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## Spatial analysis of electrical energy demand patterns in Greece: Application of a GIS-based methodological framework

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### Abstract

We investigate various uses of the Electrical Energy Demand (EED) in Greece (agricultural, commercial, domestic, industrial use) and we examine their relationships with variables such as population and the Gross Domestic Product. The analysis is performed on data from the year 2012 and have spatial resolution down to the level of prefecture. We both visualize the results of the analysis and we perform spatial cluster and outlier analysis. The definition of the spatial patterns of the aforementioned variables in a GIS environment provides insight of the regional development model in Greece.

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*Keywords:* cluster and outlier analysis ; electrical energy demand ; GIS ; Greece ; Gross Domestic Product ; population ; spatial analysis

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### 1. Introduction

Numerous studies concerning the analysis of the Electrical Energy Demand (EED) in Greece in the time domain and its relationship with climate-related and socio-economic variables have been published. A list of the most recent papers can be found in [1]. However, the spatial analysis of the EED, or relevant energy variables in Greece has been the subject of a limited number of studies including [2-4].

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In this study we investigate various uses of the EED in Greece (agricultural use, commercial use, domestic use, industrial use) and we examine their relationship with variables such as population and the Gross Domestic Product (GDP). The analysis is performed on data from the year 2012 and have annual temporal resolution and spatial resolution down to the level of prefecture. We perform a spatial cluster and outlier analysis and we visualize the results. The definition of the spatial patterns of the aforementioned variables in a GIS environment provides meaningful insight and better understanding of the regional development model in Greece.

**2. Data and methods**

In Section 2 we present the data and the methods that were used in Section 3 to perform the analysis.

**2.1. Data**

Table 1 presents the data that were used in the analysis. Until the year 2012, Greece was divided to 51 Greek prefectures, which are illustrated in Fig. 1. The data have spatial resolution down to the level of prefecture. They also have annual temporal resolution and cover the year 2012.

Table 1. Examined variables for every Greek prefecture for the year 2012. Data are annual. The cases column includes the number of examined variables (data source: Hellenic Statistical Authority).

| Variable   | Unit of measurement | Cases |
|--|---------------------|-------|
| EED (agricultural use, commercial use, domestic use, industrial use) | MWh                 | 4     |
| GDP  | 10 <sup>6</sup> €   | 1     |
| Population   | people              | 1     |

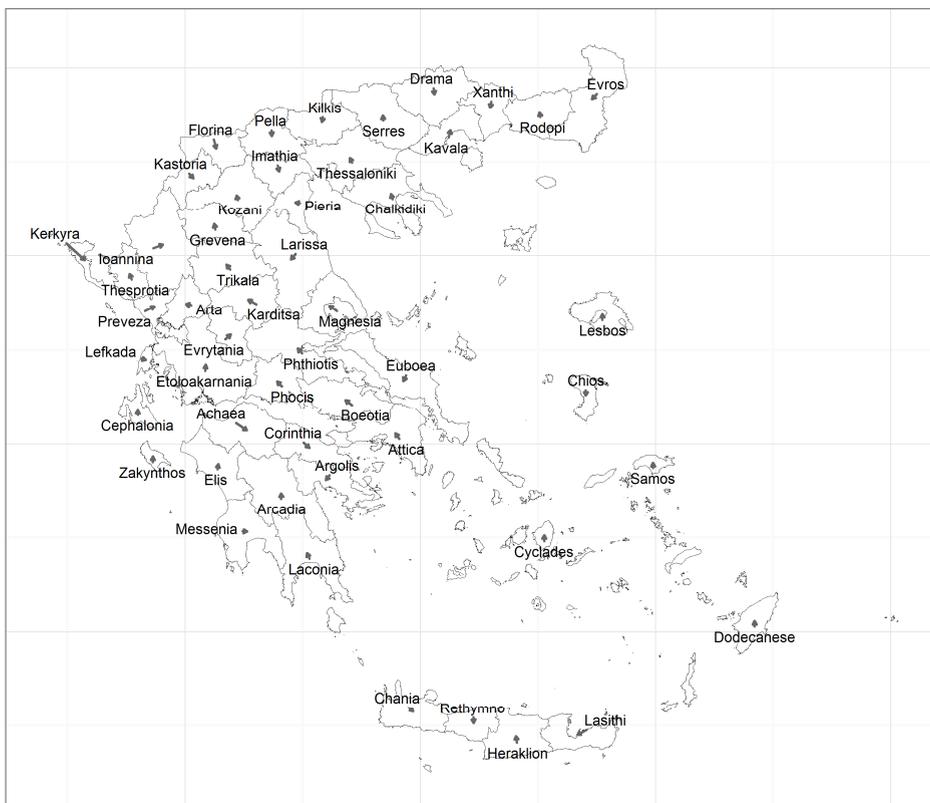


Fig. 1. Greek prefectures as at the year 2012.

Furthermore, we examined several variable combinations (i.e. variables which came after operations on the variables of Table 1), which are presented in Table 2. The transformed variables are in particular scaled over the population, the GDP etc. We visualized 35 variables, which is the sum of the number of examined cases in Table 1 and Table 2 (cases column).

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 <sup>2</sup> | 1     |
| GDP / capita                     | 10 <sup>6</sup> € / capita   | 1     |
| EED per use / total EED          | 10 <sup>6</sup> € / capita   | 6     |
| EED per use / GDP                | 10 <sup>6</sup> € / capita   | 7     |
| EED per use / capita             | 10 <sup>6</sup> € / capita   | 7     |
| EED per use / population density | 10 <sup>6</sup> € / capita   | 7     |

## 2.2. Methods

We could obtain an initial inference with the data visualization, which could be enhanced with the application of statistical methods. Thus we performed cluster and outlier analysis using the Anselin Local Moran's I statistic (see Table 3). The cluster and outlier analysis locates spatial clusters of high or low values or spatial outliers (high/low outliers surrounded by features with low/high values). We used the relevant tool of Esri [5]. Table 3 contains the parameters of the tool which were used in the case study, and its documentation. We applied the cluster and outlier analysis to all 35 cases, and the results are illustrated in 35 Figures. The possible outcome of the analysis is presented in Table 4 and is depicted as legend in the Figures of Section 3.

Table 3. Esri tools [5] 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 | [6]        |

Table 4. Output Feature Class of the Cluster and Outlier Analysis (Esri [5]).

| 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 |

## 3. Results

In Section 3 we present part of the analysis for selected variables. We show agricultural, commercial, domestic and industrial uses of EED combined with variables such as the GDP and the population. The EED variable depends on variables such as the GDP and the population. The spatial distribution of these variables is non-uniform. The EED is distributed to various uses as presented in Table 1. Even the spatial distribution between the various EED uses is extremely non-uniform. We can observe various spatial patterns, possibly associated with regional development plan of Greece, due to the EED spatial variability. In Section 3 we illustrate the spatial distributions of some of these variables.

The population of Greece is concentrated in Attica and Thessaloniki prefectures (see Fig. 2). We also observe the highest population density in these two prefectures (Fig. 2). There is spatial variability of the GDP per capita (Fig. 3). Prefectures with the highest GDP per capita are again Attica and Thessaloniki, and furthermore Middle Greece (i.e. Boeotia, Larissa, Magnesia, Phthiotis), Kozani, Cyclades and other prefectures. We also observe the highest total EED in Attica, Thessaloniki and Middle Greece (Fig. 3).

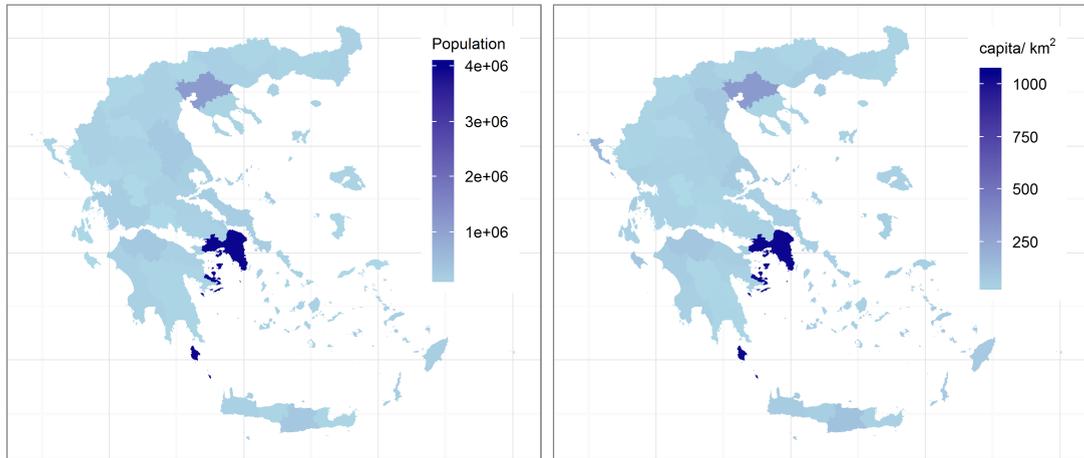


Fig. 2. Population (left) and population density (right) of the Greek prefectures as at the year 2012.

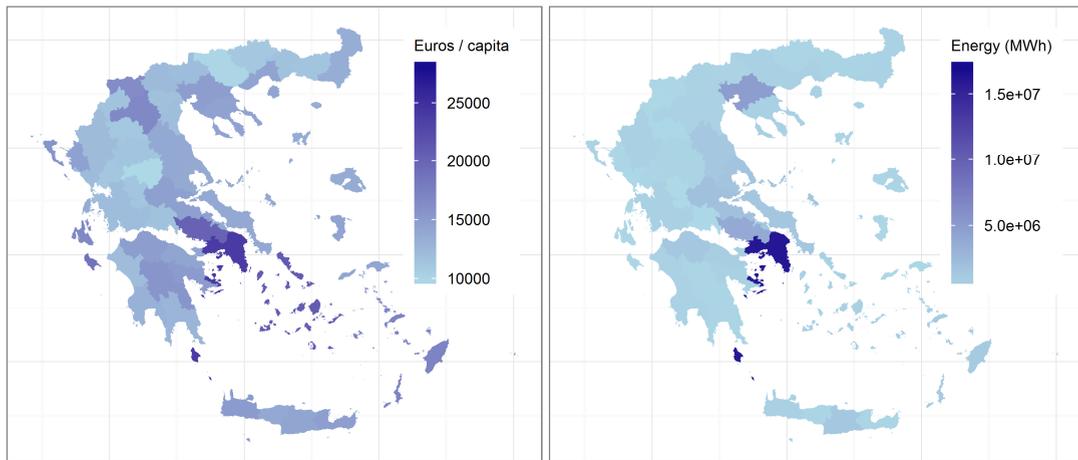


Fig. 3. GDP per capita (left) and total EED (right) of the Greek prefectures as at the year 2012.

In Fig. 4 we observe that Boeotia and Larissa (part of Middle Greece) form a cluster of high values of the EED for agricultural use per capita. Some islands (including Cyclades and Samos) form a cluster of low values. Attica is a low outlier. Argolis and Laconia are also prefectures with high values (see Fig. 4, left).

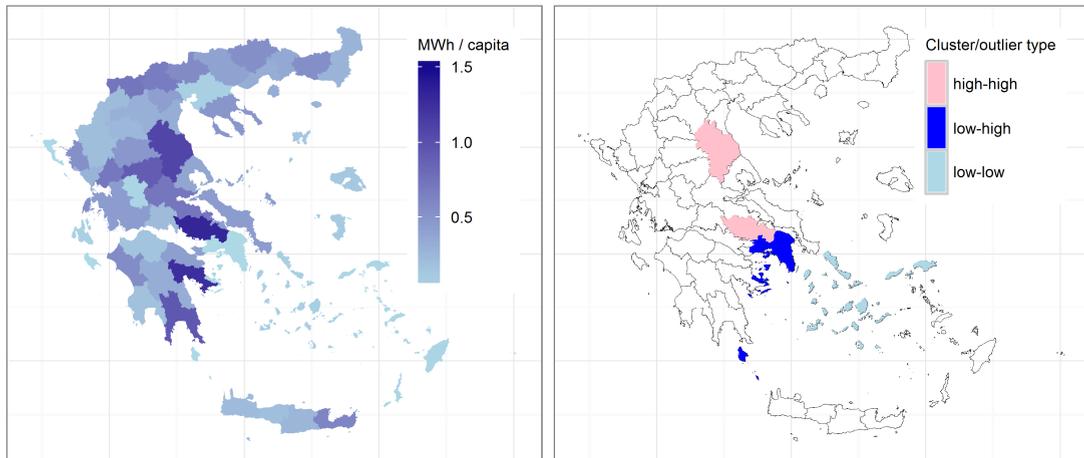


Fig. 4. EED for agricultural use per capita of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

Middle Greece forms a cluster of low values of the ratio of EED for commercial use to total EED (Fig. 5). On the other hand, we observe a cluster of high values in the islands (Chania, Heraklion, Rethymno, Lasithi (i.e. the four prefectures of Crete island), Dodecanese and Samos). We also observe some remote islands with high values of the ratio such as Lefkada.

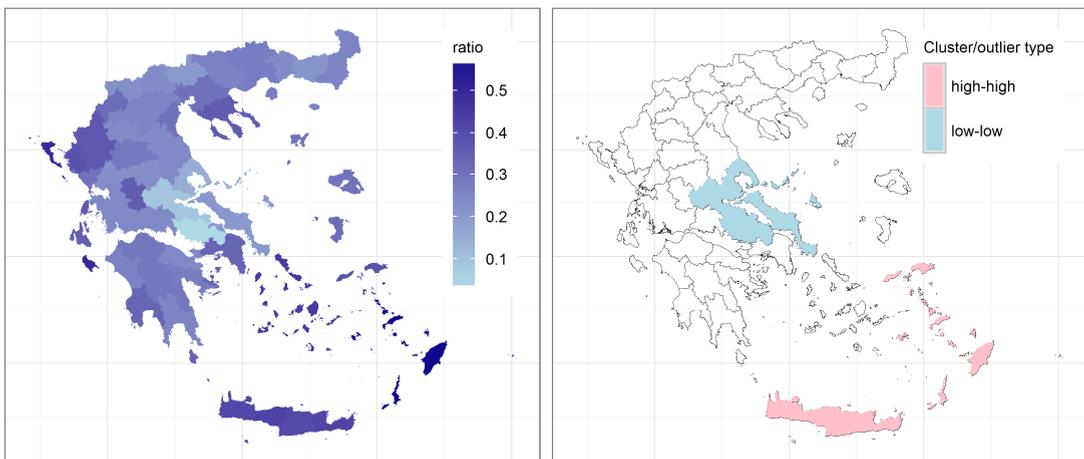


Fig. 5. Ratio of EED for commercial use to total EED of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

Argolis, Attica and Euboea form a cluster of high values of the EED for domestic use per capita (Fig. 6). We observe an outlier of high values in Western Greece, which is adjacent to a cluster of low values. Chalkidiki prefecture is another area with high value of the ratio (Fig. 6, left).

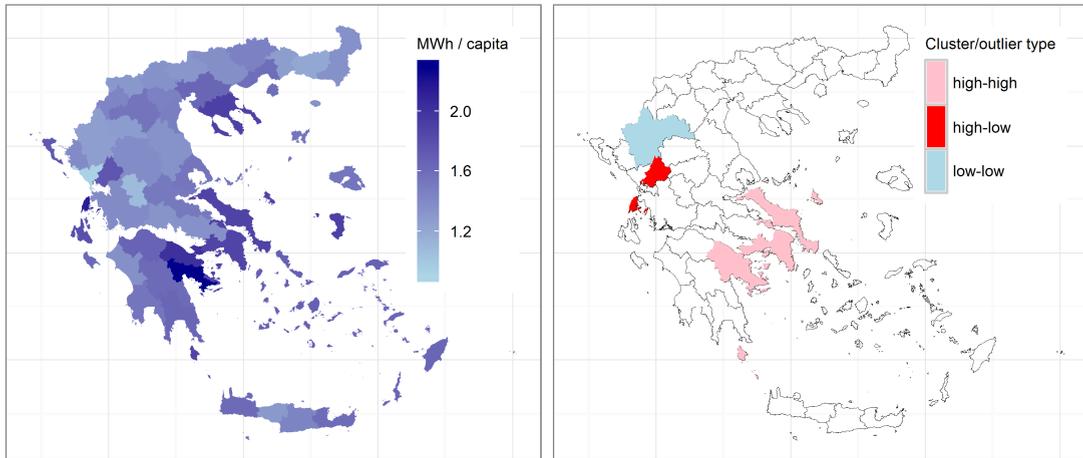


Fig. 6. EED for domestic use per capita of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

In Fig. 7 we observe that Middle Greece consists a cluster of high values of the ratio of EED for industrial use to total EED.

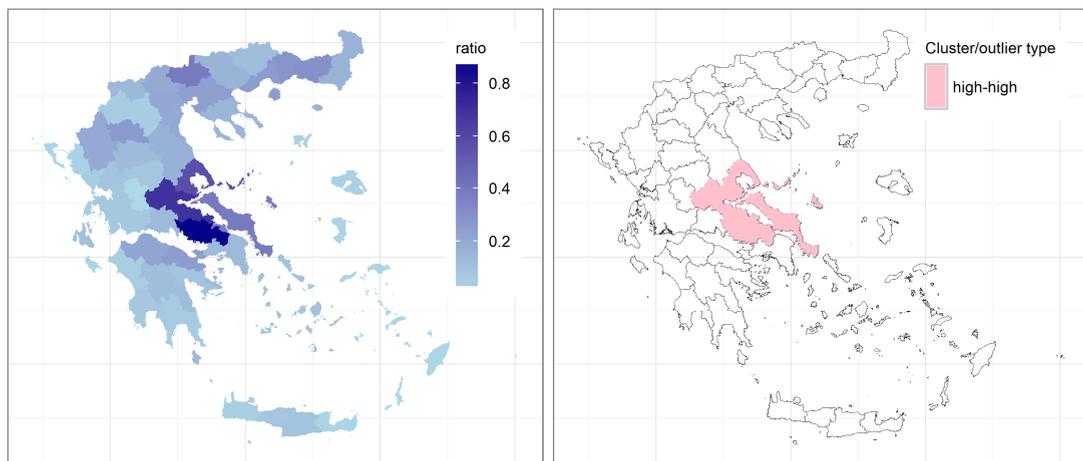


Fig. 7. Ratio of EED for industrial use to total EED of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

In Fig. 8 we present the energy intensity (ratio of total EED to GDP) which is used as an official indicator of local economic performance and energy conversation policies in China [7]. Middle Greece forms a cluster of high values, while Attica is a low value outlier.

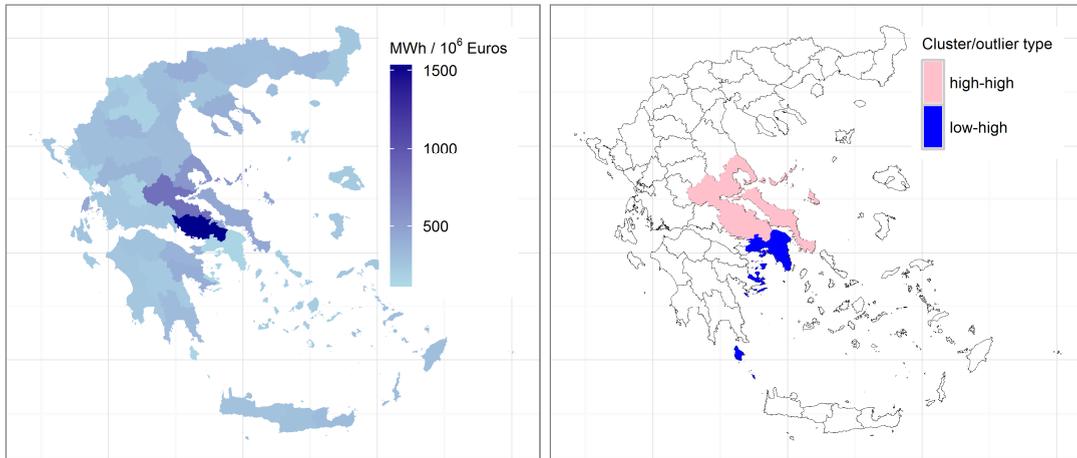


Fig. 8. Ratio of total EED to GDP of the Greek prefectures (left) and corresponding cluster and outlier analysis (right, legend explained in Table 4) as at the year 2012.

#### 4. Discussion and conclusions

The EED for agricultural use per capita could be used as an index to classify a region as agricultural. Agricultural regions seem to be dispersed in mainland. On the other hand, this index is low in the big prefectures of Attica and Thessaloniki and in the islands. The islands, and in general regions adjacent to the sea, could be classified as commercial. Possibly this is due to the touristic character of these regions. The areas with high values of domestic use in Greece seem to be dispersed, thus we cannot infer on this. The Middle Greece could be classified as an industrial region. We observe high values of the energy intensity in industrial regions. In overall, various types of activities are dispersed in Greece, with the exception of the islands which are oriented towards commerce and the industrial Middle Greece.

Summarizing we investigated the patterns of EED in Greece. The investigation was performed with the visualization of EED and socio-economic data and their analysis using a spatial cluster and outlier analysis. We present part of the analysis for the year 2012 and for selected variables in this study. The results are useful to infer about the regional development model of Greece and could be used for the management of the Greek electrical system and the application of optimum policies for improving the regional development model.

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