Comparative Evaluation of CO_2 Emissions in Europe and Turkey Using GIS

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1 Introduction

Turkey is a rapidly growing country with an increasing energy demand. Turkey's energy demand is supplied by domestic and import energy resources. Domestic energy resources include lignite, hard coal, oil, natural gas, hydroelectricity, geothermal, wood, animal and plant wastes, solar, and wind. The total lignite reserve is 11.5 billion tonnes which accounts for 7.7% of the world's lignite reserve, and the total hard coal reserve is 1.3 billion tonnes. Therefore, coal is the dominant energy source with significant reserve availability throughout the world and in Turkey as well. In the future, coal is expected to be a significant primary energy resource throughout the world (Tokgöz 2011). Figure 1 presents the share of coal in energy production among primary energy sources in Turkey (IEA 2016).

The growing environmental awareness and sensitivity related to global warming and climate change causes increasing public pressure on the utilization of fossil fuels especially coal because lignite shares the significant portion in climate change, which is induced mainly by CO_2 emissions and acidification impact categories, as seen in Fig. 2.

There have been several research studies conducted to investigate the CO_2 emission related to coal consumption for Turkey. Demirbaş and Bakış (2004) reviewed the status of Turkey's renewable energy resources and made future projections. The authors claimed that replacing more carbon-intensive fuels with renewables will contribute to the mitigation of urban pollution and CO_2 emissions. Kaygusuz (2004) reviewed the relationship between energy consumption and climate change mitigation in Turkey. This study reveals that hard coal and lignite will remain as a primary energy resource. Turkey's energy production using coal and

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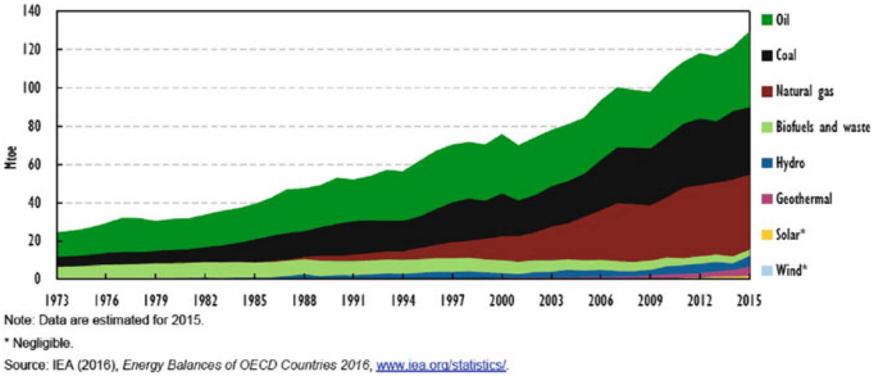


Fig. 1 Primary energy sources in Turkey (IEA 2016)

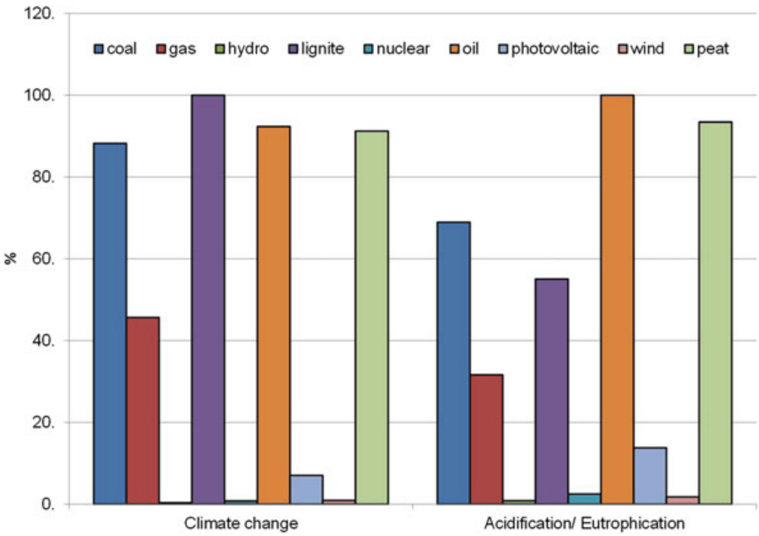


Fig. 2 Comparison of primary energy sources in terms of climate change and acidification impacts

lignite will be estimated to be 45,954 Kton in 2030, while it was 21,259 Kton in 2005 (MENR 2001). The author stated that encouraging and enforcing pollution control and environmental management measures for the mining sector is essential. Demirbaş (2006) reviewed Turkey's renewable energy resources and claimed that increasing use of domestic lignite has rapidly increased SO_2 emissions, which is mainly originated from the power sector, in recent years in Turkey (Demirbaş 2006). Say and Yücel (2006) conducted a study to overview the total energy consumption and CO_2 emissions in Turkey from 1970 to 2002. The authors performed a regression analysis between total energy consumption and total CO_2 emissions to be able to forecast the CO_2 emissions based on an economic growth and energy consumption for the future. It was claimed by the authors that the increase in the energy consumption would cause 9.9% increase in the CO_2 emission in average annually. Total CO_2 emission was estimated to increase from 480,244 Gg for 2010 to 631,781 Gg for 2015 using IPCC method. Yüksel and Sandalcı (2011) presented a review for the development of climate change, energy and environment in Turkey. The authors asserted that carbon intensity in Turkey is higher than the Western developed national average and the greenhouse gas emissions should be monitored and investigated regularly for policy development. Tokgöz (2011) developed a model to numerically evaluate the impact of CO_2 from fossil fuel consumption on global warming and climate change on a global scale. The author appealed that Turkey was affected by the CO_2 production of countries to the North and North-west and the CO_2 emission of countries in the West. It was stated that every year, 20.47 Giga tonnes of CO_2 was released into the atmosphere in the Northern Hemisphere coming over Turkey via atmospheric air movements from the West towards the East. Although all these research studies provided significant insight into Turkey's CO_2 emissions and energy consumption, none of them included a GIS-based comparative evaluation of coal consumption on climate change in Europe and Turkey.

This paper investigates the CO_2 emission trends of European countries with respect to their coal consumption and production for 26-year period from 1980 to 2006 using GIS. The research methodology followed in this study essentially entails four main stages: (i) collection and pre-processing of temporal-spatial data, (ii) generation of a database, (iii) performing GIS cluster analysis including cluster and outlier analysis and hot spot analysis, and (iv) interpreting the results.

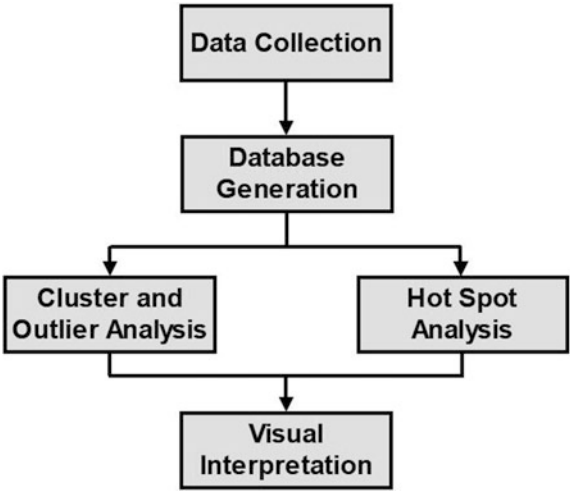


Fig. 3 Research framework followed in this study

The research framework is simply illustrated in Fig. 3. Historical data from 1980 to 2006 for coal production, coal consumption and CO_2 emissions in European countries including Turkey were acquired. Cluster analysis, consisted of cluster and outlier analysis and hot spot analysis, was performed to identify statistically important places based on the compiled historical data.

2 Data and Database Generation

Historical data for CO_2 emission, coal production and coal consumption for all European countries from year 1980 to year 2006 were acquired (IEA 2016). The database includes annual CO_2 emission (Mtons), coal production (Mtons), lignite production (Ktons) and coal consumption (Mtons) for 26-year period from 1980 to 2006 for Europe. The database also contains populations and areal extend of each country. The European countries under investigation are Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Faroe Island, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Macedonia, Moldova, the Netherlands, Norway, Poland, Portugal, Romania, Serbia and Montenegro, Slovakia, Slovenia, Spain, Svalbard, Sweden, Switzerland, Turkey, Ukraine, and UK. Based on the obtained historical data, the emission trends for European countries are represented. For instance, Fig. 4 illustrates the increase in the CO_2 emissions from 1990 to 2008 with respect to different industrial fields. Figure 4 also presents that energy and conversion sector plays an important role by accounting the largest CO_2 emission levels for in 2008. Since energy-related emissions are dominating among the other industrial fields and coal, especially lignite, is an indigenous energy resource for Turkey, coal production and consumption values are considered as important indicators for emission comparison in

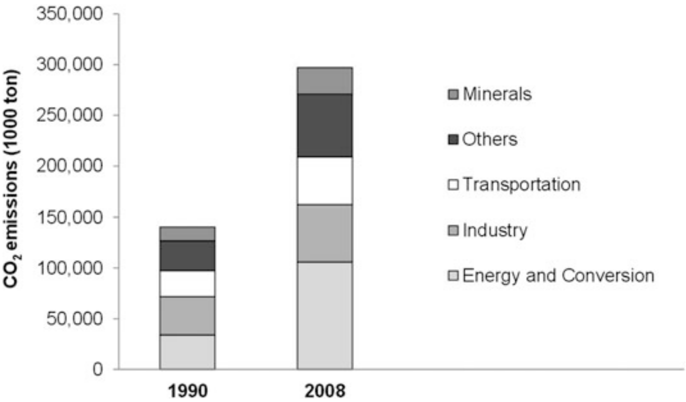


Fig. 4 Turkey's CO_2 emission levels with respect to some industrial fields from 1990 to 2008

the database. Because, when coal is exploited besides methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO), coal dust, radon gas, acid alkaline, sulphuric acid, trace metals, and rock wastes are emitted (IEA 2016).

3 GIS-Based Emission Monitoring of Turkey and Europe

Kyoto protocol requires emission reductions to decrease the detrimental impacts of environmental challenges, such as, acidification and climate change. Determining and monitoring countries' emissions and comparing them on a technically equivalent basis is an emerging issue for taking essential measures for sustainability. Turkey signed the Kyoto Protocol in February 2009 and, thus, was faced with policies for cleaner development and emission reduction. In order to implement reliable emission reduction appointments, it is essential to identify the current situation with respect to other countries and understand the possible margins for improvement. GIS provides an effective tool to monitor different attributes of various spatial locations. In this study, a comparative evaluation of coal impacts on climate change was completed for Europe and Turkey using GIS. Cluster and outlier analysis and hot spot analysis were implemented to identify the current status and historical changes in Turkey's CO_2 emissions when compared to European countries. Before initiating the GIS analysis, the recently obtained CO_2 emissions, coal production and coal consumptions values were analysed and mapped for European countries.

As it can be seen in Fig. 5, there is a close relationship between coal production, coal consumption, and CO_2 emission values due to the fact that the major carbon dioxide emission was generated during the combustion of coal (lignite) at the power plant. In Fig. 5a, the first five countries where the highest CO_2 emissions values are monitored are Germany, Poland, the UK, Ukraine, and Spain. Turkey is the ninth country in terms of the CO_2 emission intensity. When coal production and coal consumption values are considered, the order shows a change. Table 1 lists the top ten countries where the highest CO_2 emission, coal production, and coal consumption values are monitored from 1980 to 2006.

Although Turkey ranks 8th with respect to CO_2 emissions, the total CO_2 value of Turkey, 1,656 million ton, is much lower than the average CO_2 emission values of the first ten countries which is 3,655 considering the fact that in Turkey, the majority of energy production is based on coal, specifically lignite with a total share of 43%.

3.1 Cluster and Outlier Analysis

Cluster and outlier analysis determined the clusters of features with values similar in magnitude. The features with values that are very different from the surrounding

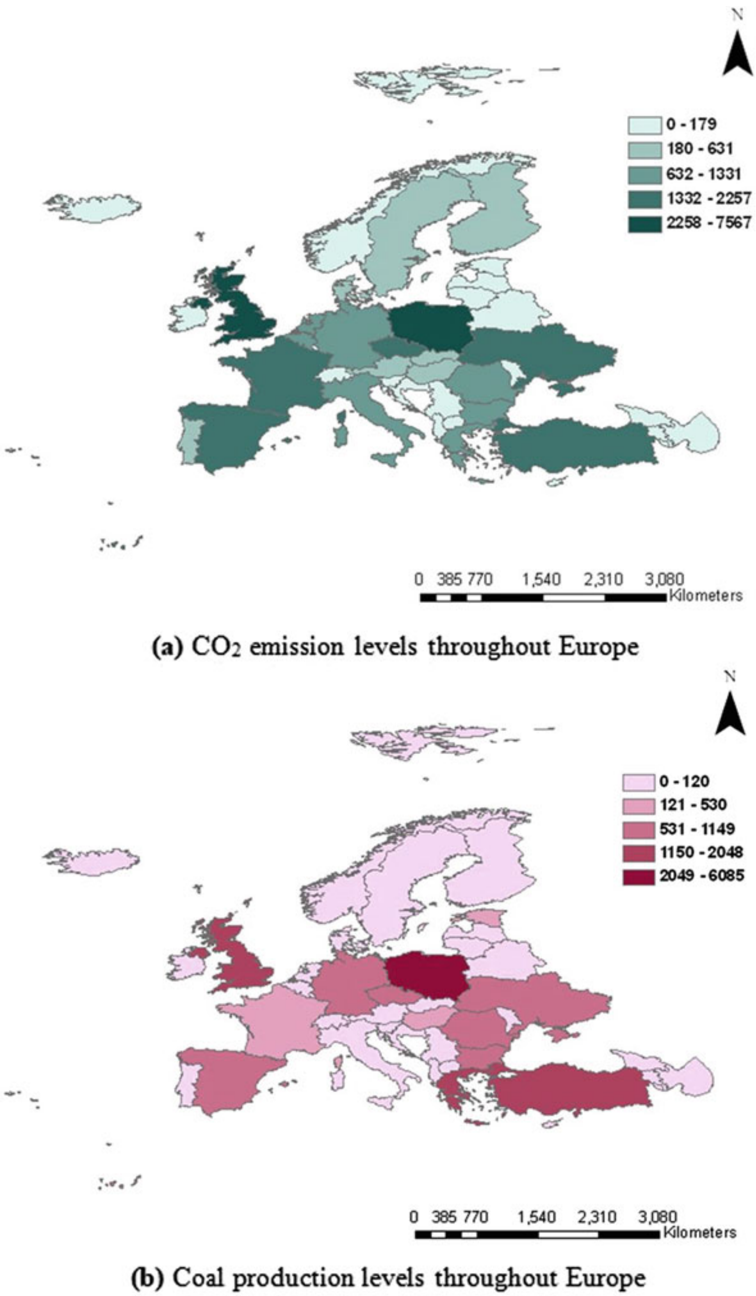
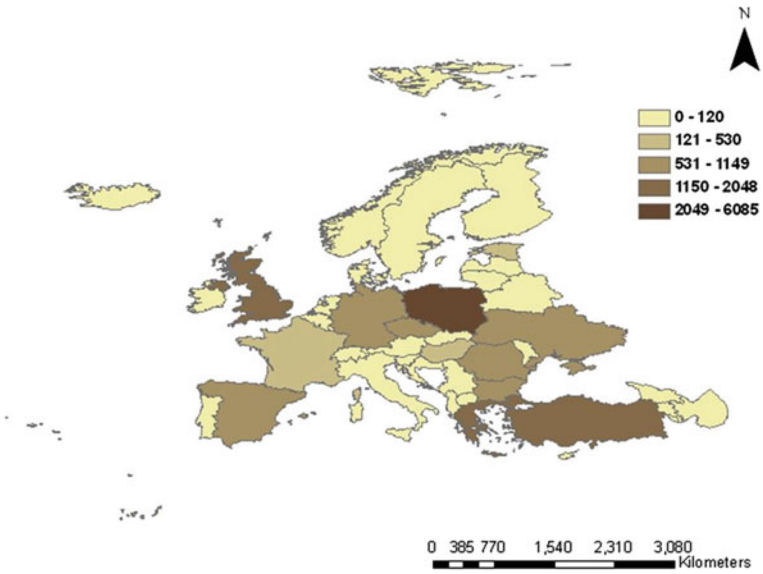


Fig. 5 CO_2 (**a**), coal production (**b**) and consumption (**c**) map for Europe



(c) Coal consumption levels throughout Europe

Fig. 5 (continued)

Table 1 First ten European countries in terms of CO_2 emissions, coal production, and consumption values

	CO_2 emissions (Mtons)		Coal production (Mtons)		Coal consumption (Mtons)	
1	Germany	11,250	Germany	10,228	Germany	10,856
2	Poland	7567	Poland	6085	Poland	5239
3	UK	5442	UK	2048	UK	2581
4	Ukraine	2257	Greece	1548	Turkey	1663
5	Spain	2233	Turkey	1430	Greece	1582
6	France	1831	Romania	1149	Spain	1441
7	Czech Republic	1790	Ukraine	1144	Romania	1326
8	Turkey	1656	Czech Republic	1061	Ukraine	1225
9	Italy	1331	Spain	1032	Bulgaria	1018
10	Romania	1196	Bulgaria	869	Czech Republic	985

feature values are also determined. Cluster and outlier analysis utilizes a Local Moran's I value, a Z-score, a p-value and a code representing the cluster type for each feature. The Z-score and p-value represent the statistical significance of the computed index value. Local Moran's I value is given in Eq. 1 (Mitchell 2005).

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq 1}^{n} w_{i,j}(x_i - \bar{X}) \tag{1}$$

In Eq. 1, x_i is an attribute for feature i, $\overline{X}$ is the mean of the corresponding attribute, and $w_{i,j}$ is the spatial weight between feature and j. In this study, CO_2 emission values from 1980 to 2006 are identified as a set of values for the European countries. This analysis identified the country or countries having very low or high CO_2 emissions throughout Europe. Conceptualization of spatial relationship was chosen to be an inverse distance to specify how spatial relationships among features are conceptualized. In the inverse distance, all features impact all other features, but the farther away something is, the smaller the impact it has. Distance method, which specifies how distances are calculated when measuring spatial autocorrelation, was chosen as Euclidean distance. As it can be seen in Fig. 6, Poland and Germany were determined as the clusters differing from neighbouring countries with high CO_2 emission values.

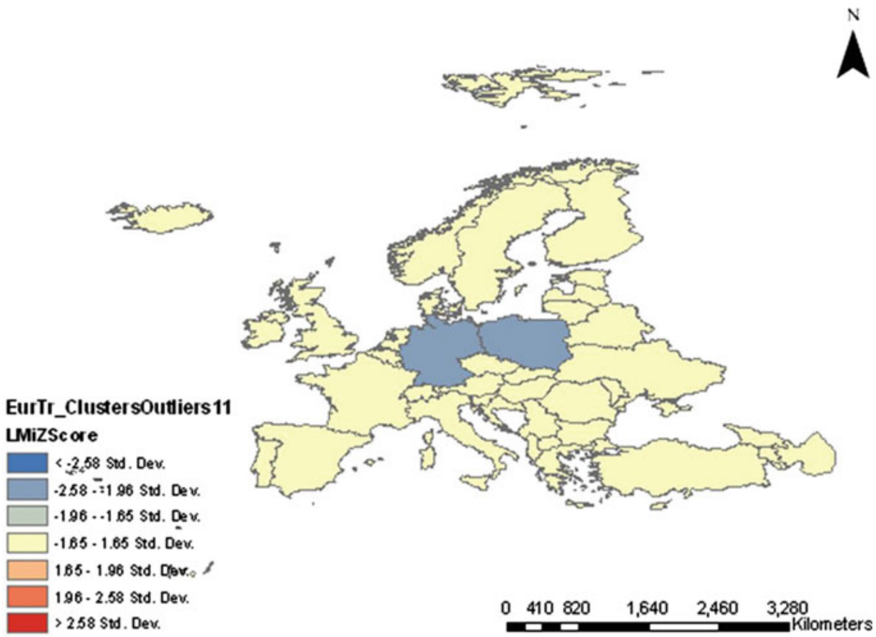


Fig. 6 Cluster and Outlier analysis results for the total CO_2 emission from 1980 to 2006

3.2 Hot Spot Analysis

In this study, the countries, which have high emission values and also are surrounded by countries having high emission values, are determined using hot spot analysis in GIS environment. In the hot spot analysis, the Getis-Ord Gi statistic for each feature in a data set is calculated and the spatial clusters of features with high or low values are determined using the resultant Z-score. This tool works by looking at each feature within the context of neighbouring features. A feature with a high value is interesting, but may not be a statistically significant hot spot. Getis-Ord Gi local statistic is given in Eq. 2 (Mitchell 2005).

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \tag{2}$$

In Eq. 2, x_j is the attribute value for feature j, $\mathrm{w}_{i,j}$ is the spatial weight between feature i and j, and n is equal to the total number of features and:

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n} \tag{3}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_J^2}{n} - (\overline{X})^2} \tag{4}$$

To be statistically significant hot spot, a feature will have a high value and be surrounded by other features with high values as well. The local sum for a feature and its neighbours is compared proportionally to the sum of all features; when the local sum is more different than the expected local sum, that difference is too large to be the result of random chance, a statistically significant Z-score result. Figure 7 illustrates the results of the hot spot analysis. As it can be seen from Fig. 7, Belgium, Luxemburg, and Greece were determined to be the hot spots. Turkey was not determined to be a hot spot with its average score.

These two analyses, considering the total CO_2 emissions of European countries from 1980 to 2006, resulted that Turkey with its total CO_2 emission is not critical when compared to other European countries. In addition to these analysis, the map of CO_2 normalized with coal production was also generated (Fig. 8). Figure 8 illustrates that Turkey is one of the countries having the lowest normalized CO_2 with respect to coal production value of 0.5158–1.146. This means that, when CO_2 emissions normalized with the coal production is considered, Turkey can be regarded as a country influencing Europe's CO_2 emissions the least.

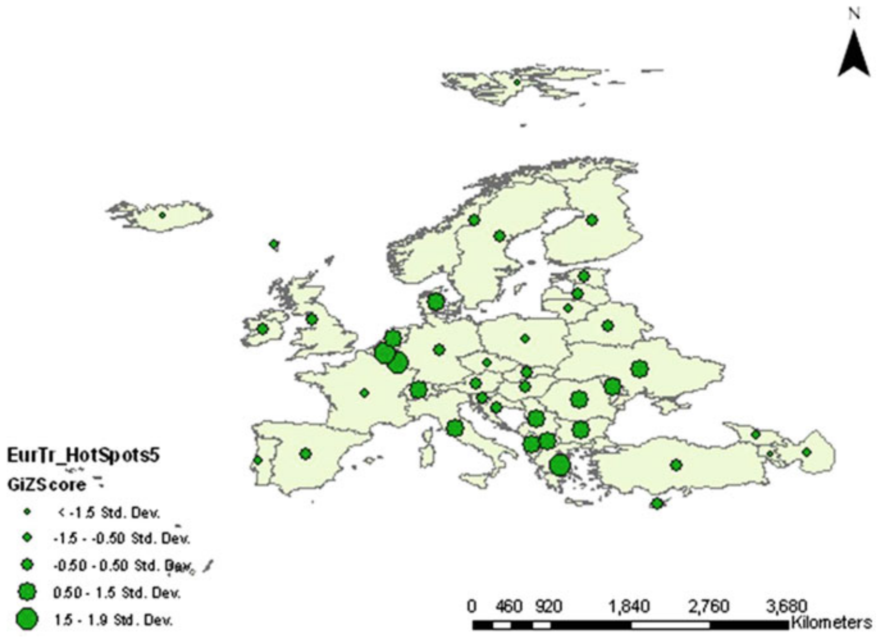


Fig. 7 Cluster CO_2 hot spot analysis

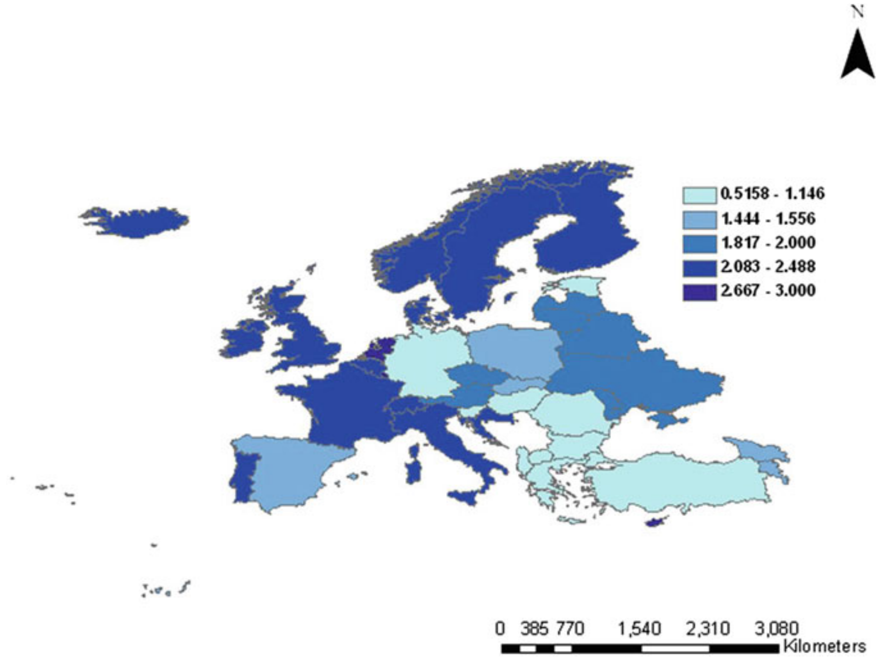


Fig. 8 Normalized CO_2 emission to coal production

4 Conclusions

In this study, comparative evaluation of CO_2 emissions of Turkey and European countries was carried out using GIS. Cluster and outlier analysis and hot spot analysis results revealed that Turkey, with total 1.656 million ton CO_2 emissions from 1980 to 2006, ranks 8th in Europe and Turkey's CO_2 emission is much lower than the average CO_2 emission values of the first ten countries which is 3,655 million ton. The normalized CO_2 emissions with coal production resulted that Turkey is one of the countries having the lowest normalized CO_2 with respect to coal production value of 0.5158–1.146. However, it is still essential to meet the guidelines and regulations to contribute the emission reduction efforts of Europe.

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