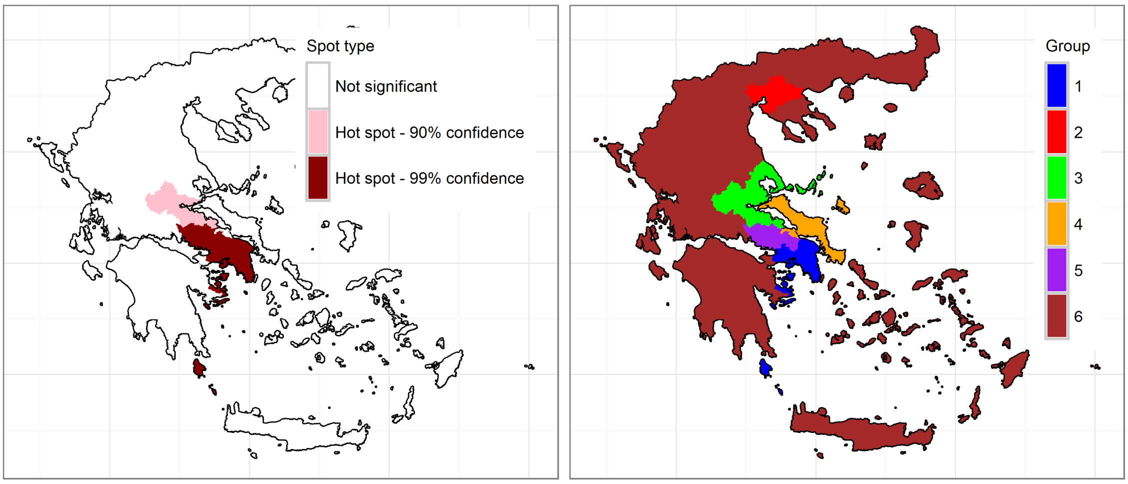

Figure 14. Hot spot analysis of the EED for industrial use of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

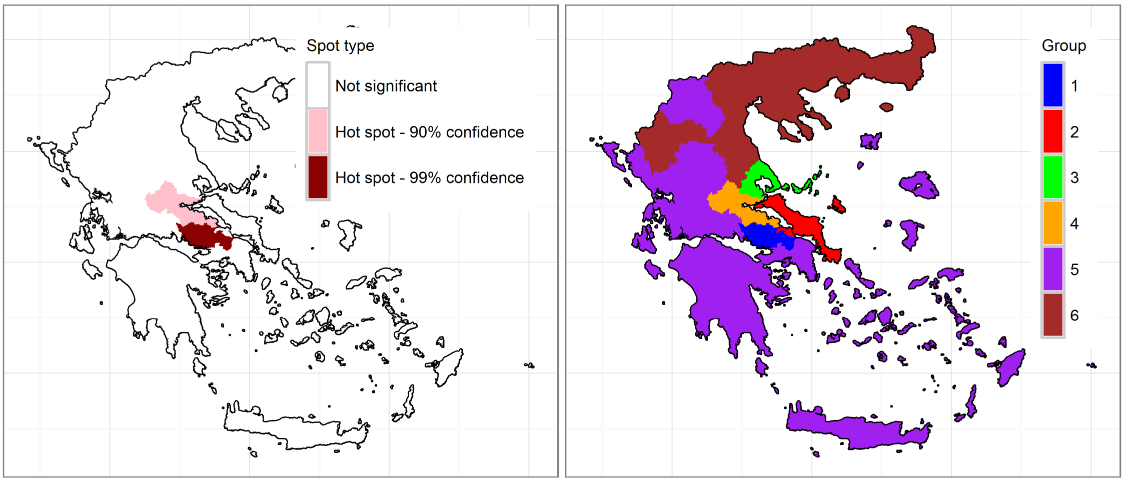

Figure 15. Hot spot analysis of the EED for industrial use per capita of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

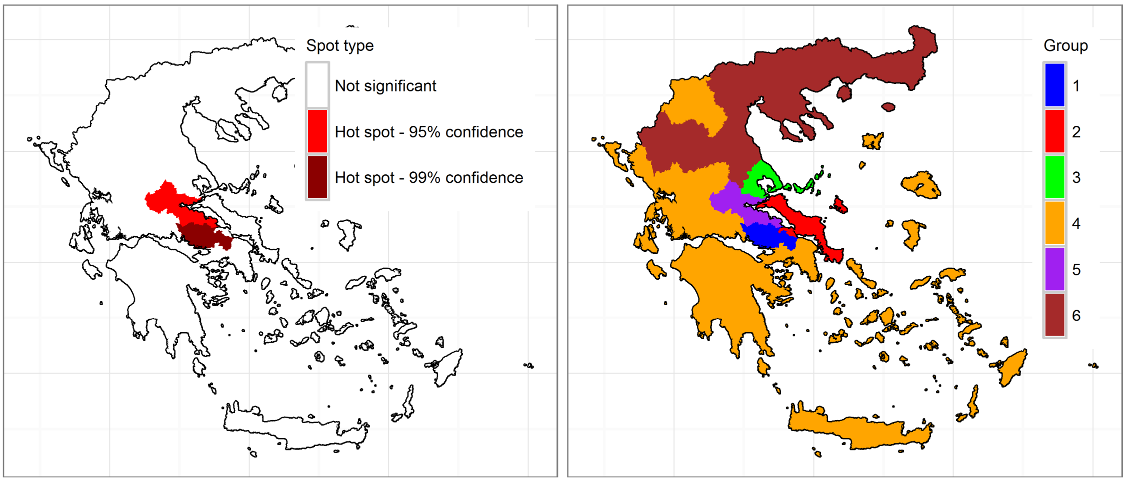

Figure 16. Hot spot analysis of the ratio of the EED for industrial use to the GDP of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

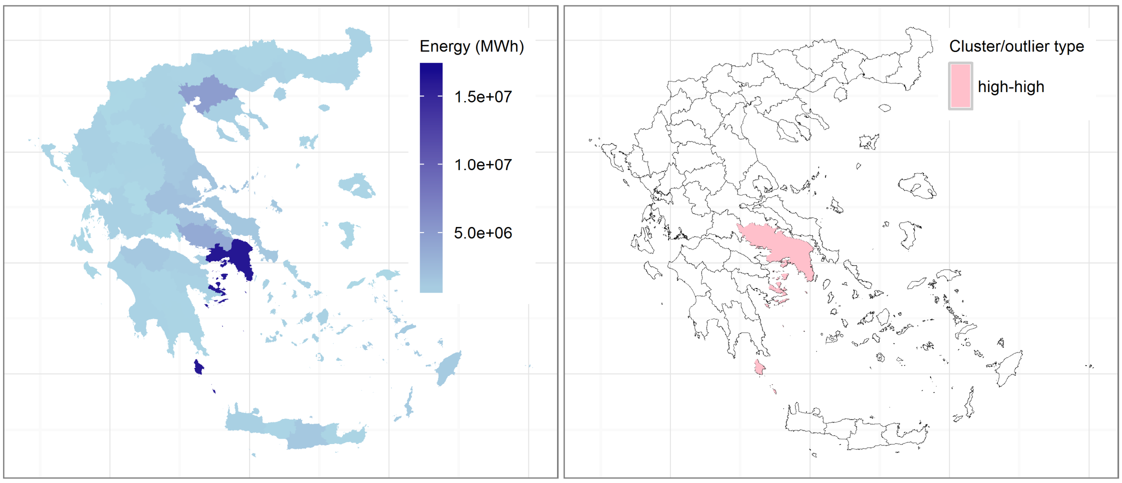

Figure 17. Total EED of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

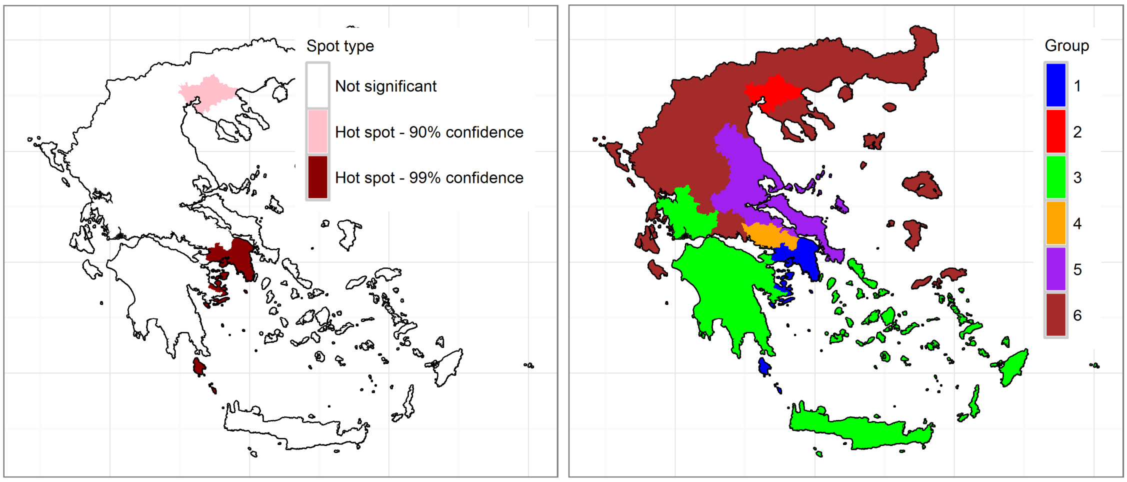

Figure 18. Hot spot analysis of the total EED of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

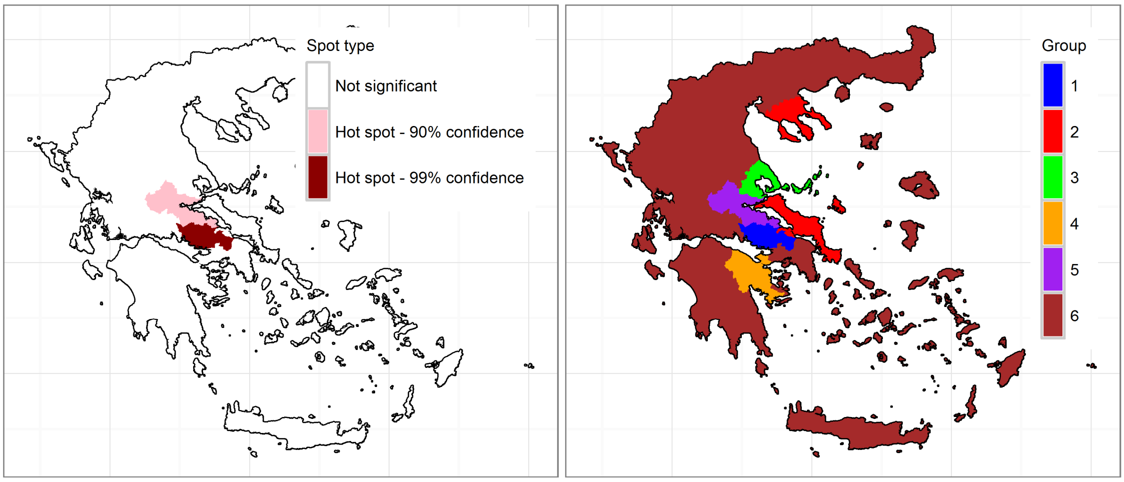

Figure 19. Hot spot analysis of the total EED per capita of the Greek prefectures (left) and corresponding grouping analysis (right) as at the year 2012.

Figure 20. Heatmap which summarizes the standardized values of the variables examined in Section 3. The x-axis presents the examined variables and the y-axis presents the prefectures. The prefectures were clustered, conditional on the standardized values of the variables. Darker colours correspond to higher values of variables.