sciendo

GEOSCAPE

ORIGINAL PAPER

Relation of economic and environmental indicators to the European Union Emission Trading System: a spatial analysis

Vít Pászto [1,2] ✉ — Jarmila Zimmermannová [3]

[1]Department of Geoinformatics, Palacký University Olomouc, 17. listopadu 50, 771 46 Olomouc, Czech Republic
[2]Department of Computer Science and Applied Mathematics, Moravian Business College Olomouc, tř. Kosmonautů 1288/1, 779 00 Olomouc, Czech Republic
[3]Department of Economics, Moravian Business College Olomouc, tř. Kosmonautů 1288/1, 779 00 Olomouc, Czech Republic
✉ *vit.paszto@gmail.com*

Abstract

The main goal of this contribution is to evaluate the development of CO_2 emissions and selected economic indicators of EU28 countries in the period from 2005 to 2015, and to capture geographical pattern and spatial distribution of countries emitting pollution. This will be performed within the context of the EU Emissions Trading System (ETS), which has represented a major scheme in Europe to cope with CO_2 emissions since 2005. The actual situation in the field of the EU ETS is described and key scientific studies focusing on the EU ETS are presented. Based on a broad set of indicators we examine and evaluate possible geographical pattern in the development of selected indicators within the EU and provide detailed spatial analysis of economic and environmental data of EU28 countries, with the use of (geo)visual analysis of spatial data and spatial statistics (grouping analysis). The preliminary results of the (geo)visual analysis show that CO_2 emissions within EU countries were decreasing in the selected period 2005–2015, with some exceptions (e.g. Iceland and Latvia). As the development of CO_2 emissions in all EU countries is not similar, the other economic and environmental indicators were included (e.g. GDP, Investments) into the analysis in order to reveal a common (geographical) pattern and explain the current situation. Based on grouping/cluster analysis, it is possible to form territorial groups of EU states with similar development, which are almost perfectly in the line with current EU member states strategies of CO_2 emissions trade. The current auction markets are well in tune with geographical and economic characteristics of particular EU countries. Results of grouping analysis of all indicators in 2015 using six K-nearest neighbours underline current separate auction markets for Germany, the United Kingdom and Poland.It indicates that the system of emission auctions has logical background and the markets represent natural platforms for emission trading, corresponding to both economic and spatial characteristics of particular countries/polluters. Presented approach thus brings valuable information for policymakers both on the national and international level for the next phases of EU ETS scheme planning.

Highlights for public administration, management and planning:

- The changes in the EU Emission Trading System (EU ETS) since its introduction in 2005 are connected with the geographical distribution of economic and environmental indicators in EU countries.
- Multivariate statistics and consequent (geo)visualisation of relevant indicators revealed otherwise hidden aspects of EU ETS policies.
- Based on the cluster analysis, Germany, Poland and the United Kingdom proves that separate allowances auction markets for these countries are reasonable.

Keywords

Spatial analysis, Emission Trading System, Economic indicators, Cluster analysis, EU28

Received:
28 August 2018
Received in revised form:
02 May 2019
Accepted:
09 May 2019

GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001

1 Introduction

The European Union established a scheme for CO_2 emissions decreasing, the EU Emissions Trading System (EU ETS) in 2005. Based on this system, CO_2 became a significant member of the European commodity trading market. However, there is a fundamental difference between trading in CO_2 and more traditional commodities. Sellers are expected to produce fewer emissions than they are allowed to, so they may sell the unused allowances to someone who emits more than the allocated amount. Therefore, the emissions become either an asset or a liability for the obligation to deliver allowances to cover those emissions (Benz & Trück 2009).
Generally, the market price of the allowances is determined by supply and demand, however, there can be also other so-called "price drivers". Both in the first and in the second trading period, the EU emission allowances were traded mostly on the BlueNext trading exchange. In the third trading period, there has only been one big exchange which can be used for emission rights trading – European Energy Exchange - EEX (EEX 2018).
European Energy Exchange has offered trading emission allowances on the base of the EU ETS since 2005, and currently runs a secondary market for continuous trading on a Spot and Derivatives basis for EU ETS allowances (European Emissions Allowances – EUA, European Aviation Allowances - EUAA) and Kyoto credits.
Currently, the EU ETS is in operation for more than a decade; moreover, in 2018 the European Commission adopts rules for the next 4th trading period. The key questions connected with these new rules are: (i) Was the amount of CO_2 emissions (in CO_2 equivalent) increasing or decreasing during the previous periods of EU ETS, and (ii) Are there any geographical similarities within the EU countries connected with their ETS related indicators? This paper will focus on these two questions in more detail.
The EU ETS covers more than 11.000 power stations and manufacturing plants in the 28 EU member states as well as Iceland, Liechtenstein and Norway. Aviation operators flying within and between most of these countries are also covered. In total, around 45% of total EU emissions are limited by the EU ETS (European Commission 2013).
The EU ETS covers both European Emissions Allowances – EUAs (since 2005) and European Aviation Allowances – EUAAs (since 2012). The market price of the allowances is determined by supply and demand at the exchange.
Generally, the first period (2005−2007) of the EU ETS was a three-year pilot period for the purposes of the preparation for the second, Kyoto based, period (2008-2012). Emission allowances were allocated for free (grandfathering, see also critical discussion below), based on so called National allocation plans and historical emissions. The aim of the first period was to establish a carbon market, determine the market price of carbon and build the necessary infrastructure for monitoring, reporting and verifying actual emissions. The data generated from the first period subsequently filled the information gap and helped to set national emission limits (caps) for the second phase. The EUA spot price fluctuated between 25 EUR/t CO_2 at the beginning of the period and the nearly zero level in the end of the period.
The second period (2008−2012) corresponds with the targets set under the Kyoto Protocol. The European Union committed itself to achieving an overall 8% reduction in CO_2 emissions in the period 2008−2012 compared to 1990 levels (Official Journal of European Union 2002). On the basis of the verified emissions reported in the first period, the volume of emission allowances allocated in the second period was reduced by 6.5% compared to the 2005 level. The EUA spot price fluctuated in the range 6–25 EUR/t CO_2.
In the third, post-Kyoto period (2013−2020), the conditions for the functioning of the EU ETS have changed in connection with so called Climate and Energy Package, based on the amendment of Directive 2003/87/EC by Directive 2009/29/EC (Official Journal of European Union 2003, 2009a). Moreover, the additional directive on CO_2 geological storage (Official Journal of European Union 2009b) was adopted and the European Commission presented the EU's energy and climate change targets for 2020 (known as the 20-20-20 targets). One of these targets was also to reduce EU greenhouse gas emissions by 20% compared to 1990 levels. Since the EU emission allowances were previously grandfathered – for free (Wettestad et al. 2012), from year 2013 the significant yield of the emission allowances is auctioned. Grandfathering was widely criticized, mostly because it introduced significant distortions to the EU ETS (Falbo et al. 2013). Auctioning is the most transparent method of allocating allowances and puts into practice the polluter pays principle (Vicha 2011; European Commission 2013). Sectorial differentiation was also introduced, with (initially) far more auctioning of allowances for energy producers than energy-intensive industries. The fourth phase of the EU ETS (2021-2028) was prepared, known as the "Post-

2020 Reform of the EU Emissions Trading System" (Erbach 2018), which is now translated into the Directive 2018/410/EU (Official Journal of European Union 2018). At the beginning of 2018, the fourth phase of the EU ETS has been approved by both the European Parliament and the EU Council. On 19 March 2018, the final text of Directive 2018/410/EU amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments was published in Official Journal of the European Union (2018).

The main goal of this contribution is to evaluate the development of CO_2 emissions and selected economic indicators of EU28 countries in the period from 2005 to 2015 – the year 2005 is the first year of the EU ETS introduction and year 2015 represents the last year with CO_2 emissions available data.It should be noted that the "CO_2 emissions" are understood as overall volume of emissions of greenhouse gases expressed as indirect CO_2 emissions (in CO_2 equivalent). Moreover, building on the previous goal, authors will examine and evaluate possible geographical pattern in the development of selected indicators within the EU. Analysis of a geographical pattern and spatial distribution of countries emitting pollution is important in order to understand a common geopolitical context of such countries.It can be assumed that historical development, geographical setting, and (more or less) EU-oriented political environments, may have a profound influence on decision making. Results from a spatial analysis could be used by decision-makers in order to identify discrepancies or similarities among countries, and consequently be able to take actions that will create balanced carbon emission policies across Europe. Authors will provide detailed spatial analysis of economic and environmental data of EU28 countries, with the use of (geo)visual analysis of spatial data and spatial statistics (grouping analysis). Obtained results will be presented using analytical maps, and broad discussion and the future research and policy challenges drawn from the results will be outlined.

2 Literature overview

Regarding scientific studies focusing on the EU ETS, it is important to distinguish between different EU ETS trading periods, due to different institutional conditions and trading rules in particular periods. Research studies analyzing the first pilot trading period (2005–2007) and the second trading period, the so-called Kyoto phase of the EU ETS (2008–2012), focused in particular on the analysis of market prices of tradable emission allowances, their impact on the behavior of stakeholders in the emission allowance market, and on the behavior of the polluters themselves. The issue of modeling and predicting the prices of tradable emission allowances was dealt with, for example, by the studies of Benz and Trück (2009), Li et al. (2011), Conrad et al. (2012), Garcia-Martos et al. (2013), Lutz et al. (2013), the marginal costs of energy-intensive industries (Lund 2007; Chernyavska & Gulli 2008), the impact of emissions trading on the electricity producer (Lund 2007; Chernyavska & Gulli 2008; Falbo et al. 2013), or the innovative effects of the EU ETS (Rogge et al. 2012).

The authors of these scientific studies used a whole range of advanced methods. For example, Li et al. (2011) uses fuzzy modelling for the planning of CO_2 emissions trading in industrial enterprises under uncertain conditions, Conrad et al. (2012) used the GARCH (Generalized AutoRegressive Conditional Heteroskedasticity) model for the purpose of the analysis of the adaptability processes of the price of tradable EUA emissions permits in connection with the proclamation of the regulator regarding planned changes, especially those which are macroeconomic in nature. Aatola et al. (2013) created a model of the equilibrium of the emission permit market for the purpose of the balanced settings of the price of a EUA tradable emission permit. Falbo et al. (2013) created a model based on the function of profit for the purpose of the observation of the effects of EUA on the optimization of the policy of a producer of electricity. Garcia – Martos et al. (2013) used ARIMA (autoregressive integrated moving average) and VARIMA (vector autoregressive integrated moving average) models for the creation of a multivariant model for the setting of permit prices. Lecuyer and Quirion (2013) created analytical and numerical models of the energy and carbon markets in the EU and monitored the effects of the zero level of the price of coal on the selection of an optimal tool for setting economic policy. Lutz et al. (2013) used Markov´s regime-switching GARCH model for the determination of relations between the EUA price and economic indicators.It is possible to find also other empirical studies analyzing the second trading period using an official data, questionnaire surveys and interviews. Such studies can be found mainly in the field of the impact of the EU ETS on innovation and investment in Germany (Rogge et al. 2011), in Sweden (Lofgren et al. 2014) or in the European

Union as a whole (Feng et al. 2013; Martin et al. 2014).

Research studies dealing with the third ETS trading period focus more on the effects of regulator intervention on the functioning of the EU ETS and its parameters, in particular on the development of the EUA (European Emission Allowance) emission allowance price; one unit of EUA stands for a permit to emit 1 ton of CO_2 or its equivalent (under the EU ETS). Creti and Jöets (2017) observed price bubbles, speculations, and analyze the development of the EUA emission allowance price in relation to changes in climate or energy policy. A similar topic is solved by Fan et al. (2017), they provide us with a detailed overview of the effects of EU regulatory policy measures on the EUA allowance price. Skovgaard (2017) analyzed the decision-making of particular Ministries of Finance in the Netherlands, Denmark and Germany in connection with interventions and regulation of the EU ETS.

In the Czech Republic, the issue of the EU ETS was addressed by Chmelík and Zámyslický (2007), who carried out a comparison of emission allowances schemes based on statistical data and legislation. Zámyslický (2013) investigat-ed the impact of greenhouse gas emissions trading on the renewable energy economy. Solilová and Nerudová (2014) focused on emissions trading and carbon taxation in the European Union and Zimmermannová (Zimmermannová 2015; Zimmermannová & Čermák 2014) carried out an ex post analysis of the beginning of the third trading period of the EU ETS.

There are only a few scientific studies focusing on the EU ETS from a spatial point of view. Moreover, these studies are not up-to-date. For example Bailey and Maresh (2009) argue that critical exploration of the territorial logics and practices of EU emissions trading from regime creation to operation provides new insights into the emerging spatial politics of neoliberal environmental governance and its implications for climate protection, Hepburn and Fankhauser (2010) analysed the design of carbon markets in space (i.e. geographically) and Knight (2010) examines the temporal and spatial geography of European carbon trading. Knight (2010) underlines that carbon markets must be understood in all their complexity across physical and spatial geographies. The inherent tension between global solutions and local economies makes climate change a natural area for economic geography to make an important contribution (Knight 2010).

Given the aforementioned lack of studies focusing simultaneously on carbon markets and spatial indicators, the authors will examine and evaluate possible geographical pattern in the development of selected relevant indicators within the EU and provide detailed spatial analysis of economic and environmental data of EU28+ countries, with the use of (geo)visual analysis of spatial data and spatial statistics (grouping analysis).

3 Methods and data

For the analysis presented in this paper, the Eurostat database concerning greenhouse gas emissions and complementary macroeconomic data were used (Eurostat 2018) in order to cover years 2005 and 2015. Namely, all sectors' indirect CO_2 emissions in total, fuel combustion in energy industries, gross domestic product at market prices, consumption expenditure of households, and gross capital formation (see basic statistical overview in Table 1). Emission indicators (indirect CO_2 emissions, fuel combustion in energy industries) were selected because they represent the most used measures

Table 1 Basic statistical characteristics of input data

Indicator	Minimum value (2005/2015)	Maximum value (2005/2015)	Median (2005/2015)	Standard Deviation (2005/2015)
indirect CO_2 emissions (mil. tonnes of CO_2 eq.)	0.3/0.2	1 015/927	71/62	239/209
fuel combustion in energy industries (mil. tonnes of CO_2 eq.)	0.0/0.0	383/335	22/14	79/68
gross domestic product (mil. EUR)	5 032/3 625	2 300 860/3 043 650	158 653/168 473	590 151/730 646
consumption expenditure of households (mil. EUR)	3 154/2 872	1 293 533/1 593 410	63 927/91 330	347 281/422 134
gross capital formation (mil. EUR)	999/726	432 896/582 812	34 731/27 768	120 395/143 848

GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001 Available online at content.sciendo.com

for evaluation of environmental impact, and are very intuitive in the sense of interpretation. Moreover, the EUA trading units implicitly count with CO_2 emissions equivalents, therefore this indicator was subject included in this study. As the energy industries are one of the most important polluters (thus directly affected by allowances trading system), also the fuel combustion of such industries was selected. In the same logic – authors used the most known and understandable economic indicators, which are still related to environmental issues. Particularly, the gross domestic product serves as a general economic indicator that covers all economic aspects and agents. Further on, consumption expenditure of households represents behavior of individual households (summarized on the country level in this case), and gross capital formation could be treated as an indicator for investment activities of companies (again, on the country level). Aforementioned indicators were used in order to identify and capture the most general characteristics (both economic and spatial) of the allowances market (EU ETS system), therefore, any other derivative and specific indicators (e.g. environmental investments, environmental education, R&D, fossil fuels consumption, renewable energies etc.) were not taken into account for this study. Geographically, all indicators were available on the country level, while some indicators were not available for all EU28+ countries (e.g. GDP for Liechtenstein).

Reference spatial data covering study area of EU28+ countries were obtained from Eurostat as well, specifically from its subordinate unit for geographical data management – GISCO (Geographic Information System of the COmmission). These data represents the last officially valid release from 2014.

The paper uses absolute data (total CO_2 emission (in CO_2 equivalent), Gross domestic product) for the analysis because the initial emission target (the emission cup) was set as % decrease of the absolute amount of the greenhouse gas emissions. Therefore, absolute data is preferred over the analysis of relative data (e.g. per capita, per square kilometre area etc.). Emission target is set for the EU as a whole - the EU ETS follows a “cap-and-trade” approach: the EU sets a cap on how much greenhouse gas pollution can be emitted each year, and companies need to hold European Emission Allowance (EUA) for every ton of CO_2 (in CO_2 equivalent) they emit within one calendar year.

Methodologically, two main methods were applied – geovisual analytics and grouping analysis. Firstly, geovisual analytics (see more e.g. in Marek et al. 2015b) was used in order to evaluate the development of greenhouse gas emissions and complementary macroeconomic indicators spatially. For this purpose, data from 2005 (EU ETS system came into a force) and 2015 (last available data about greenhouse gas emissions) were visualised and consequently analysed. Geovisual analytics is described as the science of analytical reasoning and decision-making with geographic information, facilitated by interactive visual interfaces, computational methods, and knowledge construction, representation and management strategies (Andrienko et al. 2007). Geovisual analytics was performed with the use of two cartographical approaches: (i) categories (colours assigned to each qualitative information, or group of information sharing common attribute), and (ii) proportional symbol technique (symbol size varies according to the attribute – quantitative measure).

For the first case (categories), colours were complemented with the number expressing a percentage difference between 2005 and 2015, i.e. yellow colour stands for a decrease, and violet colour stands for increase. As for the proportional symbol technique, intervals were set with the use of Jenks method (natural breaks), which maximises differences between intervals, and at the same time minimises differences inside intervals (Jenks 1967). Target five intervals were adjusted according to the cartographical rules for interval border-values (Voženílek et al. 2011). Abovementioned basic methods of thematic cartography allow to display, analyse, and understand source data more efficiently due to the geographical context inherent in data.

In the next step, the grouping analysis was performed to find classes/groups in the data according to their attributes and spatial relationships (Marek et al. 2015a). ESRI (2016) describes this process as “a solution where all the features within each group are as similar as possible, and all the groups themselves are as different as possible”. It is important to mention that only spatial relationship (X, Y coordinates) were examined by grouping analysis, to form five groups using K-nearest neighbours (there were six neighbours set, which represents and average number of neighbours per country in EU28+ countries, including overseas „connections“, and the algorithm searched for them in terms of Euclidean distances).

4 Results

There are all EU member states included in EU ETS system, nevertheless, Norway, Liechtenstein and Iceland is monitored as well (together with Turkey that were included by the authors just for this study). In order to help the reader to orient in Europe basic geographies, Fig. 1 displays the geopolitical situation (countries). Geovisualisation of the overall volume of emissions of greenhouse gases expressed as an indirect CO_2 emissions (in CO_2 equivalent) was done for two key years – 2005 and 2015. Absolute numbers of total emissions of CO_2 equivalent is depicted in Fig. 2 (2005) and Fig. 3 (2015), while Fig. 4 displays the relative increase/decrease of the same indicator. It is vital to display all maps together since relative increase/decrease could, in fact, represent only a small portions of CO_2 emissions in absolute numbers (e.g. in the case of Iceland).
Although it is not visible at first glance due to the interval settings in Figs. 2 and 3, there are four countries (France, Italy, Croatia, and Greece) that reduced their CO_2 emissions over the ten years (from 2005 to 2015) in a way that they fall into another category in 2015. However, the main purpose of map visualization in Figs. 2 and 3 is to provide an overall picture of absolute amounts of CO_2 emissions across Europe.It is obvious, that smaller countries (e.g. central, eastern and northern European countries) emit less than larger ones, however with some exceptions – Netherland, Belgium, and the Czech Republic. The biggest polluters in terms of abso-

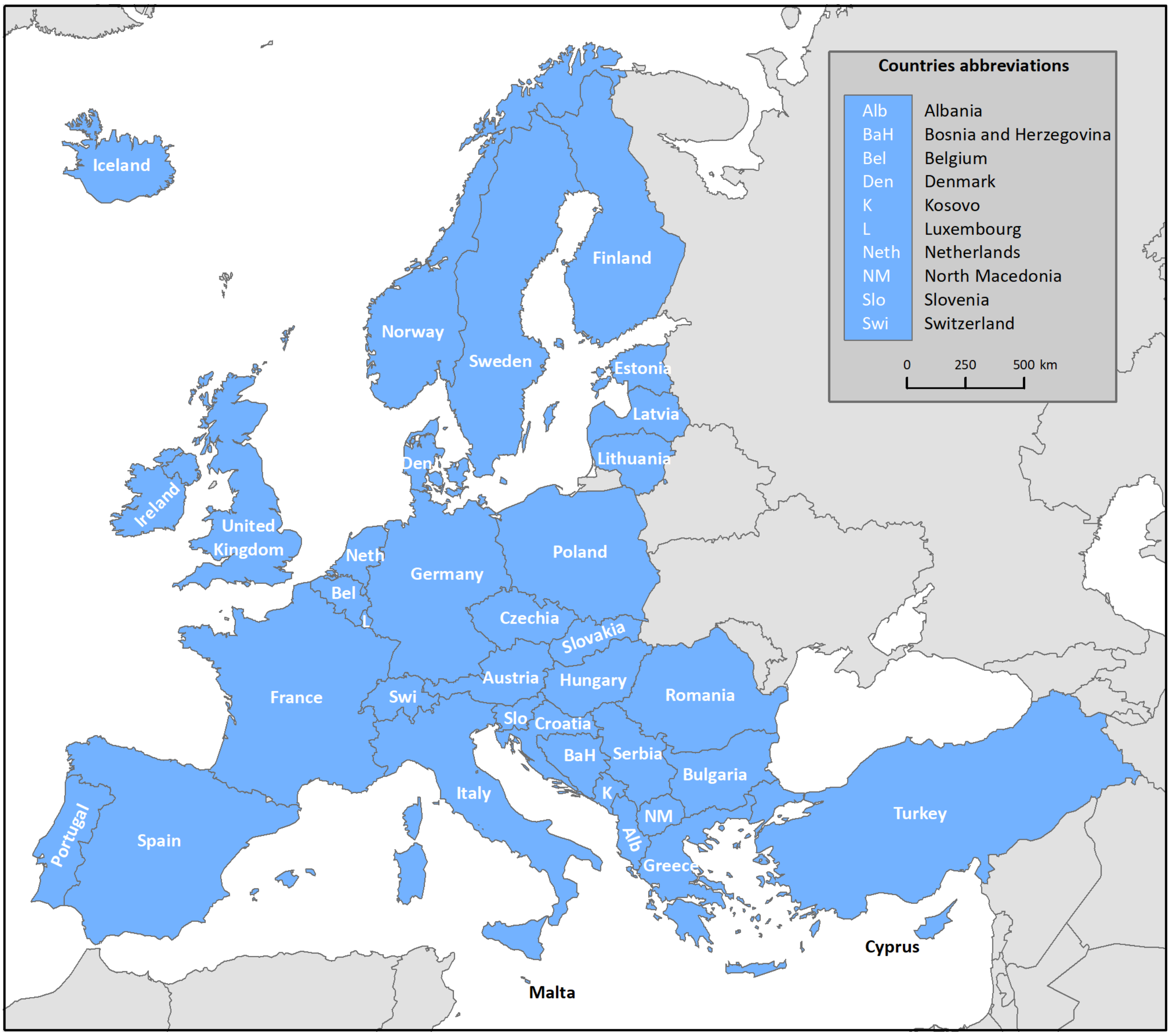

Fig. 1 European countries used in this study. Source: Eurostat, authors.

GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001 Available online at content.sciendo.com

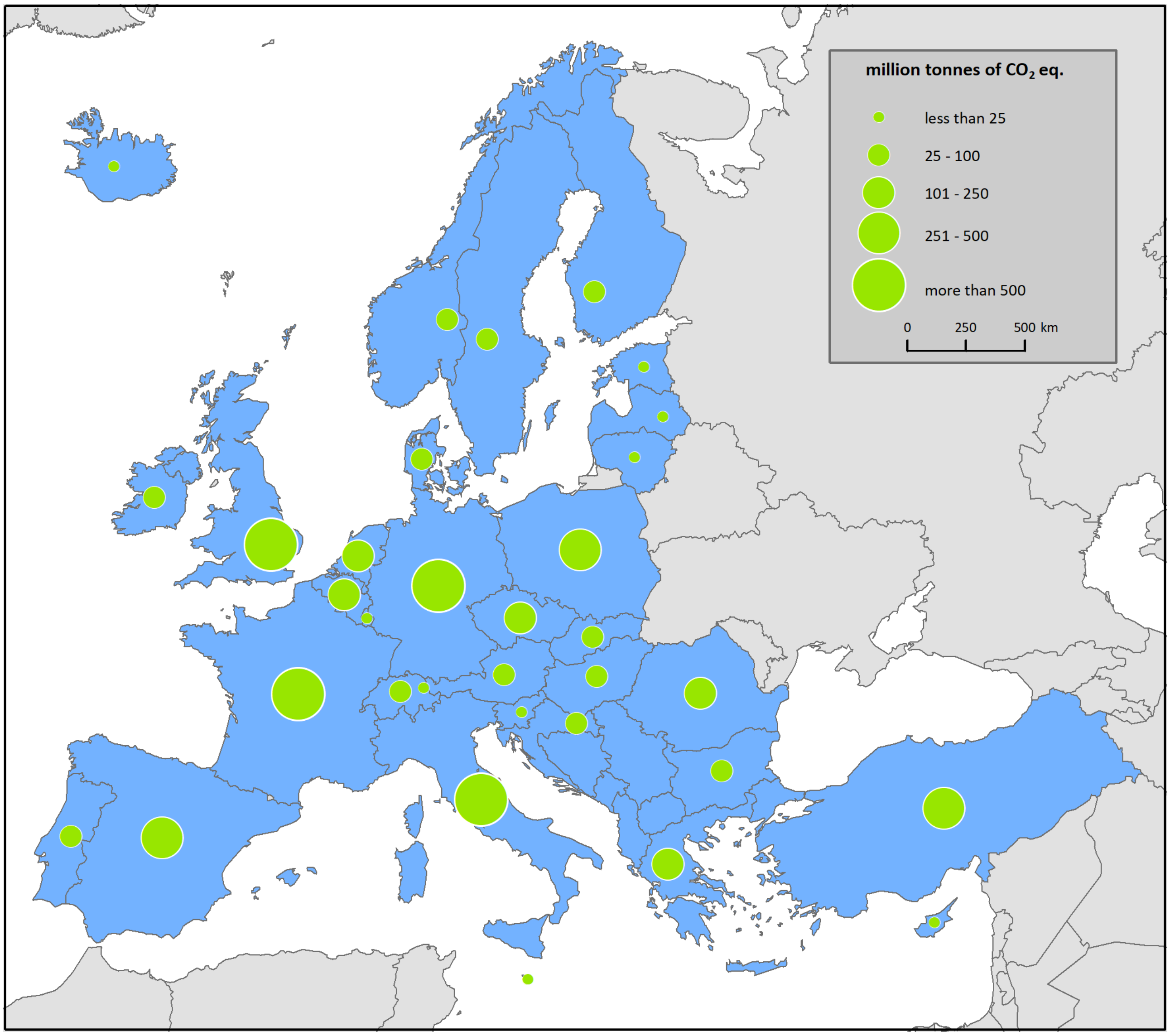

Fig. 2 All sectors' greenhouse gases emissions expressed as indirect CO_2 emissions in total (million tonnes of CO_2 equivalent) in 2005.

lute numbers can be seen as a "core" economies in Europe, i.e. the United Kingdom, France, Germany, Italy, and Spain; plus Poland and Turkey. Fig. 4 shows differences in the total amount of all sectors' indirect CO_2 emissions, and it is evident that all of the studied countries decreased their emissions volume – except Turkey, Iceland, and Latvia. It is important to note that Turkey is not a member of EU ETS system; however Turkey is a long-lasting aspirant to EU membership, thus worth to observe. Countries with a decreasing trend ranges, in sense of percentage numbers, from 29% (Greece) to 1.1% (Norway). Czech Republic with 13.3% decrease ranks among the countries with moderate decrease. However neighbouring Poland and Germany have shown even lower decrease. On the other hand, Turkey has raised total amount of emission by 42.8 percent since 2005. It is also interesting that Iceland, as a country with "green/eco" policies, increased emission by 22.4% since 2005. Nevertheless, here the combination of both visualization is in place – i.e. in absolute numbers, Iceland production of emissions is in a few units of millions tonnes of CO_2 eq. compared to hundreds of million tonnes in the case of Germany or Poland.

The second part of the study was dealing with grouping analysis of EU28+ countries. Two types of grouping analyses were performed. Firstly, grouping analysis without spatial constraints (in this sense, the grouping analysis represents non-spatial clustering) was calculated based on all five indicators; dividing the dataset into five

Available online at content.sciendo.com GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001

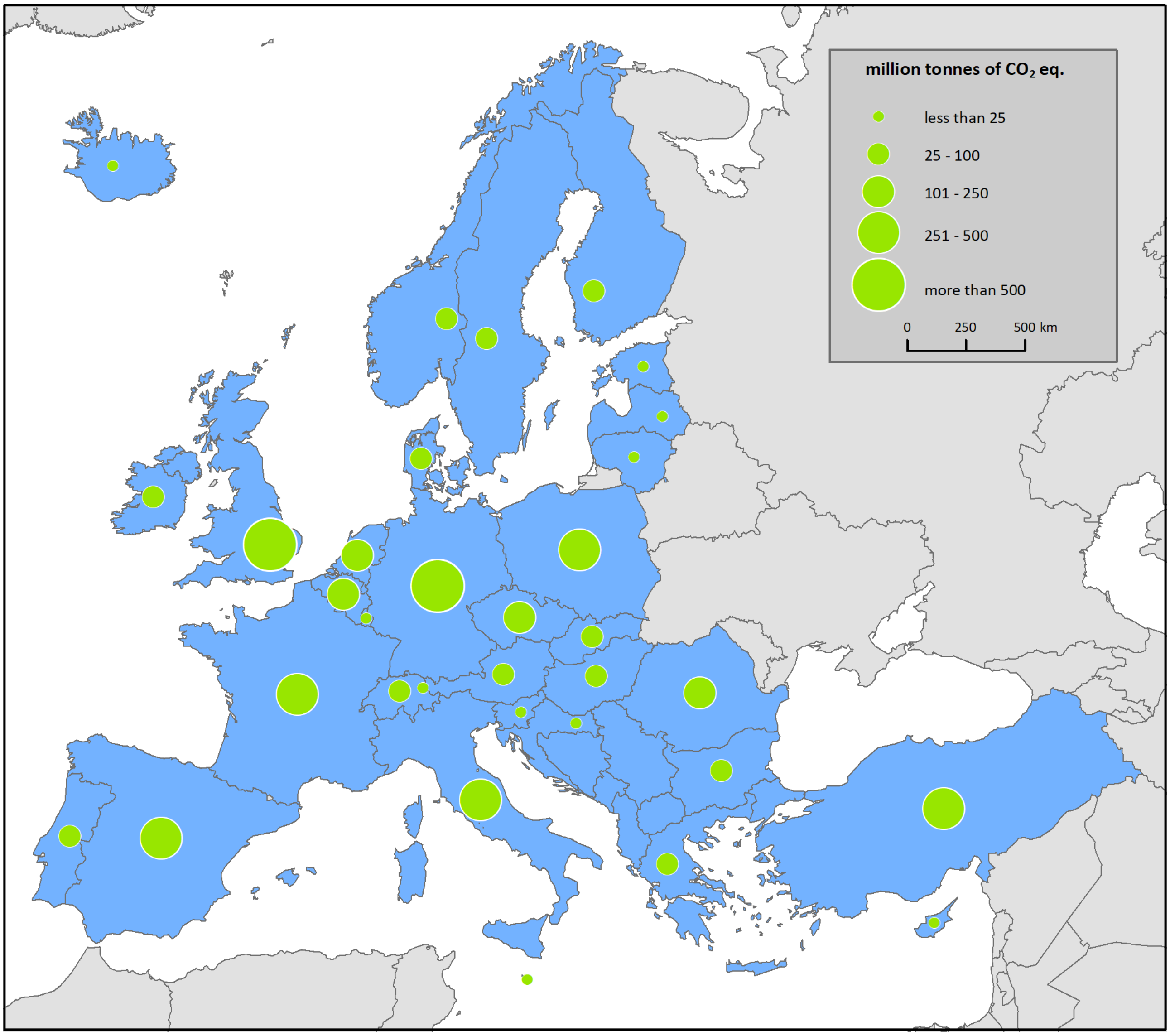

Fig. 3 All sectors' greenhouse gases emissions expressed as indirect CO_2 emissions in total (million tonnes of CO_2 equivalent) in 2015. Source: Eurostat, authors.

groups/clusters. The resulting visualizations for 2005 and 2015 are depicted in Fig. 5 and 6. Since the paper focuses on the implications of EU ETS system, the main commentary will be provided for the 2015; with some key differences between 2005 and 2015 to be mentioned. It is clear that one group (cluster no. 4) is formed only from one single country in both years – Germany – which is caused by high values in all indicators in comparisons with the rest of the dataset. This confirms the fact that Germany represents the strongest (and most vital) economy in EU28+; however producing the highest amount of emissions in 2015, which is almost a double the amount than France. While talking about France, it created also individual cluster in 2005 (Fig. 5), probably due to the lowest values as regards fuel combustion in energy industries in comparison with other major countries (i.e. United Kingdom, Germany, Italy, Spain, and Poland). Two-member group in 2015 (cluster no. 5) contains France and United Kingdom (in the same cluster together with Italy and Spain in 2005), i.e. two similar and strong economies (in sense of input indicators) with comparable amount of total emissions.

Following group (cluster no. 3) in 2015, containing Italy and Spain (formerly in a cluster with United Kingdom) plus Poland, is typical with comparably high amount of emissions within the group, while other macroeconomic indicators are considerably lower in the case of Poland compared to Italy and Spain. Aforementioned clusters, and coun-

GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001 Available online at content.sciendo.com

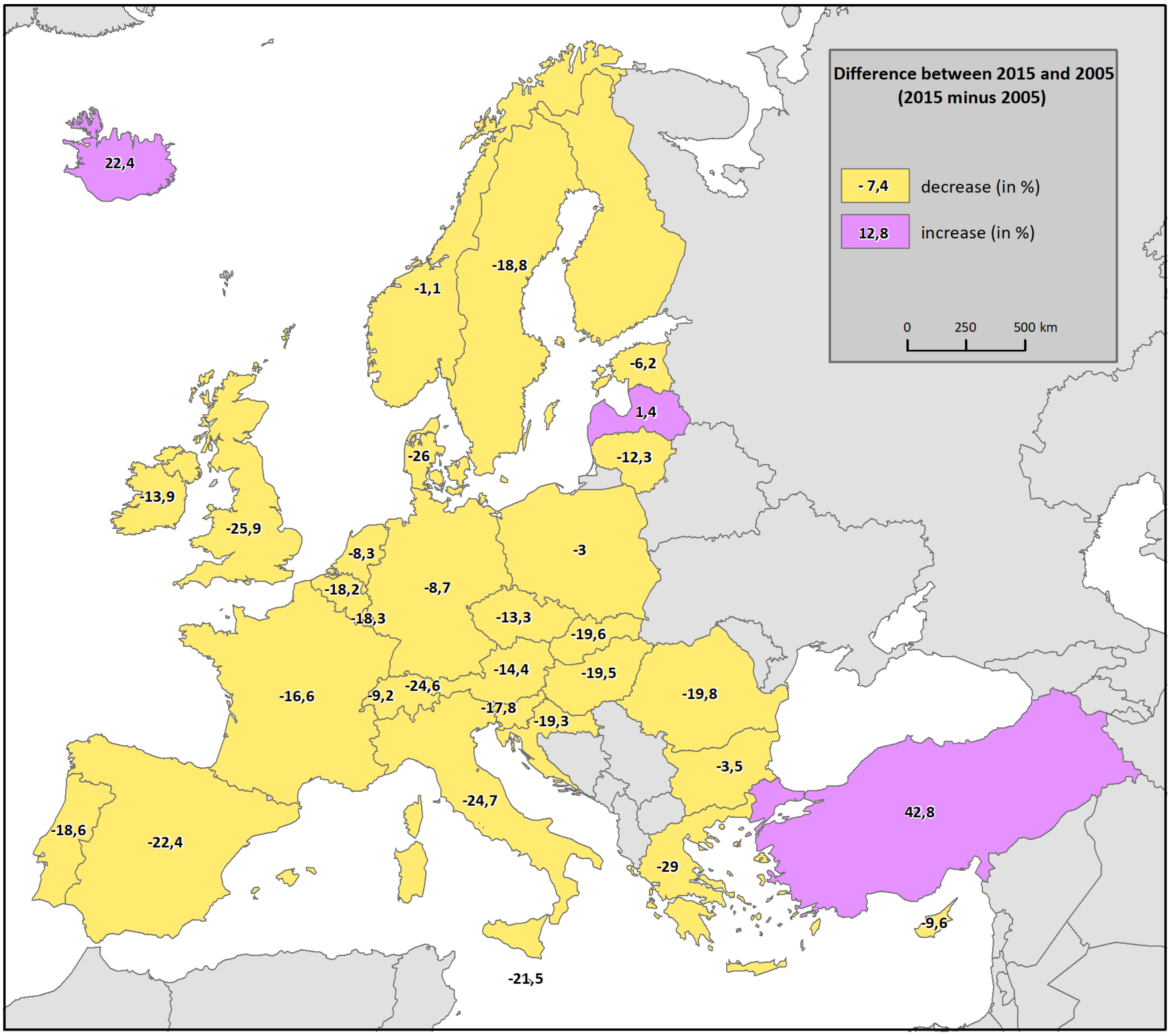

Fig. 4 All sectors' greenhouse gases emissions expressed as indirect CO_2 emissions in total (difference between 2015 and 2005). Source: Eurostat, authors.

tries, respectively, can be treated as economically-industry leaders in Europe. Cluster number 2 contains countries with rather stronger economies (in terms of GDP) and higher amounts of emissions. On the other hand, the last group in 2015 (cluster number 1) is composed of countries combining lower economies and lower emissions at the same time (Turkey is member of this cluster only due to missing values of economic indicators), whereas Denmark, Portugal, Finland, and Ireland (formerly in 2005 in another cluster) joining the group.
Secondly, grouping analysis with the use of K-nearest neighbours (neighbours were set to 6) was performed. Opposite to the previous grouping analysis, this time spatial relationships were taken into account. The results for 2005 and 2015 are depicted in Fig. 7 and 8, where also five target clusters were created. In this case, there are three groups in 2015 composed of one single country, i.e. cluster no. 5, 2 and 3. In 2005, all the leading countries formed their groups as well, but with a bit different distribution (Poland and Italy as individual clusters, France and Spain forming another, and Germany with United Kingdom their own). These clusters are based on the same input indicators as in previous case, but this time within a spatial context. Therefore, Poland and Germany formed their own groups, since both countries are producing high amount of emissions (in comparison to neighbouring countries), while Poland shows significantly lower economic performance. This is the main reason, why Germany and Poland

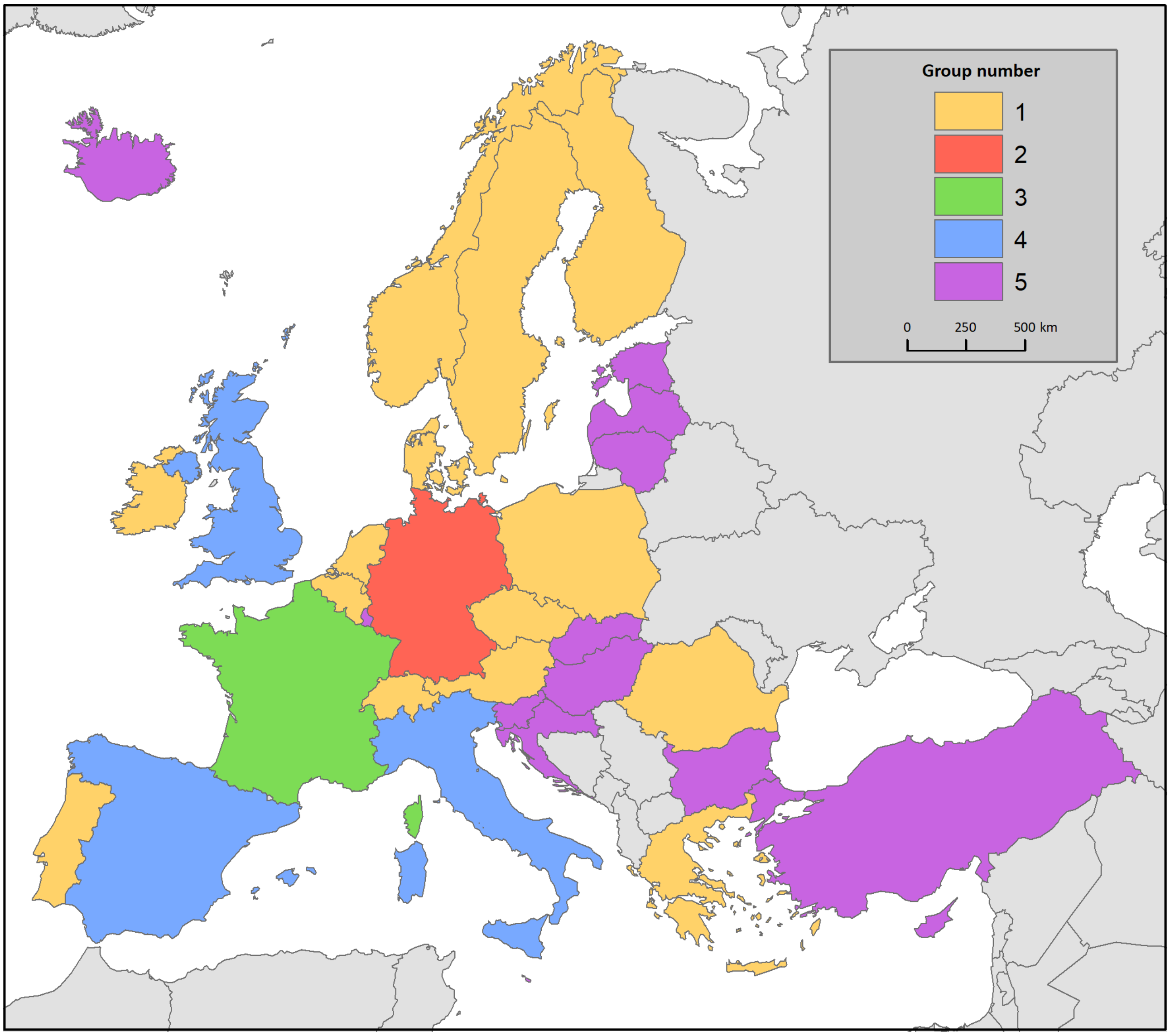

Fig. 5 Non-spatial grouping analysis of five input indicators in 2005. Source: Eurostat, authors.

did not form common group in 2015. United Kingdom (cluster no. 5) is in a specific position as an island country forming individual group, which is spatially correct, but economically rather not (opposite to the situation in 2005). However, the difference in the input indicators in 2015 caused that United Kingdom and Germany were "separated". Three-member group (cluster no. 1) contains France, Italy and Spain. In contrast to previous non-spatial analysis from 2015, the France substituted Poland, which is more appropriate both spatially (proximity of the countries) and economically (comparable economies). The last group (cluster no. 4) is composed of remaining countries. Ambiguity of this cluster in 2005 and 2015 is considerably high; therefore it is a bit problematic to find well-fitted characteristics for this large group of countries. However, they are separated from the core countries in both years with any single country being "diverted", which confirms the economic/industrial importance of the core countries.

5 Discussion

The results of the (geo)visual analysis show that CO_2 emissions within EU countries were decreasing in the selected period 2005–2015, with some exceptions (e.g. Iceland and Latvia). As the development of CO_2 emissions in all EU countries is not similar, the other economic and environmental indicators were included (e.g. GDP, Gross capital formation) into the analysis in order to reveal a com-

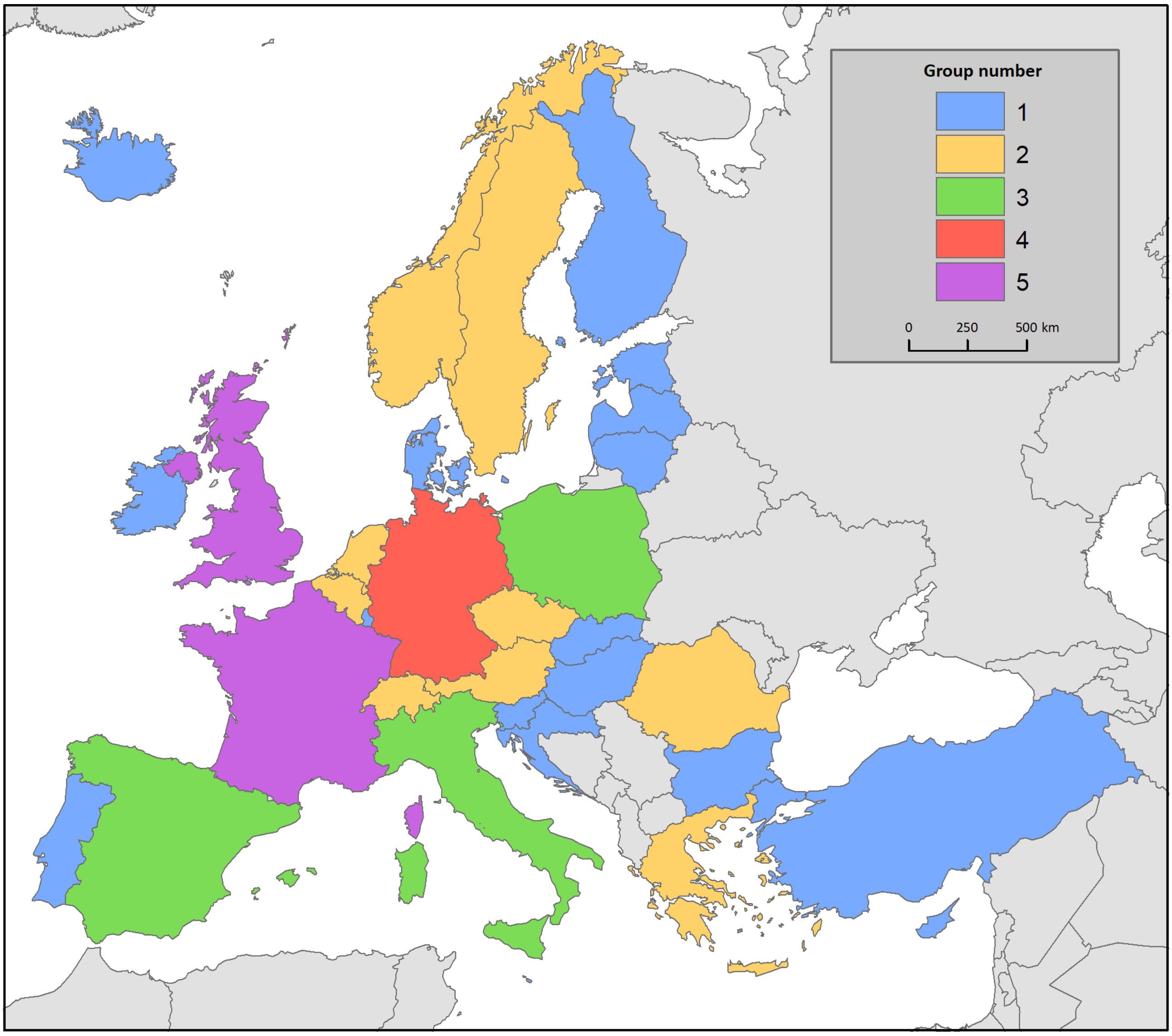

Fig. 6 Non-spatial grouping analysis of five input indicators in 2015. Source: Eurostat, authors.

mon (geographical) pattern and explain the current situation. Based on grouping/cluster analysis, it is possible to form groups of EU states with similar development. The authors need to stress out, that the grouping analysis is very sensitive to initial settings (number of target clusters, number of neighbours, etc.) and both quality and quantity input data (missing values, number of indicators, etc.). Moreover, it is always crucial to confront clustering results with input data and overall geographical and topical context (economical context in this case), see e.g. Kaufman and Rousseeuw (2009), or Marek et al. (2015a). Nevertheless, the proper interpretation should be done very carefully and with the respect to individual values of input indicators. Ideally, experts from both geoinformatics/geography and economy should discuss the implications coming from the analysis. However, authors are convinced that presented approach can be used as a complementary source of information by policymakers both on the national and international level. Currently, there are four separate EUA trading markets within EU ETS, where the companies and/or traders can buy emission allowances. Under the emission allowance trading rules, new allowances from individual Member States are launched in primary auctions (European Commission 2019). Two auction platforms are in place - the European Energy Exchange (EEX) in Leipzig is the common platform for the large majority of countries participating in the EU ETS. EEX also acts as Germany's and Poland's auction platform. The second auction platform is ICE Futures Europe (ICE) in London, which acts as the

Available online at content.sciendo.com GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001

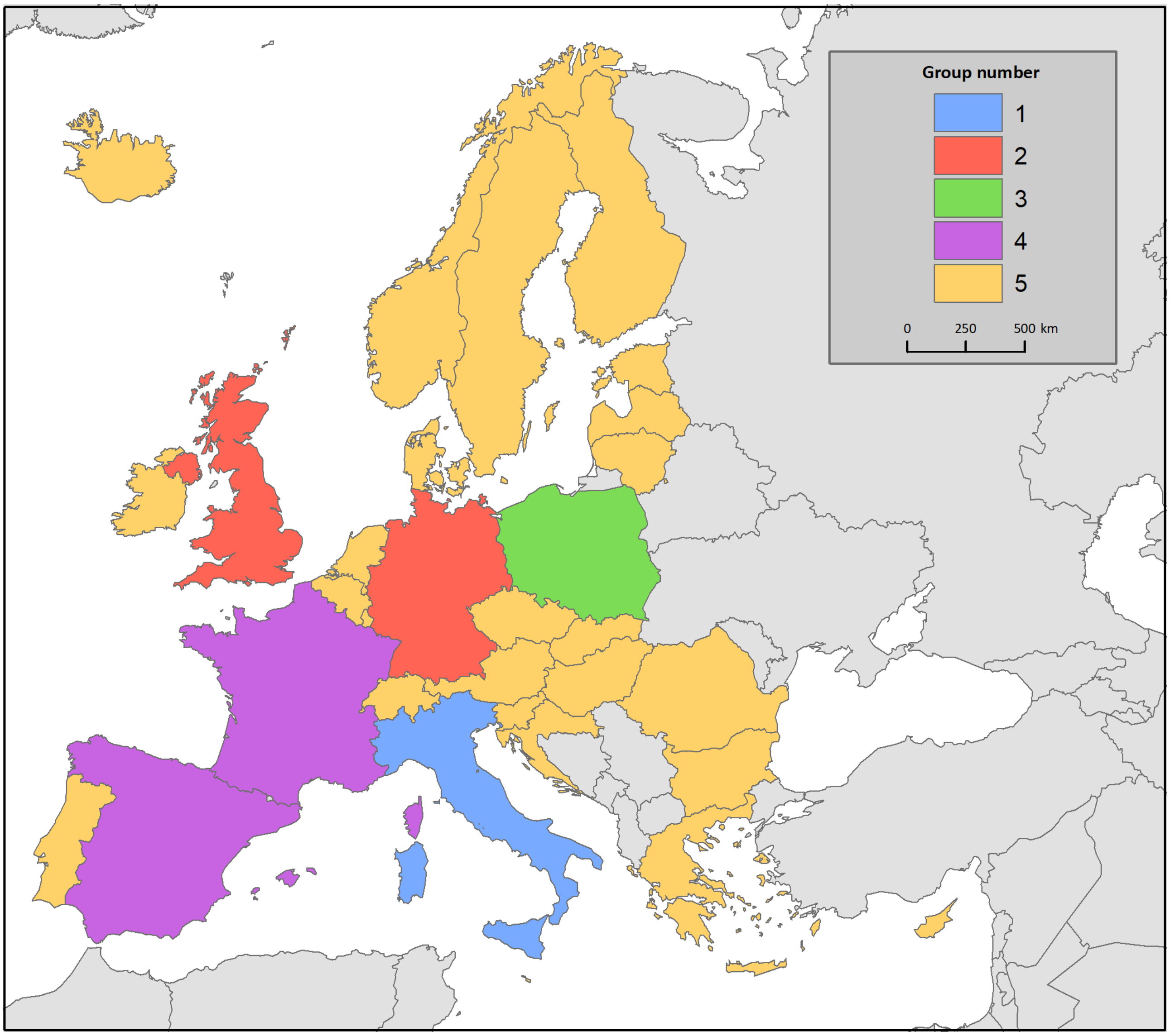

Fig. 7 Grouping analysis of all indicators in 2005 using six K-nearest neighbours. Source: Eurostat, authors.

United Kingdom's platform (European Commission 2019). The volume of these auctions is predetermined and each EU member state shall appoint an auctioneer. More than one member state may appoint the same auctioneer. Currently, the auctions are held separately for Germany, the United Kingdom and Poland and together for the other 25 EU Member States. This particular auction markets were created by political decision of EU member states (Official Journal of European Union 2010, last amendment 2017), based on the national environmental policy strategies of Germany, the United Kingdom, Poland and other EU member states. The United Kingdom, along with Germany and Poland, informed the European Commission that they would exercise opt out markets and appoint national auction platforms (HM Treasury 2011). It is the question, what were the main reasons for the above mentioned policy decisions.It could be the total volume of emission allowances in auctions in year 2012; focusing on the amount of allowances auctioned in 2012 (Official Journal of European Union 2010, last amendment 2017), Germany had more than 23 million allowances, the United Kingdom and Poland more than 10 mil. allowances; on the other hand, Spain and Italy had also more than 10 million allowances, but these countries did not ask for national auction platforms. Generally, emission allowances trading systems represent the policy instruments, connecting economic and spatial aspects of pollution. Based on our research and above described results, we can say that the current auction markets are well in tune with geographical and economic

GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001 Available online at content.sciendo.com

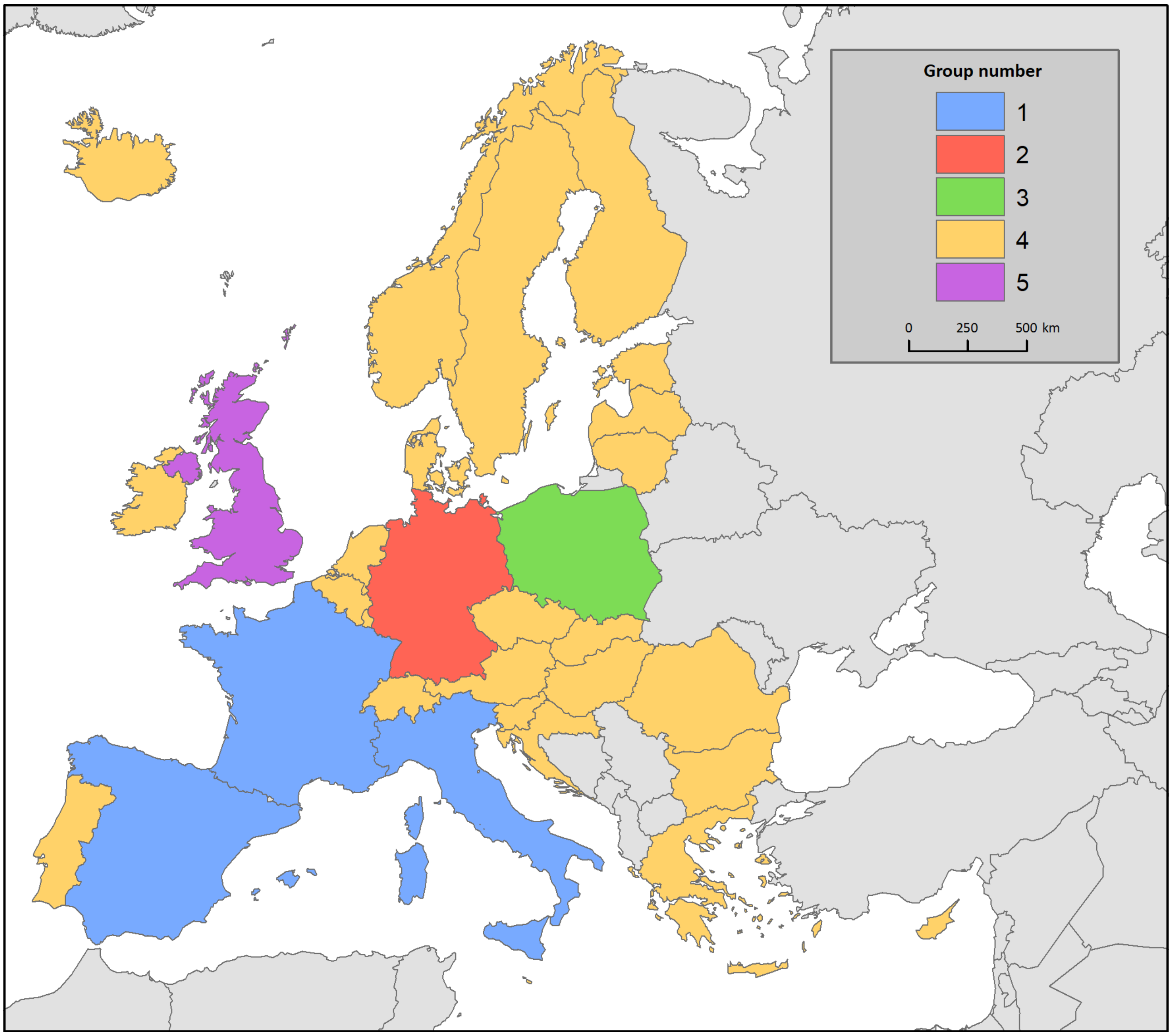

Fig. 8 Grouping analysis of all indicators in 2015 using six K-nearest neighbours. Source: Eurostat, authors.

characteristics of particular EU countries.It can be good result for policy makers, because it indicates, that the system of emission auctions has logical background and the markets represent natural platforms for emission trading, corresponding to both economic and spatial characteristics of particular countries/polluters. Regarding policymakers and EU ETS rules, results of grouping analysis of all indicators in 2015 using six K-nearest neighbours underline current separate auction markets for Germany, the United Kingdom and Poland. On the other hand, it can be valuable to discuss also additional separate market for Spain, Italy and France. Based on our results, these countries are characteristic by similar economic, environmental and spatial indicators. Furthermore, Spain and Italy represent the countries with high amount of auctioned emissions. Focusing on the study published by the European Environment Agency (2018), Italy, together with Germany and the United Kingdom, have so far received the highest revenue from auctions in the third trading period (Germany 4.8 billion EUR, the United Kingdom 2.5 billion EUR Italy 2.3 billion EUR). Dealing with future of emission trading and auctioning in the EU countries, results of the grouping analysis using six K-nearest neighbours confirms that the EU ETS (and generally emission trading) is economic instrument connected with space – it is spatially conditioned (Kolstad 2010). Based on our current knowledge, policy makers are not explicitly using sophisticated spatial methodology for the purposes of their decision making. This paper can serve as an additional source of information for them and also as an idea for their future evaluation of the EU ETS.

Available online at content.sciendo.com GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001

6 Conclusions

Presented study captures the development of CO_2 emissions from both EU policy and spatial (geographical) point of view. Using five fundamental economic and environmental indicators, and within the context of the EU ETS trading system, the results confirms current spatial and economic distribution of EU countries. Specifically, the cluster analysis showed that the major economic forces in Europe, i.e. United Kingdom, Germany, France, Italy, Spain, and Poland, are coherent in terms of forming individual or small groups with common properties. As mentioned before, in the case of Germany, Poland and United Kingdom, the cluster analysis independently proves that separate allowances auction markets for these countries are reasonable. Moreover, it proves the significance of these countries in Europe. Besides, the (geo)visual helped to identify regions (countries) with low amount of CO_2 emissions as well as those countries polluting the most. By displaying the absolute values, it is also possible to compare the countries between themselves.It must be noted, that there is a very positive trend in terms of CO_2 emissions reduction – only one EU member state increased CO_2 emissions from 2005 to 2015 (but just only about 1.4 percent). Focusing on topics of future research, the authors argue if visible decrease of CO_2 emissions is somehow connected with innovations in green/eco technologies and energy savings, or (on the other hand) if the decrease of CO_2 emissions is simply not a cause of the investments and production decrease after the economic crisis started in 2008. Moreover, it would be beneficial to include more socio-economic indicators in the cluster analysis, as it could justify and "polish" clustering results. Authors believe that this could be partially clarified by the use of regression analysis (regression modelling) of EU28+ countries, which is in the authors' future outlook.

Acknowledgement

This paper is supported by the Spationomy project (2016-1-CZ01-KA203-024040) funded by the European Union. The early version of the paper was presented and discussed at the SEDER Conference – Social and economic development regional policy, held at UJEP Ústí nad Labem in June 2018.

References

Aatola P, Ollikainen M, Toppinen A (2013) Price determination in the EU ETS market: Theory and econometric analysis with market fundamentals. Energy Economics 36: 380–395.

Andrienko G, Andrienko N, Jankowski P, Keim D, Kraak M J, MacEachren A, Wrobel S (2007) Geovisual analytics for spatial decision support: Setting the research agenda. International Journal of Geographical Information Science 21(8): 839–857.

Bailey I, Maresh S (2009) Scales and networks of neoliberal climate governance: the regulatory and territorial logics of European Union emissions trading. Transactions of the Institute of British Geographers 34(4): 445–461.

Benz E, Trück S (2009) Modeling the Price Dynamics of CO_2 Emission Allowances. Energy Economics 31(1): 44–15.

Chernyavska L, Gulli F (2008) Marginal CO_2 cost pass-through under imperfect competition in power markets. Ecological Economics 68: 408–421.

Chmelík T, Zámyslický P (2007) EU Emissions Trading Scheme as Implemented in the Czech Republic. Acta Polytechnica 47(6): 43–45.

Conrad C, Rittler D, Rotfuß W (2012) Modeling and explaining the dynamics of European Union Allowance prices at high-frequency. Energy Economics 34: 316–326.

Creti A, Joëts M (2017) Multiple bubbles in the European Union Emission Trading Scheme. Energy Policy 107: 119–130.

EEX (2018) EU Emission Allowances – Prices and Trading Volumes. Available from: <https://wwweexcom>

Erbach G (2018) Post-2020 reform of the EU Emissions Trading System, European Parliamentary Research Service, European Parliament. Available from: <http://www.europarleuropa.eu/RegData/etudes/BRIE/2018/621902/EPRS_BRI(2018) 621902$_{2E}Npdf$ >

ESRI (2016) How Grouping Analysis works. Available from: <http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/how-grouping-analysis-works.htm>

European Comission (2019) EU ETS – Auctioning the allowances. Available from: <https://ec.europa.eu/clima/policies/ets/auctioning_en>

European Commission (2013) The EU Emissions Trading System (EU ETS). European Union, October 2013. Available from: < http://ec.europa.eu/clima/publications/docs/factsheet_ets_en-pdf>

European Comission (2019), EU ETS – Auctioning the allowances. Available from: <https://ec.europa.eu/clima/policies/ets/auctioning_en>

European Environment Agency (2018) Trends and projections in the EU ETS in 2018. The EU Emissions Trading System in numbers.

Eurostat (2018) Greenhouse gas emissions. GDP and its components. Available from: http://ec.europa.eu/eurostat/

Falbo P, Felletti D, Stefani S (2013) Free EUAs and fuel switching. Energy Economics 35: 14–21.

Fan Y, Jia JJ, Wang X, Xu JH (2017) What policy adjustments in the EU ETS truly affected the carbon prices? Energy Policy 103: 145–164.

Feng ZH, Wei YM, Wang K (2012) Estimating risk for the carbon market via extreme value theory: An empirical analysis of the EU ETS. Applied Energy 99: 97–108.

García-Martos C, Rodríguez J, Sánchez MJ (2013) Modelling and Forecasting Fossil Fuels, CO_2 and Electricity Prices and their Volatilities. Applied Energy 101: 363–375.

Hepburn C, Fankhauser S (2010) Designing carbon markets, part II: carbon markets in space. Energy Policy 38(8): 4381–4387.

HM Treasury (2011) Regulating auctions of EU emissions allowances. Available from: <hm-treasurygov.uk>

GeoScape 13(1) — 2019: 1—15 doi: 10.2478/geosc-2019-0001 Available online at content.sciendo.com

Jenks GF (1967) The Data Model Concept in Statistical Mapping. International Yearbook of Cartography 7: 186–190.

Kaufman L, Rousseeuw PJ (2009) Finding groups in data: an introduction to cluster analysis (Vol 344). John Wiley & Sons, New York.

Knight E R (2010) The economic geography of European carbon market trading. Journal of Economic Geography 11(5): 817–841.

Lecuyer O, Quirion P (2013) Can Uncertainty Justify Overlapping Policy Instruments to Mitigate Emissions?. Ecological Economics 93: 177–191.

Li MW, Li YP, Huang GH (2011) An Interval-Fuzzy Two-Stage Stochastic Programming Model for Planning Carbon Dioxide Trading under Uncertainty. Energy 36(9): 5677–5689.

Lofgren A, Wrake M, Hagberg T, Roth S (2014) Why the EU ETS needs reforming: an empirical analysis of the impact on company investments. Climate Policy 14(5): 537–558.

Lund P (2007) Impacts of EU carbon emission trade directive on energy-intensive industries — Indicative micro-economic analyses. Ecological Economics 63: 799–806.

Lutz B J, Pigorsch U, Rotfuß W (2013) Nonlinearity in cap-and-trade systems: The EUA price and its fundamentals. Energy Economics 40: 222–232.

Marek L, Pászto V, Tuček P (2015a) Using clustering in geosciences: examples and case studies. In: 15th International Multidisciplinary Scientific Geoconference, Informatics, Geoinformatics and Remote Sensing 2: 1207–1214.

Marek L, Tuček P, Pászto V (2015b) Using geovisual analytics in Google Earth to understand disease distribution: a case study of campylobacteriosis in the Czech Republic (2008–2012). International Journal of Health Geographics 14(1): 7.

Martin R, Muuls M, De Preux LB, Wagner UJ (2014) On the empirical content of carbon leakage criteria in the EU Emissions Trading Scheme. Ecological Economics 105: 78–88.

Official Journal of the European Union (2002) Directive 2002/358/EC, available from: <http://data.europa.eu/eli/dec/2002/358/oj>

Official Journal of the European Union (2003) Directive Official Journal of the European Union (2003) Directive 2003/87/EC. Available from: <http://data.europa.eu/eli/dir/2003/87/oj>

Official Journal of the European Union (2009a) Directive 2009/29/EC. Available from: <http://data.europa.eu/eli/dir/2009/29/oj>

Official Journal of the European Union (2009b) Directive 2009/31/EC. Available from: <http://data.europa.eu/eli/dir/2009/31/oj>

Official Journal of the European Union (2017) Commission Regulation 2017/1902. Available from: <https://data.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R1902>

Official Journal of the European Union (2018) Directive 2018/410/EU. Available from: <http:// data.europa.eu /eli/dir/2018/410/oj>

Rogge KS, Schneider M, Hoffmann VH (2011) The innovation impact of the EU Emission Trading System — Findings of company case studies in the German power sector. Ecological Economics 70: 513–523.

Skovgaard J (2017) The Role of Finance Ministries in Environmental Policy Making: The case of European Union Emissions Trading System reform in Denmark, Germany and the Netherlands. Environmental Policy and Governance 27(4): 351–364.

Solilová V, Nerudová D (2015) Evaluation of Greenhouse Gas Emissions and Related Aspects: Case of the Czech Republic. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 63(1), 281–292.

Vícha O (2011) K právním nástrojům zachytávání, přepravy a ukládání oxidu uhličitého. In: Dienstbier F (ed.) Nástroje ochrany životního prostředí – role práva. Sborník z mezinárodní vědecké konference. Právnická fakulta Univerzity Palackého, Olomouc, pp. 87–93.

Voženílek V, Kaňok J et al. (2011) Metody tematické kartografie - Vizualizace prostorových jevů. UP, Olomouc.

Wettestad J, Eikeland PO, Nilsson M (2012) EU climate and energy policy: A hesitant supranational turn?. Global Environmental Politics 12(2): 67–86.

Zámyslický P (2013) Vliv obchodování s emisemi skleníkových plynů na ekonomiku obnovitelných zdrojů energie. Disertační práce. České vysoké učení technické v Praze, Fakulta elektrotechnická, Katedra ekonomiky, manažerství a humanitních věd.

Zimmermannová J (2015) Pilot Analysis of the Behaviour of Companies Within the 3rd Trading Period of the EU ETS in the Czech Republic. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 63(6): 2213–2220.

Zimmermannová J, Čermák P (2014) Possibilities of Multiagent Simulation Model Application in the Emission Allowances Trading Area. Procedia Economics and Finance 12: 788–796.

