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SPATIAL DIFFERENTIATION OF THE EMISSIVITY OF AGRICULTURE IN EUROPE[2]

Key words: greenhouse gases, emissions, agriculture, spatial differentiation, spatial statistics

ABSTRACT. This paper presents the results of a study aimed at determining the spatial variation in the carbon intensity of the agricultural sector in Europe. The analyses used the volume of greenhouse gas emissions from the agricultural sector (in 2020), expressed in carbon dioxide equivalent, calculated according to the IPCC methodology for 31 European countries. To reduce variance and the impact of country size on emissions, three emissivity factors were calculated, depending on: agricultural area, value of goods produced by agriculture and population. To verify the relationship between emissivity and location, the Moran autocorrelation coefficient was used, calculated on a modified weighting matrix that, in addition to the criterion of a common border, takes into account the similarity of objects in terms of the values of diagnostic variables (similarity determined using cluster analysis) – in this case indicators describing the emissivity of the agricultural sector. The study showed that there was no reason to reject the hypothesis of a random distribution of objects in space with respect to the values of the indicators included in the study. It can therefore be concluded that there are some similarities in the emissivity from the different European economies, as evidenced by the cluster analysis results, while there is no spatial correlation.

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INTRODUCTION

Progressive climate change and human-induced environmental degradation [Meadows et al. 1972, Steffen et al. 2015] pose a serious threat to the global economy. Population growth is considered to be the cause of these processes [UN 2022]. A phenomenon accompanying the aforementioned processes is the emission of greenhouse gases (GHG).

Awareness of the impact of greenhouse gas emissions on climate change is expressed in a number of changes in international policy. Modifications to the ETS (European Emissions Trading Scheme operated by industry) are being considered to extend it to additional sectors, e.g. agriculture. There are also plans to introduce the CBAM scheme [EP Regulation 2023/956], a price adjustment mechanism for products from outside of the European Union (EU) to take into account emissions in the country of origin. Strategic programmes are also being developed, such as, for example, the European Green Deal, part of which is a farm-to-table strategy –intended to ensure climate neutrality in the food sector.

There is a noticeable feedback loop between the impact of GHG emissions on agriculture and the environmental impact of the sector. As Jan Pawlak [2017] argues, agriculture, on the one hand, is susceptible to climate change due to its biological nature and, on the other hand, contributes significantly to climate change. The most significant in the agricultural sector are emissions from soil (nitrous oxide, which mainly comes from mineral and organic fertilisers) and emissions from enteric fermentation (methane, which mainly comes from cattle) and animal excreta (methane and nitrous oxide emissions) [IOŚ 2018]. According to Elżbieta Wójcik-Gront [2020], in 2017, among the gases emitted by agriculture, 51% were methane, 47% nitrous oxide and 2% carbon dioxide. It is believed that despite the positive changes in agricultural emissions [Bujanowicz-Haraś 2018, Harsányi et al. 2021], it is still necessary to look for solutions that could help to reduce them. According to Jan Pawlak [2018], reducing emissions in agriculture is possible by spreading practices that optimise the use of fertilisers.

As Ludwik Wicki and Aleksandra Wicka [2022] argue, past efforts aimed at reducing emissions have had the greatest effect in countries where the agricultural sector is less developed (especially technologically) - due to the greater potential to improve production techniques. Thus, it should be noted that the volume of GHG emissions is linked to the type of agriculture practised in a given country [Czyżewski and Kryszak 2017, Koloszko-Chomentowska et al. 2021]. There are also observed links between emissions from the agricultural sector and the level of development of a country - in poorer regions, lack of access to technology hinders the development of the sector (and indirectly the increase in emissions), while in rich countries, reduction of mechanisation and chemisation and investment in energy-saving technologies are postulated [Czyżewski and Kryszak 2018]. It is believed that the effectiveness of future changes in climate regulation may largely depend on a proper diagnosis of the size and origin of emissions in European countries.

Based on the literature review, a research gap was identified, which is to include the location of the object in space and the link to neighbouring objects in the study of the emissivity of the agricultural sector. Thus, the aim of the study was to determine the spatial differentiation of the agricultural sector's emissivity in Europe in 2020. The relationship between emissivity and spatial location was verified using the Moran autocorrelation coefficient estimated on a modified spatial weights matrix. Use of this method represents a new approach to considering the emissivity of the agricultural sector in Europe.

MATERIAL AND METHODS

In the research, data from a database administered by the Food and Agriculture Organisation of the United Nations (FAO) was used. The „IPCC agriculture" aggregate expressed in CO_2 equivalent (calculated for 2020) was used as the level of emissions from the agricultural sector. The study scope was limited to 2020 due to the need to obtain a complete data set for all units of the study population. In addition, it should be noted that only the spatial relationship was studied (the variability over time was omitted). To reduce the variance of the results, it was decided to calculate three emission factors:

- emissions per hectare of agricultural land (in tonnes per hectare),
- emissions per capita (in tonnes per capita),
- emissions per unit of value of goods produced by agriculture (in tonnes per USD 1,000).

Due to the assumptions of the applied method, it was decided to discard observations with missing data. The dataset used in the study contained information about 31 European countries.

For the verification of the relationship between emissivity and location in space, the Moran autocorrelation coefficient was used, which combines the concept of Pearson's correlation coefficient and gamma statistics. As well as examining the relationship between the values of a variable and location, the coefficient can also be used as a tool to group individuals in space. The estimation of the measure requires the determination of the weight matrix W and the correlation matrix A. The general form of the gamma statistic can be written as (1):

$$\Gamma = WA = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} a_{ij} \tag{1}$$

where: w_{ij} – elements of the weights matrix W, a_{ij} – elements of matrix A.

Moran's statistic can thus be written as (2):

$$\Gamma = \sum_{i} \sum_{j} w_{ij} (z_i \times z_j) \tag{2}$$

where: z_i i z_j are the standardised values of the random variable x.

The matrix notation of Moran's global spatial correlation statistic is shown in equation (3):

$$I_g = \frac{n}{S_0}\frac{z\prime Wz}{z\prime z} \tag{3}$$

$$Z(I_g) = \frac{I_g - E(I_g)}{var(I_g)^{\frac{1}{2}}} \sim N(0,1)$$

where: z is a vector of elements $z_i = x_i - \bar{x}$, S_0 is the sum of all elements of the weight matrix.

The Moran correlation coefficient makes it possible to verify the hypothesis H_0 about the random distribution of the values of the variable in space, against the alternative hypothesis H_1 about the non-random distribution of the values of the variable in space. The result of the analysis is visualised by a Moran diagram (Figure 1), presenting the dispersion of observations and the nature of the relationship:

- negative (where: $I_g < E(I_g)$, $Z(I_g) < 0$) (Figure 1A),
- positive (where: $I_g > E(I_g)$, $Z(I_g) > 0$) (Figure 1B) lub
- no-dependence (where: $I_g \approx E(I_g)$, $Z(I_g) \approx 0$) (Figure 1C).

In addition, the diagram (Figure 1) illustrates the relationship between the observed value and the mean in neighbouring areas, by placing objects in each quadrant of the diagram:

- quadrant 1. (HH): high values surrounded by high values (red in Figure 4),
- quadrant 2. (HL): high values surrounded by low values (green in Figure 4),
- quadrant 3. (LL): low values surrounded by low values (yellow in Figure 4),
- quadrant 4. (LH): low values surrounded by high values (blue in Figure 4).

The analysis uses a modification of the spatial weights matrix developed by Robert Pietrzykowski [2011, 2014], in which, besides the criterion of a common boundary, the similarity of objects in terms of economic characteristics selected by the researcher is also taken into account. The above method has not been applied before in the research of spatial differentiation of emissivity of the agricultural sector. The spatial weights matrix was developed using an agglomerative cluster analysis method (Ward's method). The number of clusters was set at 4, due to the four quadrants in the Moran diagram. As a measure of the distance of the objects, a metric was used, calculated according to formula (5), for p equal to 2:

$$d_{ik} = \left[\sum_{j=1}^{m} \left|x_{ij} - x_{kj}\right|^p\right]^{\frac{1}{p}} \tag{5}$$

where: p is the number indicating the type of metric, m is the number of characteristics, x_{ij}, x_{kj}, determine the realisation of the j-th characteristic in the i-th and k-th objects.

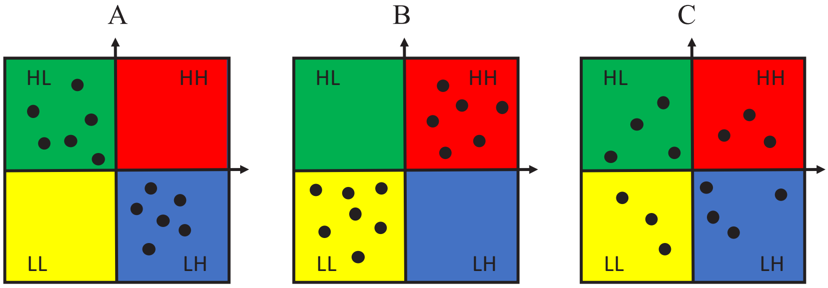

Figure 1. Examples of Moran diagrams showing the occurrence of negative (A), positive (B) and no (C) spatial autocorrelation

Source: own elaboration based on [Pietrzykowski 2020]

RESULTS

Figure 2 shows the absolute emissions volume from the agricultural sector in 31 European countries. Western European countries, i.e. France, the UK and Germany, had the highest greenhouse gas emissions in the study period.

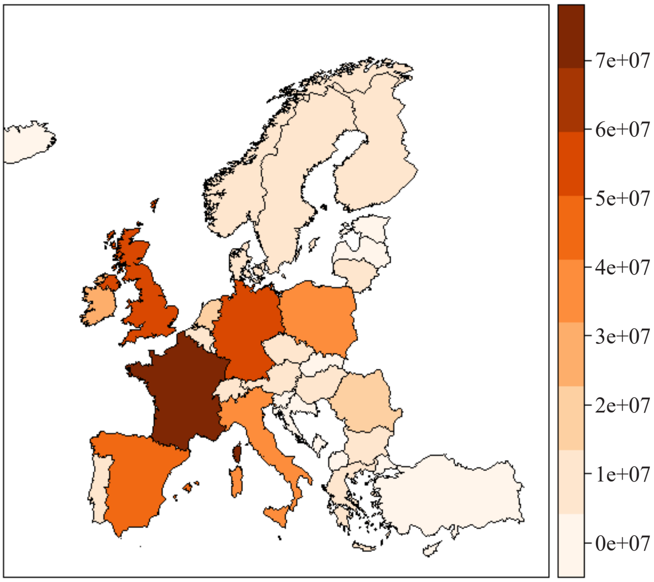

Figure 2. Greenhouse gas emissions in European countries from the agriculture sector (total emissions expressed in carbon dioxide equivalent)

Source: own elaborationna based on FAO data

Figure 3 shows the values of the emissivity factors (GHG emissions per hectare of agricultural land, GHG emissions per USD 1,000 of value of goods produced by agriculture and GHG emissions per capita) for the countries included in the study. The Benelux countries (Belgium and the Netherlands) and Norway and Ireland were the leaders in terms of emissions per hectare of UR, while the lowest values were observed in southern Europe. In terms of the volume of GHG emissions per value of goods produced by agriculture, a small range of variability was observed, with maximum values in the Baltic countries (Lithuania, Latvia, Estonia), Scandinavian countries (Sweden and Finland) and Ireland. In the remaining countries, the coefficient remained stable. During the period under review, only Ireland was characterised by significantly higher per capita emissions than the other countries.

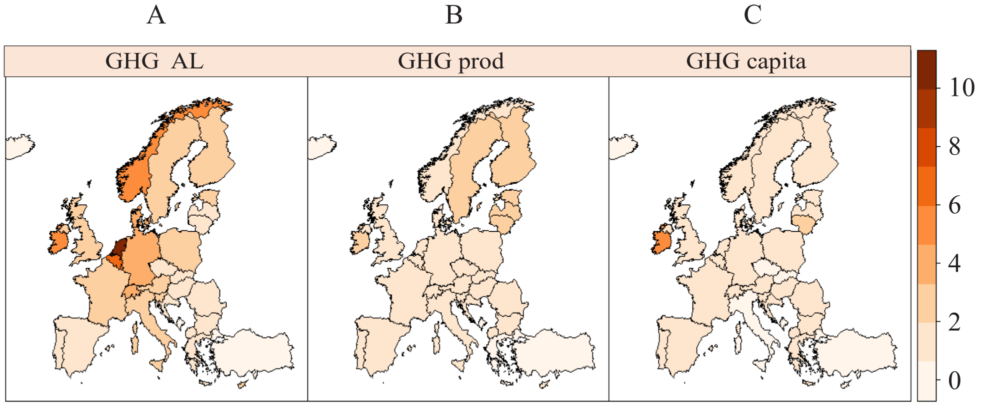

Figure 3. Greenhouse gas emissions level in European countries by agricultural land (A), unit of value of goods produced by agriculture (B) and per capita (C)

Source: own elaboration

Table 1 shows the characteristics of the four clusters formed by the cluster analysis. Cluster 2 had very high average emission per hectare of agricultural land. On the other hand, cluster 4 is characterised by very high average emissions *per capita*. The lowest average emissions per hectare of agricultural land were observed in cluster 3. In cluster 1, the average GHG emissions per hectare of agricultural land were most similar to the overall sample average. Average emissions per production value and average emissions per capita in cluster 3 were very similar to the overall sample averages.

The value of the Moran statistic estimated for the modified neighbourhood matrix was -0.27 (p-value = 0.78). Figure 4 shows the breakdown of countries resulting from the cluster analysis (A) and the breakdown of countries created by assigning them to

Table 1. Mean (± standard deviations) values of indicators across clusters and survey sample

Cluster number	Countries belonging to the cluster	Average value of the GHG emission factor		
		per hectare of agriculture land	on the unit of value of production	*per capita*
1.	Austria, Switzerland, Cyprus, Germany, Finland, France, Italy, Slovenia, Sweden, United Kingdom	2.98 ± 0.41	1.37 ± 0.53	0.78 ± 0.24
2.	Belgium, Malta, the Netherlands	8.68 ± 1.73	1.35 ± 0.34	0.70 ± 0.48
3.	Bulgaria, Czech Republic, Greece, Estonia, Spain, Croatia, Hungary, Latvia, Macedonia, Lithuania, Poland, Portugal, Romania, Slovakia	1.61 ± 0.41	1.48 ± 0.62	0.94 ± 0.46
4.	Denmark, Ireland, Luxembourg, Norway	4.97 ± 0.51	1.93 ± 0.78	2.20 ± 1.82
	All countries (31)	3.08 ± 2.29	1.55 ± 0.59	1.07 ± 0.82

Source: own elaboration

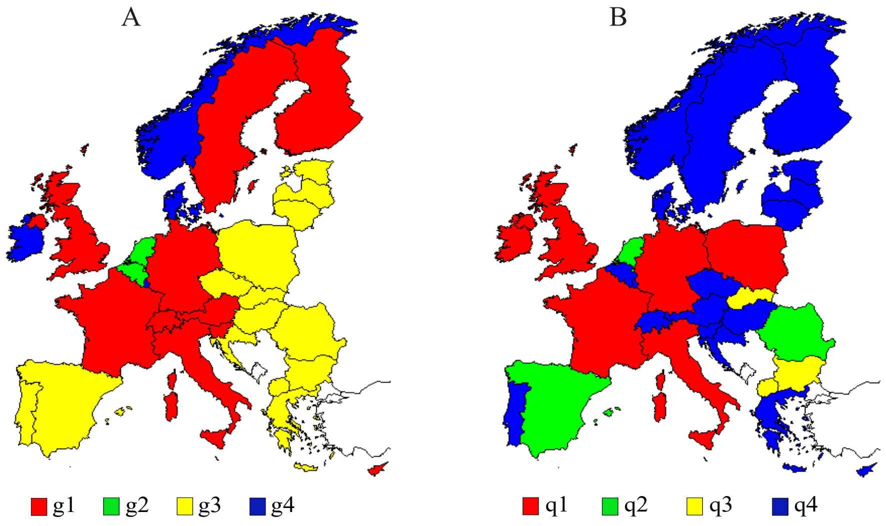

Figure 4. The belonging of European countries to the clusters identified in the cluster analysis (A) and the level of greenhouse gas emissions by European countries obtained using the Moran coefficient and a modified weights matrix taking into account the 3 diagnostic variables (B)

Symbols: g1-g4 correspond to the numbers of clusters shown in Table 1, 1q-4q correspond to the numbers of quadrants in the Moran scatter plot (see material and methods)

Source: own elaboration

the quadrants of the Moran's diagram (B). It should be noted that the clusters identified from the cluster analysis differ strongly from those resulting from the Moran scatter plot. The use of Moran's method, allows us to take into account, in addition to the values of variables, an additional factor, the location of the analysed objects, so the clusters obtained by this method are different from those obtained by cluster analysis. As can be observed, the lack of Moran's autocorrelation shows the randomness of the location of the studied objects, which means that there is no clear structure – the „spatial regimes" are not observed, in other words, the countries do not form spatial clusters, and their similarity is not due to their mutual location.

SUMMARY

The adaptation processes caused by climate change include modifications of legislation at national and international level. Despite the changes that have taken place so far in terms of environmental pollution from agricultural activities, new solutions (including legal ones) must be found to reduce, for example, greenhouse gas emissions. The effectiveness of future changes in legislation will largely depend on the proper identification of the volume and origin of emissions.

If we compare the values in Figures 2 and 3, it is important to note the change resulting from putting the values in relative terms. For example, France, despite having the highest greenhouse gas emissions in Europe (in absolute terms), does not excel in terms of agricultural emissivity indicators values. It should be noted that the composition of the group of countries with the highest emissivity depends on the chosen indicator. Nevertheless, in terms of each criterion, Ireland is always in the group of countries with the highest agricultural emissivity.

Inferring from the value of Moran's coefficient, it should be concluded that there are no reasons to reject the null hypothesis about the random location of objects in space. Therefore, it can be assumed that the amount of emissions from the agricultural sector in European countries is not related to their location, but depends on factors that were not included in the above analysis and the influence of which has been studied by other authors - for example: type of farming, country/sector development. Furthermore, it can be concluded that there are some similarities in the emissivity of European economies, as indicated by the results of the cluster analysis, however there is no spatial correlation. Thus, it can be concluded that future agricultural emissivity regulations should not be imposed equally on the entire set of European countries, due to their diversity, resulting, for example, from the type of farming [Czyżewski and Kryszak 2017] or the level of development of the sector [Wicki and Wicka 2022]. The choice of instruments and the degree of reduction should be made dependent on the conditions in a particular country or group of countries.

Further research is needed to clarify the similarities of European countries in terms of the emissivity of the agricultural sector, because previous studies in this area describe the phenomenon only in a fragmentary way, limiting themselves to a specific factor or group of factors. The above study fills the research gap which was the link between emissivity and the location of a country. This study should be seen as a another element to fully describe the origin and volume of greenhouse gas emissions in European agriculture.

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PRZESTRZENNE ZRÓŻNICOWANIE EMISYJNOŚCI ROLNICTWA W EUROPIE

Słowa kluczowe: gazy cieplarniane, emisja, rolnictwo, zróżnicowanie przestrzenne, statystyka przestrzenna

ABSTRAKT. W artykule podjęto próbę określenia przestrzennego zróżnicowania emisyjności sektora rolnictwa w Europie. W analizach wykorzystano wolumen emisji gazów cieplarnianych z sektora rolnictwa (w 2020 roku) wyrażony w ekwiwalencie dwutlenku węgla, obliczony zgodnie z metodyką IPCC, dla 31 państw europejskich. W celu zmniejszenia wariancji oraz zredukowania wpływu wielkości kraju na wolumen emisji, obliczono trzy wskaźniki emisyjności, których wartość zależała od: powierzchni użytków rolnych, wartości dóbr wytworzonych przez rolnictwo i liczby mieszkańców. Do weryfikacji zależności pomiędzy emisyjnością, a lokalizacją w przestrzeni wykorzystano współczynnik autokorelacji Morana, obliczony na podstawie zmodyfikowanej macierzy wag. W toku badań stwierdzono, że brak jest podstaw do odrzucenia hipotezy o losowym rozmieszczeniu obiektów w przestrzeni pod względem wartości wskaźników ujętych w badaniu. Można zatem wysunąć wniosek, że w zakresie emisyjności gospodarek europejskich uwidaczniają się pewne podobieństwa, o czym świadczą wyniki analizy skupień, natomiast brak jest powiązania przestrzennego.

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