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

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# 1. Abstract

We investigate various uses of electricity demand in Greece (agricultural, commercial, domestic, industrial use as well as use for public and municipal authorities and street lighting) and we examine their relation with variables such as population, total area, population density and the Gross Domestic Product. The analysis is performed on data which span from 2008 to 2012 and have annual temporal resolution and spatial resolution down to the level of prefecture. We both visualize the results of the analysis and we perform cluster and outlier analysis using the Anselin local Moran's I statistic as well as hot spot analysis using the Getis-Ord  $G_i^*$  statistic. The definition of the spatial patterns and relationships of the aforementioned variables in a GIS environment provides meaningful insight and better understanding of the regional development model in Greece and justifies the basis for an energy demand forecasting methodology.

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## 2. Introduction

- Tyralis et al. (2016a) present an extensive literature about the Energy Demand (ED) and the Electrical Energy Demand (EED) in Greece. They also visualize the EED in the time domain.
- Case studies including spatial analysis of the ED in various locations in Greece, were prepared e.g. by Katsoulakos and Kaliampakos (2014) and Panagiotopoulos and Katsoulakos (2014).
- The international literature includes many studies, which analyse spatially the EED. Most of them were performed in China, e.g. Sheng et al. (2014), Wang et al. (2012), Zhang and Lahr (2014) and examined the relationship of the EED with socio-economic variables.
- Many studies about the regional development model of Greece and related issues also exist, e.g. Goletsis and Chletsos (2011) and Monastiriotis (2009, 2011).
- In this study:
  - We investigate various uses of EED in Greece (agricultural, commercial, domestic, industrial use as well as use for public and municipal authorities and street lightning)
  - We examine their relationship with socio-economic variables such as population, total area, population density and the Gross Domestic Product.
  - The analysis is performed on data which span from 2008 to 2012 and have annual temporal resolution and spatial resolution down to the level of prefecture.
  - We both visualize the results of the analysis and we apply various methods of spatial analysis.
  - The definition of the spatial patterns and relationships of the aforementioned variables in a GIS environment provides meaningful insight and better understanding of the regional development model in Greece and justifies the basis for an energy demand forecasting methodology.

### 3. Data and examined variables

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 <sup>6</sup> €   | 1     |
| Area   | m <sup>2</sup>      |       |
| Population   | people              | 1     |

Examined combinations of variables, occurring after the transformation of the variables in the examined variables Table. 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                     | € / capita                          | 1     |
| EED per use / total EED          |                                     | 6     |
| EED per use / GDP                | MWh / 10 <sup>6</sup> €             | 7     |
| EED per use / capita             | MWh / capita                        | 7     |
| EED per use / area               | MWh / km <sup>2</sup>               | 7     |
| EED per use / population density | MWh / (population/km <sup>2</sup> ) | 7     |

## 4. Esri (2015) tools used for the analysis

- The Cluster and Outlier Analysis tool identifies spatial clusters of features with high or low values. The tool also identifies spatial outliers.
- The Hot Spot Analysis (Getis-Ord  $G_i^*$ ), identifies statistically significant hot spots and cold spots using the Getis-Ord  $G_i^*$  statistic, given a set of weighted features.
- The Grouping Analysis groups features based on feature attributes and optional spatial or temporal constraints.
- The Central Feature identifies the most centrally located feature in a point, line, or polygon feature class.

### Parameters of the tools and corresponding references.

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                          | Reference  |
|--|-------------------------------------|--|
| Cluster and Outlier Analysis (Anselin Local Moran's I) | $p$ -value = 0.05                   | Anselin (1995)   |
| Hot Spot Analysis (Getis-Ord $G_i^*$ )                 |                                     | Getis and Ord (1992),<br>Ord and Getis (1995)                  |
| Grouping Analysis                                      | Delaunay triangulation, six classes | Duque et al. (2007),<br>Assunção et al. (2006),<br>Jain (2010) |
| Central Feature  |                                     |  |

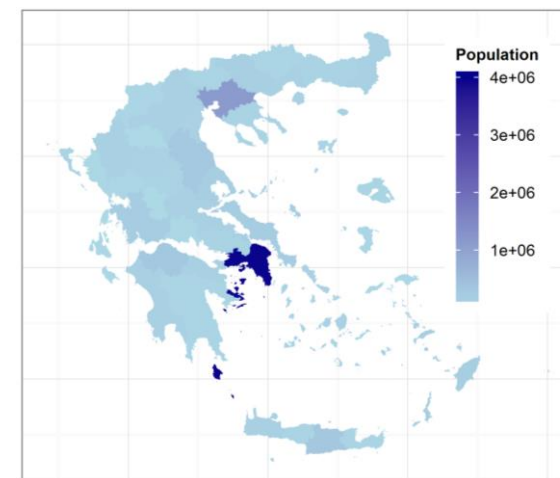


# 5. Prefectures and socio-economic variables (2012)

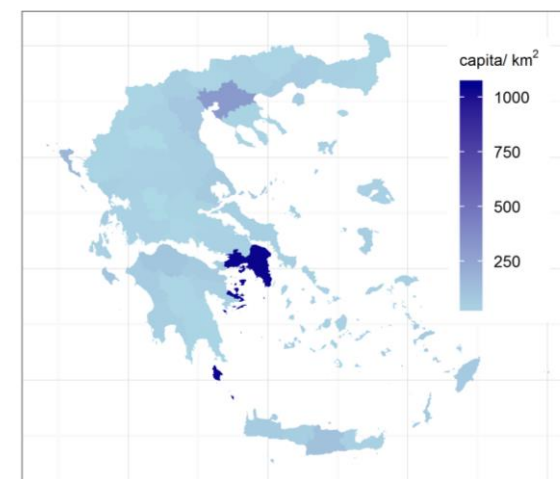
Greek prefectures



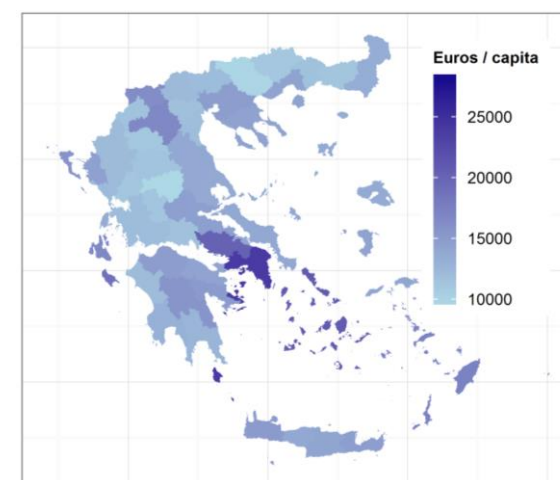
Population



Population density

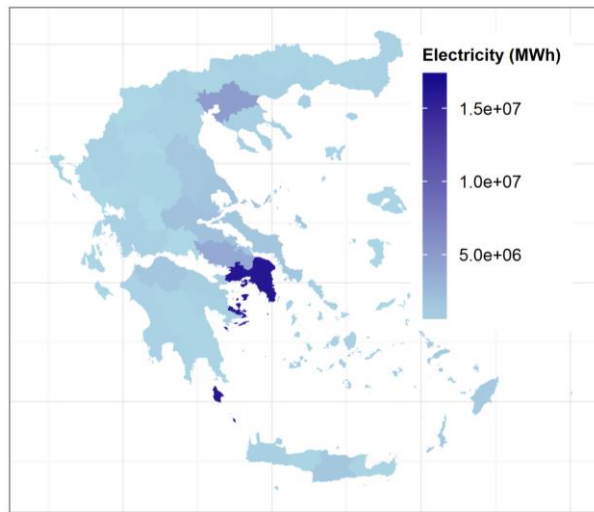


GDP per capita

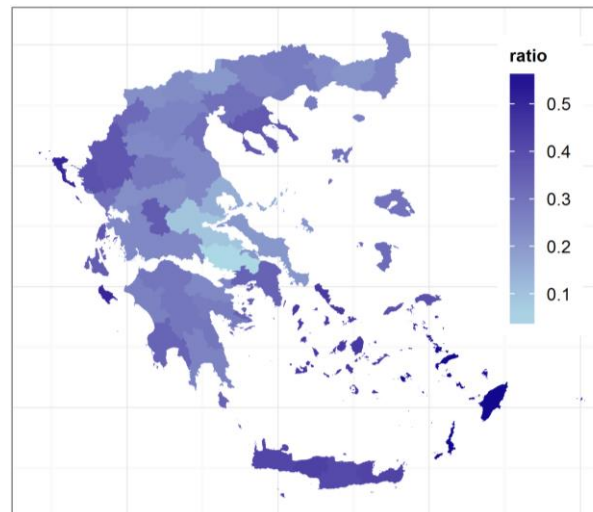


# 6. Electrical energy demand (2012)

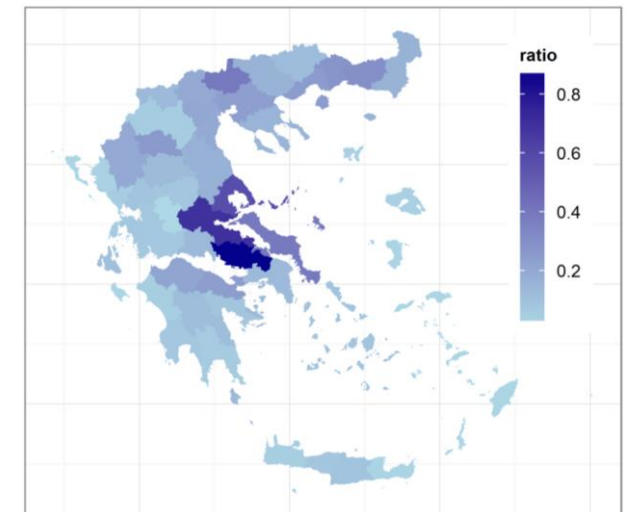
Total EED



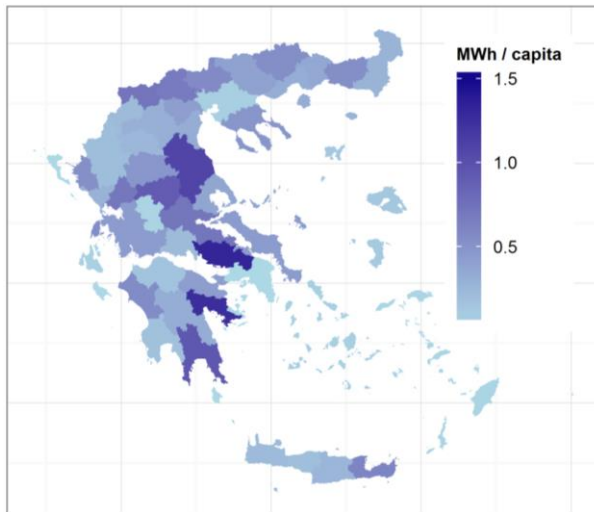
Commercial use EED/total EED



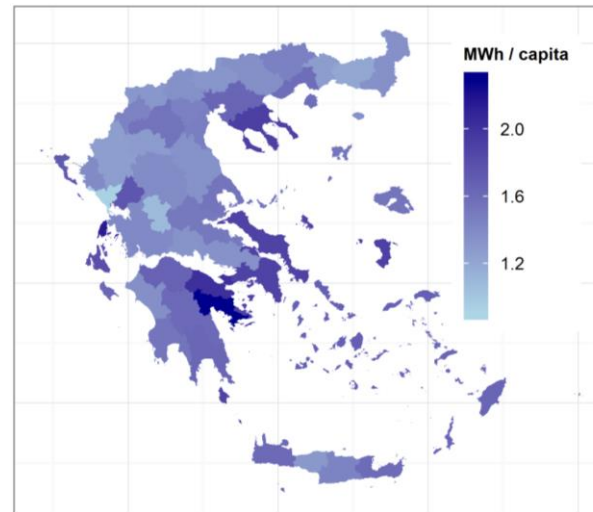
Industrial use EED/total EED



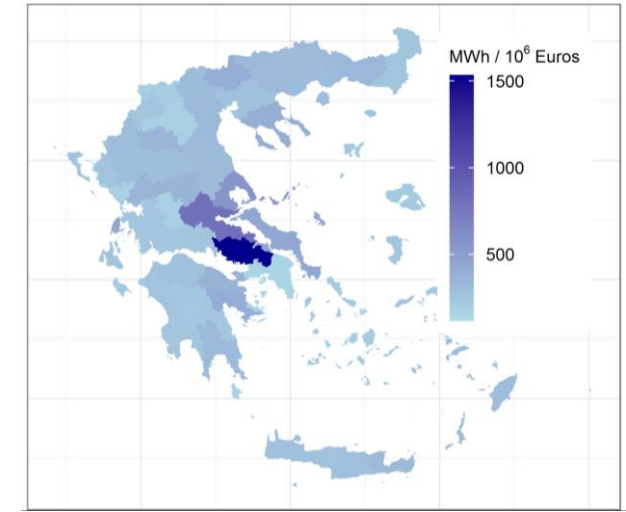
Agricultural use EED/capita



Domestic use EED/capita



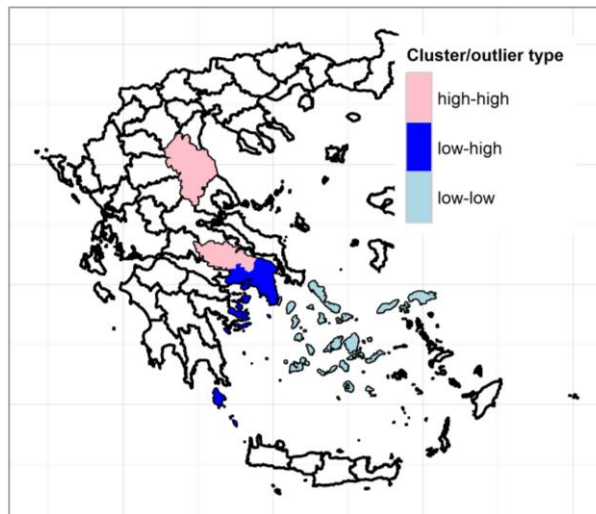
Total EED/GDP



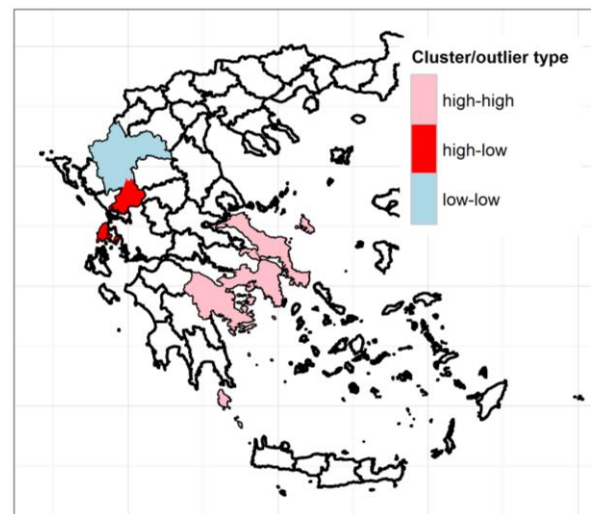
- Argolis, Boeotia, Laconia and Larissa are agricultural regions.
- Islands are commercial regions.
- Argolis, Attica (the most populous), Chalkidiki and Euboea are the most domestic EED consumers.
- Middle Greece (Boeotia, Euboea, Magnesia, Phthiotis) is industrial.
- Highest ratio of total EED/GDP is observed in industrial regions.

# 7. Cluster and Outlier analysis (2012)

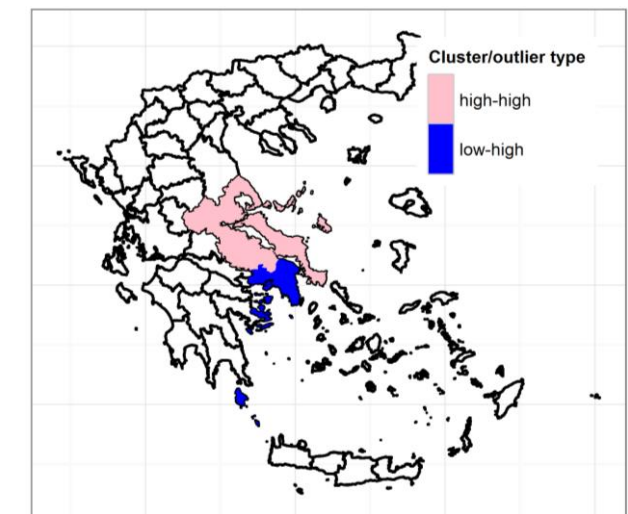
Agricultural use EED/capita



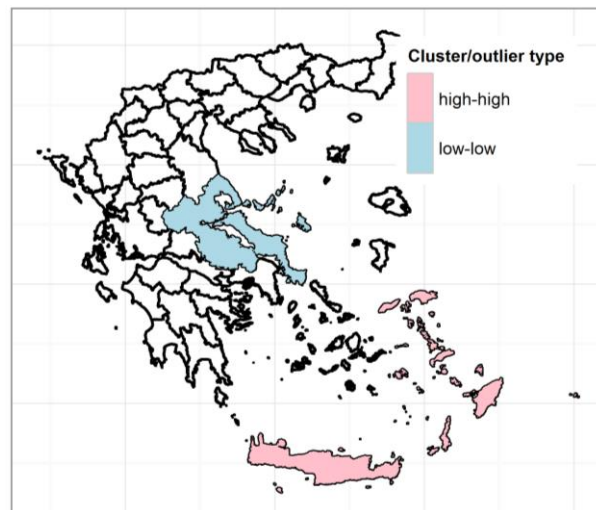
Domestic use EED/capita



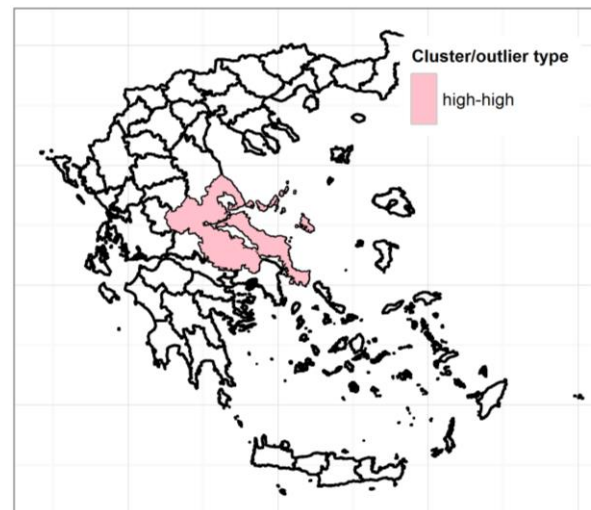
Total EED/GDP



Commercial use EED/total EED



Industrial use EED/total EED



## Cluster/outlier type

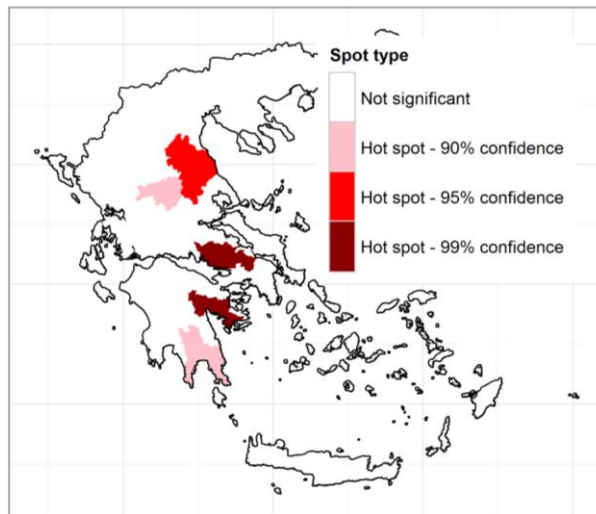
- high-high: clusters with high values.
- low-low: clusters with low values.
- high-low: outliers with high values.
- low-high: outliers with low values.

- Boeotia and Larissa form a cluster of agricultural regions. Middle Greece islands form a cluster of low values.
- Islands are commercial regions, in contrast with the industrial Middle Greece.
- Argolis, Attica (the most populous) and Euboea form a cluster of high values of domestic EED.
- Middle Greece is confirmed to be industrial.
- Highest ratio of total EED/GDP is confirmed to be observed in industrial Middle Greece, whereas Attica is a low value outlier.

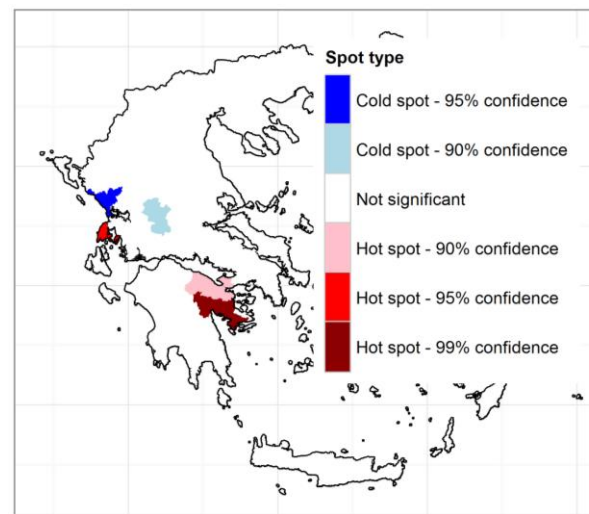


# 8. Hot Spot analysis (2012)

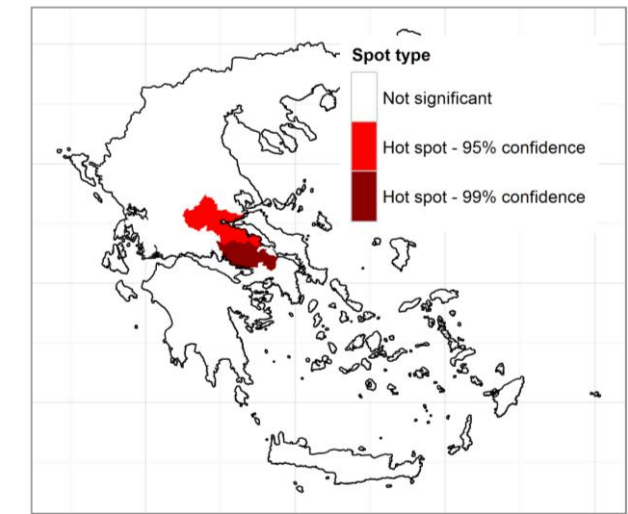
Agricultural use EED/capita



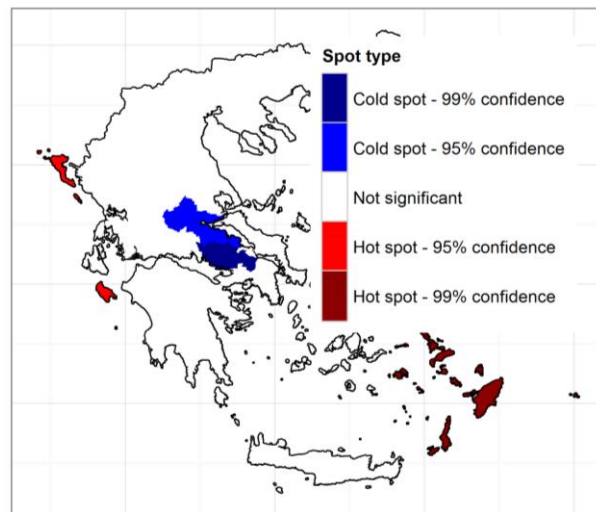
Domestic use EED/capita



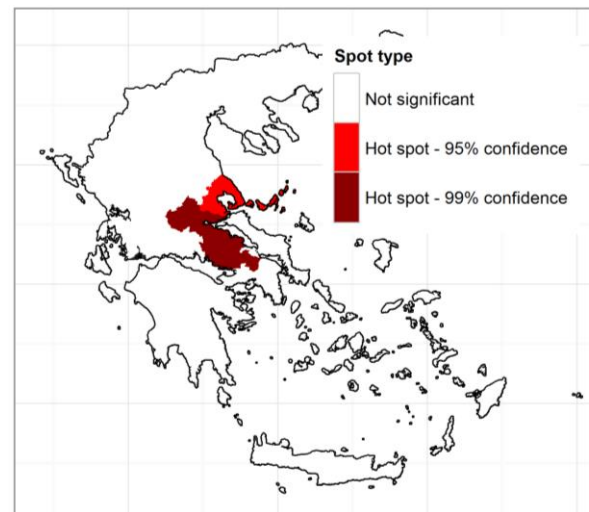
Total EED/GDP



Commercial use EED/total EED



Industrial use EED/total EED



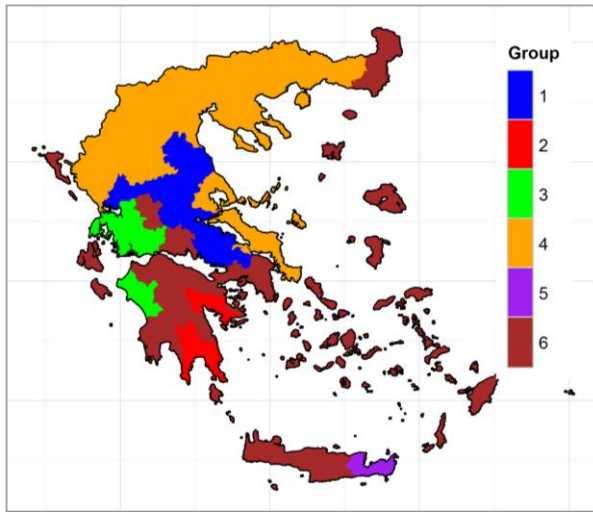
## Spot type

- Hot spot: high values.
- Cold spot: low values.
- Not Significant: medium values.

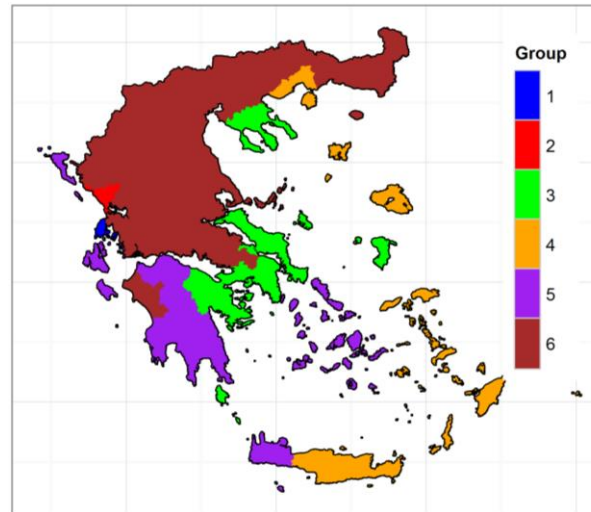
- Argolis, Boeotia, Karditsa, Laconia and Larissa are confirmed to be agricultural regions.
- Islands are confirmed to be commercial regions.
- Argolis, Corinthia and Lefkada are the most domestic EED consumers.
- Middle Greece is confirmed to be industrial.
- Highest ratio of total EED/GDP is confirmed to occur in industrial regions.

# 9. Grouping analysis (2012)

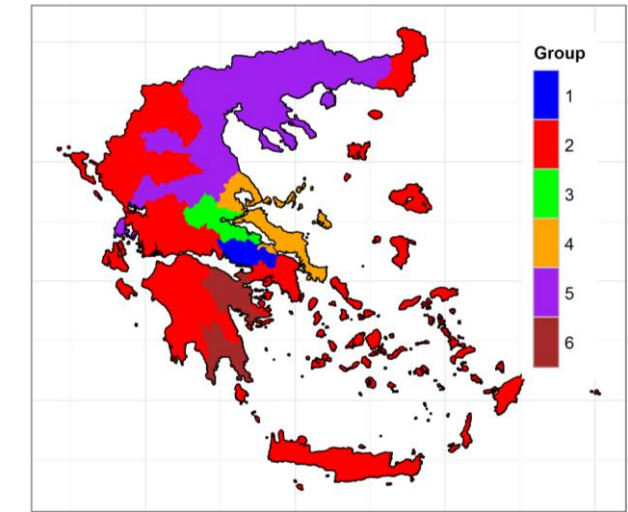
Agricultural use EED/capita



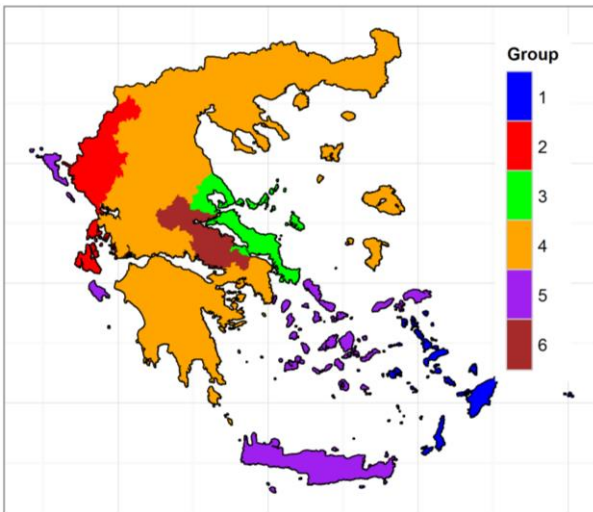
Domestic use EED/capita



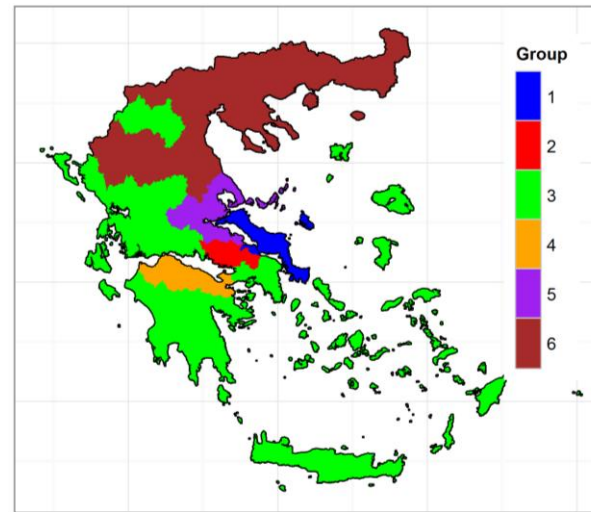
Total EED/GDP



Commercial use EED/total EED



Industrial use EED/total EED



- Three main agricultural groups, i.e. North Greece (orange), Middle Greece (blue) and islands (brown).
- Islands are confirmed to be commercial regions.
- Three groups according to domestic EED, i.e. most part of Greece (brown), islands (orange) and Attica with some adjacent regions (green).
- Middle Greece (purple) is confirmed to be industrial, but Boeotia (red) is in a separate group.
- Highest ratio of total EED/GDP is confirmed to occur in industrial regions (blue, green and orange).

# 10. Conclusions

- We investigated spatial patterns of the EED in Greece for the time period 2008-2012.
- The investigation was performed with:
  - The visualization of EED data, socioeconomic variables and their combinations.
  - The analysis with statistical methods, to find outliers, clusters, hot and cold spots and group Greece in regions with similar attributes.
- The analysis is presented in 1 125 Figures, available as supplementary material in Tyrallis et al. (2016b).
- We selected some Figures from the supplementary material, to present some interesting results.
- We present results for the year 2012.
- Greece could be classified in three regions:
  - Middle Greece could be characterized as industrial, as well as agricultural, after the addition or subtraction of some prefectures.
  - Islands could be characterized as commercial regions.
  - Attica and adjacent regions are characterized by high values of EED for domestic use.

# 11. Conclusions

- Greece could be classified in three regions according to the EED:
  - Middle Greece could be characterized as industrial, as well as agricultural, after the addition or subtraction of some prefectures.
  - Islands could be characterized as commercial regions.
  - Attica and adjacent regions are characterized by high values of EED for domestic use.
- Regarding the regional development model, Greece could be divided in three big regions:
  - The mainland, which includes middle and North regions.
  - The middle Greece.
  - The islands, with similar attributes, in specific cases, to those of Attica and Peloponnese.
- The results could be useful for the efficient management of the Greek Electric System
- The analysis of the EED could provide useful information on the regional development model for a country.



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