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Greenhouse Gas Emissions by Agriculture in EU Countries

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1. Introduction

Air pollution means the release of solid, liquid, gaseous, foreign substances into the atmosphere or natural substances present in excessive amounts that may adversely affect human health, climate, living nature, soil and water or cause other environmental damage. Air pollution comes from both anthropogenic (artificial) and natural sources. Emission of pollutants determines the mass of a substance introduced directly into the environment both from natural sources (e.g. as a result of volcanic eruptions, erosion of the earth's surface, etc.) and from anthropogenic sources (fuel combustion processes, industry, agriculture) (Elsom 1987, 1992, Farmer 2002, Bartra et al. 2007, Ionel et al. 2008, Popescu & Ionel 2010, Rokicki 2016, 2017). The amount of substances introduced into the environment and the variability of emissions over time for a given emitter, as well as the spatial distribution of emitters significantly affect the quality of air in a given area (Bereitschaft & Debbage 2013, Rodríguez et al. 2016, Lu et al. 2018).

Pollution from agriculture is a special type of surface emission. They concern emissions from machines, crops (from plants and mineral and artificial fertilizers used in production), breeding, farms, meadows (Novotny 1999, 2006, Buckley & Carney 2013). The main pollutants emitted in agricultural areas, in particular from production farms, include NH_3, N_2O, as well as odors (Bauer et al. 2016, Giannadaki et al. 2018).

2. Literature overview

The emission of pollutants in the European Union in the years 2000-2017 decreased mainly regarding the emission of SO_x, PM, O_3 and NO_2 in the air. The largest reduction was achieved for SO_x (by 77%), and the smallest for NH_3 (9%). While there was seen a reduction for classical air pollutants there is no reduction trend for greenhous gases (EEA 2019a). Activity in the agricultural sector is expressed in gross value added (GVA) in euro. Gross value added is a measure of the value of goods and services produced by a given sector (Eurostat 2019). In 2017, EU agriculture accounted for 92% of emissions NH_3, 54% CH_4, 15% of PM_{10} and 8% NO_x particles. Agriculture was the sector in which the reduction of pollutant emissions was the lowest in 2000-2017 (a decrease by less than 10%) (EEA 2019b, 2019c).

In the years 2000-2017, emissions of air pollutants showed a significant separation from economic activity measured by the value of GDP, which was desirable due to environmental protection and increased productivity. Every euro of GDP generated was associated with ever lower emissions of air pollutants in subsequent years (Brand 2016, Crippa et al. 2016, Guevara 2016, Rokicki et al. 2018, EEA 2019a, Koszela et al., 2019). EU countries were diverse in terms of GDP volume, specialization in production (including agriculture), socio-economic characteristics and innovation (Chapman & Meliciani 2017).

Greenhouse gas emissions from agriculture increased more slowly than emissions from other human activities. The increase took place mainly in developing countries due to the increase in total agricultural production there. About 60% of all CO_2-equivalent greenhouse gas emissions (metric GWP 100) from agriculture were related to animal husbandry. Their biggest source was enteric fermentation, as a result of which methane was emitted. Emissions from the use of fertilizers were also significant. It was the fastest growing source of emissions in agriculture. In addition, plant cultivation (including for animal feed) was also responsible for the emission. There was a scattering of nitrogen compounds not collected by plants and decaying crop residues from agriculture. Nitrous oxide mainly comes from soils, but also from plant and animal production. Emissions from agriculture also concerned the use of energy to power agricultural machinery and equipment (Duxbury 1994, Burney et al. 2010, Leip et al. 2014, 2015).

As a rule, an increase in unit yield in agriculture leads to an increase in the share of nitrogen in feed or in fertilizing crops. There are also differences depending on the animal species (Smith et al. 2013, 2014). The conducted research indicates differences in air pollution resulting from the growth of agriculture in individual EU countries. The greatest impact of agricultural growth on concentration of $PM_{2,5}$ occurred in Bulgaria, Romania and Italy (Giannakis et al. 2019).

Simulations show that a large reduction in $PM_{2,5}$ levels can be achieved by reducing emissions from agriculture, in particular ammonia (NH_3) from the use of fertilizers and animal husbandry. In Europe and North America, this impact is not as great as in Asia (Pozzer et al. 2017). The emission of ammonia to the atmosphere can be reduced by using, among others low-emission techniques of distributing and storing fertilizers as well as keeping and feeding animals. In animal production, you can use a breed that emits less methane in the digestion process, shorten the length of beef cattle, increase the proportion of cow grazing, or use more organic feeding. In plant production, it is possible to select appropriate varieties of plant species that have greater potential for binding carbon and nitrogen, increase the share of plants having a more efficient photosynthesis process and growing faster, which will reduce carbon dioxide emissions (Cole et al. 1997, Steinfeld & Gerber 2010, Thornton & Herrero 2010, Havlík et al. 2011, 2014, Herrero et al. 2013, Bryngelsson et al. 2016, Lamb et al. 2016).

3. Aim, materials and methods

The main purpose of the paper is to show the relationship of greenhouse gas emissions by agriculture with economic development and agricultural production parameters in the European Union. The specific objectives are: to present the diversity in greenhouse gas emissions in countries, to show the dynamics of changes in this area, to determine the regularity between the level of economic development, resources and the volume of agricultural production, and greenhouse gas emissions in EU countries. The paper presents a hypothesis according to which in the EU countries in 2004-2017, greenhouse gas emissions resulted unambiguously from the volume of agricultural production carried out in the country. In work was using EU-28 CO_2-equivalent in tons using GWP 100. The volume of agricultural production can be measured in various ways. Several measures were adopted in the study, i.e. value of agricultural production, value of animal production, area of agricultural crops, including the main crops, and the population of main animal species. Gross value added of agricultural production is the difference between global agricultural production and intermediate consumption. Intermediate consumption includes the value of agricultural products used for production purposes, coming from own production and from purchase. All EU Member States were selected for research as of December 31, 2017 (28 countries). The research period concerned the years 2004-2017. The sources of materials were EUROSTAT data, literature on the subject. The following methods were used to analyze and present materials.

The Gini coefficient is a measure of unevenness (concentration) of distribution of a random variable. When the observations y_i are sorted in ascending order, the coefficient can be represented by the formula (Dixon et al. 1987):

$$G(y) = \frac{\sum_{i=1}^{n}(2i - n - 1) * y_i}{n^2 * \overline{y}} \quad (1)$$

where:
n – number of observations,
y_i – value of the "i-th" observation,
$\overline{y}$ – the average value of all observations, i.e. $\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$

The Lorenz curve determines the degree of concentration of a one-dimensional random variable distribution (Dagum 1980). With sorted observations y_i, which are non-negative values $0 \le y_1 \le y_2 \le ... \le y_n$, $\sum_{i=1}^{n} y_i > 0$, the Lorenz curve is a polyline which apexes (x_h, z_h), for h = 0,1,…, n, have the following coordinates:

$$x_0 = z_0 = 0, \qquad x_h = \frac{h}{n}, \qquad z_h = \frac{\sum_{i=1}^{h} y_i}{\sum_{i=1}^{n} y_i} \quad (2)$$

The Gini coefficient determines the area between the Lorenz curve and the diagonal of a unit square multiplied by 2.

In the case of a nuclear density estimator, the nucleus is such a function K : R -> [0,∞] that (Kulczycki 2005):

1) $\int_{-\infty}^{\infty} K(x)dx = 1$,
2) K(0) >= K(X) for each R,
3) K – symmetrical to zero.

A nuclear estimator is a function $\hat{f}_n(x) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{X - X_i}{h})$, (3) where h is a constant called a bandwidth for h > 0.

The Doornik-Hansen test was used to determine compliance with the normal distribution (1994):

$$DH = z_1^2 + z_2^2 \tag{4}$$

where:
z_1 – transformed skewness,
z_2 – transformed oddity.

Pearson's linear correlation coefficient is a measure of the strength of a straight line relationship between two measurable features. It is expressed by means of the following formula (Jajuga & Walesiak 2004):

$$r_{XY} = \frac{C(X,Y)}{\sqrt{S_X{}^2 \cdot S_Y{}^2}} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2}} = \frac{C(X,Y)}{S_X \cdot S_Y} \tag{5}$$

where:
C(X,Y) – covariance between the X and Y features,
S_x^2 – X feature variance,
S_Y^2 – Y feature variance,
S_x – X feature's standard deviation,
S_Y – Y feature's standard deviation.

The linear correlation coefficient can be considered as normalized covariance. Correlation always takes values in the range (-1, 1).

4. Research results

Greenhouse gas emissions from agriculture can be shown for all gases. Then, the gas emissions are converted into CO_2-equivalent in tons using GWP 100. The greenhouse gas emissions from agriculture calculated in this way contain the following types of pollution: CO_2, N_2O, CH_4, HFC, PFC, SF_6, NF_3. The largest emitters of greenhouse gases from agriculture included France, Germany, Great Britain and Spain. Poland and Italy followed. When analyzing individual types of greenhouse gases from agriculture, only the order of the countries in the top six changed slightly. Table 1 presents the dynamics of changes in greenhouse gas emissions from agriculture in EU countries in 2004-2017. The results are ordered in descending order of the dynamics of changes in total greenhouse gas emissions. In addition, dynamics indicators for basic types of gases emitted by agriculture, i.e. carbon dioxide, methane and nitrous oxide, are also presented.

The largest increase in greenhouse gas emissions from agriculture occurred in developing countries, including Latvia, Bulgaria, Estonia, Hungary and Poland. In turn, the largest decreases in emissions were recorded in southern European countries. In developed countries, there were slight declines or increases in emissions. When analyzing only selected gases, it turned out that there was very large variation. For example, in Latvia, carbon dioxide emissions from agriculture increased by 13 times in 2004-2017, in Luxembourg they almost tripled. The largest decreases were recorded in Cyprus (by 55%) and in the Netherlands (by 40%). In the case of methane emissions, the changes were smaller. This gas is mainly emitted by ruminant animals, i.e. its emission should be quite well correlated with animal population. Usually changes in the population do not occur very quickly and rapidly. In the case of nitrous oxide, the rapidity of changes in emissions of this gas as a result of agricultural activities was not large. This may indicate stabilization of plant production and the level of plant fertilization. Given the EU as a whole, greenhouse gas emissions from agriculture have not fallen much. The exception was carbon dioxide, which emissions increased slightly.

Table 1. Dynamics indicators of greenhouse emissions from agriculture in the EU in 2004-2017 (2004 = 100) (EUROSTAT)

Countries	Dynamics indicators of greenhouse emissions from agriculture in 2004-2017			
	total greenhouse gases	carbon dioxide	methane	nitrous oxide
Latvia	120.19	1395.06	117.85	119.40
Bulgaria	119.43	176.36	81.02	144.32
Estonia	117.82	144.22	108.64	126.13
Hungary	110.34	140.05	102.19	115.27
Luxembourg	108.36	282.06	114.12	96.34
Poland	108.04	68.68	107.96	111.72
Lithuania	105.26	110.18	88.33	121.14
Czechia	104.56	192.97	95.55	109.88
Ireland	103.09	135.44	105.09	97.85
Austria	102.84	112.23	101.68	104.64
Germany	102.70	117.42	100.10	104.42
Netherlands	102.01	59.34	110.65	88.78
Sweden	101.46	103.50	94.65	108.20
Portugal	101.15	212.88	103.70	95.24
Slovakia	100.36	211.62	84.60	113.66
Finland	100.01	71.65	100.66	101.62
Slovenia	99.75	78.13	102.02	95.86

Table 1. cont.

Countries	Dynamics indicators of greenhouse emissions from agriculture in 2004-2017			
	total greenhouse gases	carbon dioxide	methane	nitrous oxide
France	97.21	106.30	97.33	96.62
Denmark	96.68	137.21	94.97	97.32
Belgium	96.22	107.32	98.92	92.21
Italy	94.83	74.36	102.38	84.28
United Kingdom	94.13	79.01	94.66	94.78
Romania	92.15	91.56	89.42	98.09
Spain	91.99	116.12	88.00	98.90
Malta	88.34	156.00	89.51	90.91
Greece	85.69	93.97	89.61	80.95
Cyprus	84.79	44.21	89.49	77.78
Croatia	84.25	106.83	83.86	83.64
EU-28	98.71	101.03	97.66	99.98

The distribution of greenhouse gas emissions from agriculture was also examined and was found to be uneven. To determine the degree of concentration of greenhouse gas emissions from agriculture in European Union countries, the Gini coefficient was used. The data refers to the beginning of the study period, i.e. 2004 and the final year, 2017, and the number of observations was 28. The results were presented for four types of emissions, i.e. total, carbon dioxide, methane and nitrous oxide. The Gini coefficient for total greenhouse gas emissions from agriculture in 2004 calculated from the sample was 0.59, while the estimated coefficient for the population was 0.61. This means a large concentration of these gases in several EU countries. If the study was repeated for 2017, the results were slightly lower (coefficient from the sample = 0.58, and estimated for the population = 0.61). Therefore, there were no significant changes in the distribution of this type of greenhouse gas emissions. In addition, greenhouse gas emissions from agriculture in 2017 are presented on the Lorenz concentration curve (Fig. 1).

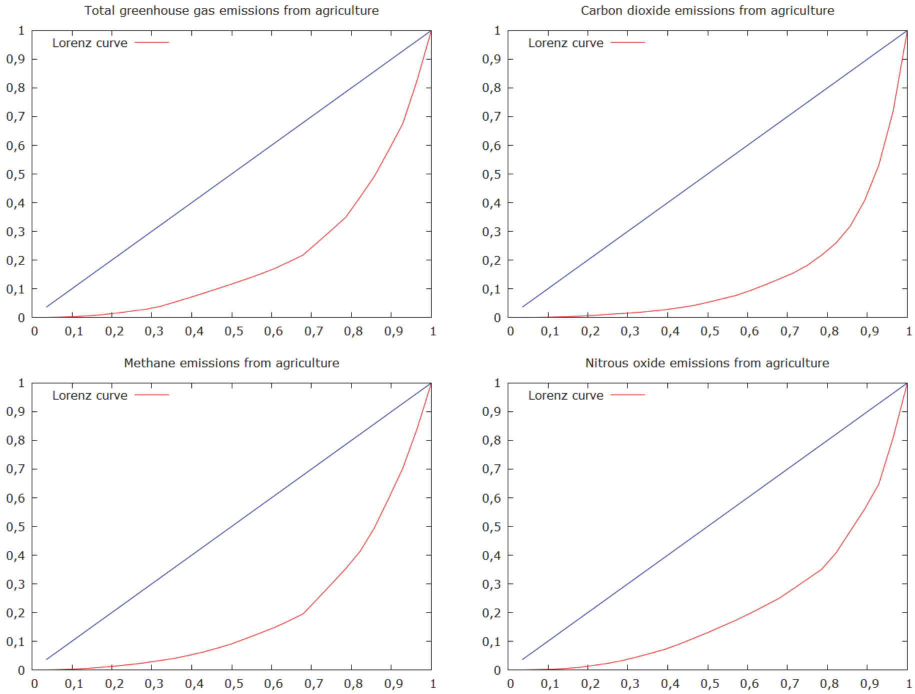

Fig. 1. Lorenz curve for greenhouse gas emissions from agriculture in EU countries in 2017

A similar approach was taken for individual greenhouse gases. For CO_2, the highest emission concentration was achieved, because in 2004 the coefficient from the sample was 0.73, and the estimated 0.75. In 2017 it was 0.71 and 0.74 respectively. The methane emission from agriculture in 2004 was strongly concentrated in several EU countries (coefficient from the sample 0.60 and estimated 0.62), similarly to nitrous oxide (coefficient from the sample 0.58 and estimated 0.60). In both cases, identical Gini coefficients were achieved in 2017. The presented results show that greenhouse gas emissions from agriculture were concentrated in several EU countries. The first four countries were the largest in terms of agriculture, i.e. France, Germany, Great Britain and Spain. In addition, in 2004-2017 the concentration factor was maintained, which means a great stabilization of the structure.

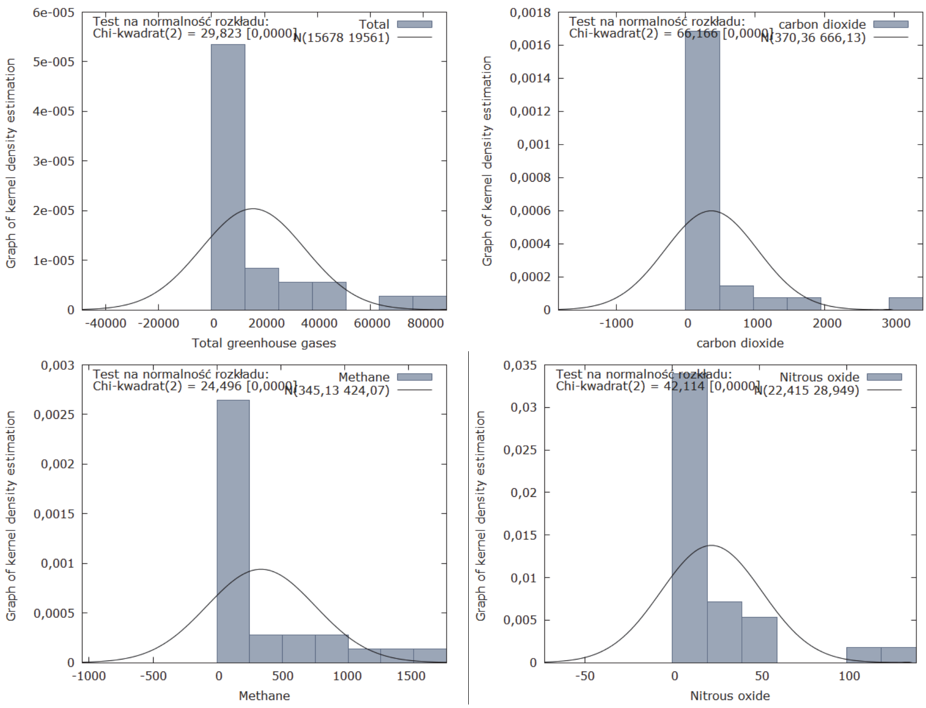

Fig. 2. Graph of kernel density estimation for greenhouse gas emissions from agriculture in EU countries in 2017

The smallest countries were of little importance in the structure of greenhouse gas emissions from agriculture. This is also confirmed by the density plots (Fig. 2). For all greenhouse gas emissions from agriculture in CO_2 equivalent for 19 countries, which accounted for 68% of all countries, emissions were less than 12,691 thousand tons of CO_2 in 2017 (in total, only 120 million tons were emitted in this group of countries, which accounted for only 27% of greenhouse gas emissions from agriculture in the EU). Greenhouse gas emissions from agriculture were not in line with the normal distribution. There were very similar relationships for methane emissions. In 19 countries with the lowest emissions, the emission of 25% of methane produced by agriculture in the EU was concentrated. For nitric oxide emissions, 19 countries in the lowest emission range achieved 30% of total EU gas emissions from agriculture. In the case of only CO_2 emissions, as many as 23 countries (82% of countries) were in one group, in which the emission was not higher than 487,000 tons in 2017. Total emissions from this group accounted for 5.6 million tons, or 54% of emissions throughout the EU.

Table 2. Pearson's linear correlation coefficients between greenhouse gas emissions from agriculture and selected economy and agriculture parameters

Parameters	Pearson's linear correlation coefficients for types of greenhouse gases			
	total greenhouse gases	carbon dioxide	methane	nitrous oxide
Correlation coefficients between the volume of greenhouse gas emissions from agriculture and				
GDP value	0.905	0.899	0.908	0.867
value of agricultural production	0.937	0.780	0.939	0.912
value of animal production	0.967	0.870	0.964	0.942
total UAA (ha)	0.857	0.660	0.873	0.820
total arable land (ha)	0.872	0.709	0.855	0.873
total area of permanent grassland (ha)	0.823	0.638	0.873	0.744
total area of permanent crops (ha)	0.386	0.130	0.452	0.309
cattle population	0.974	0.892	0.960	0.962
sheep and goat population	0.523	0.342	0.614	0.404
pig population	0.775	0.686	0.775	0.752
consumption of inorganic nitrogen fertilizers (mineral)	0.973	0.917	0.936	0.988
consumption of inorganic phosphorus fertilizers (mineral)	0.819	0.641	0.824	0.795
manure production from farm animals (in tonnes of nitrogen)	0.987	0.870	0.989	0.958
manure production from farm animals (in tonnes of phosphorus)	0.988	0.883	0.985	0.963

A p-value <0.01 was achieved for all correlation coefficients

In order to determine the relationship between the volume of greenhouse gas emissions from agriculture in the European Union and the agricultural and economic parameters (in total there were 14 such parameters) that could be associated with it, Pearson's linear correlation coefficients were calculated (Table 2). P = 0.01 was used as the limit of significance. Correlation coefficients were calculated for EU countries in the years 2004-2017. The study attempted to check the correlation that does not indicate that a given factor affects another, but that there is a strong or weak relationship between them.

All the results obtained turned out to be significant. Very strong positive relationships of greenhouse gas emissions from agriculture with the value of GDP and most agricultural parameters were found. This demonstrates the very high interdependence of the economic and agricultural situation with the amount of greenhouse gas emissions generated in agriculture. In general, the relationships were weaker in the case of CO_2 emissions, especially in relation to the total area of permanent crops, sheep population. These two parameters were the least correlated with other types of greenhouse gas emissions from agriculture. This may be due to the small share of such crops in the total agricultural area and suggests that the changes in production and fertilization level may outweigh the changes in land use for arable cropping. The share of sheep and goats in the animal population was also small. Particularly high positive relationships were achieved in the relation of greenhouse gas emissions from agriculture (various types) with the value of animal production, cattle population, consumption of inorganic (mineral) nitrogenous fertilizers, manure production from livestock in tons of nitrogen, as well as in tons of phosphorus. Such results show a large association of greenhouse gas emissions from agriculture, especially with animal production.

5. Conclusions

Nowadays, the reduction of greenhouse gas emissions is an important issue. Agriculture is one of the branches of the economy that contributes to high emissions. Therefore, it is important to determine the relationships at the macroeconomic level. The research allows the following conclusions to be drawn.

1 Greenhouse gas emissions from agriculture slightly decreased across the EU in 2004-2017. The changes, however, varied. As a rule, greenhouse gas emissions from agriculture increased in developing countries, while they remained at a similar level in developed countries. CO_2 emissions increased in the EU-28, but changes in individual countries varied widely. For other emission parameters (methane, nitrous oxide) the changes were not very large, there was less variation between countries in the dynamics of change.

2 There was a large concentration of greenhouse gas emissions from agriculture in several EU countries. The situation was stable, because from 2004 to 2017 the level of concentration did not change much. The top four emitting countries were the largest in terms of economic agricultural output, namely France, Germany, Great Britain and Spain.

3 All agricultural and economic parameters that were compared with the greenhouse gas emissions from agriculture were statistically significant. This indicates that the parameters selected for the calculations are good and that there is a close positive relationship.

4 The presented studies allow to state that the level of greenhouse gas emissions from agriculture depends on the economic situation and the terms of agriculture in the country. Regularities were in many cases straightforward, as for the relationship between greenhouse gas emissions from agriculture and the value

of animal production, cattle population, and the use of mineral fertilizers and manure production. This close relationship resulted from the fact that animal production was the part of agriculture that generated the most greenhouse gases.

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Abstract

The main objective of the paper was to show the relationship of greenhouse gas emissions by agriculture with economic development and agricultural production parameters in the European Union. All EU Member States were selected for research purposefully. The research period concerned the years 2004-2017. The sources of materials were EUROSTAT data, literature on the subject. For the analysis and presentation of materials, descriptive, tabular, graphic methods, dynamics based on a constant basis, Gini concentration coefficient, concentration analysis using the Lorenz curve, Pearson's linear correlation coefficients were used. Agriculture is one of the major economic sectors responsible for greenhouse gas emissions. In 2004-2017, emissions from this section slightly decreased in the EU. There was a wide variation between countries. Economically developing countries increased emissions, while developed countries maintained them at a similar level. Greenhouse gas emissions were highly concentrated in several EU countries. These were the countries with the most developed agriculture. In the years 2004-2017, there were no changes in the level of emission concentration. The level of greenhouse gas emissions from agriculture depended on the economic and agricultural situation in the country. The regularities were in many cases straightforward, as for the relationship of greenhouse gas emissions from agriculture with the value of animal production, cattle population, and the use of mineral fertilizers and manure production. This close relationship resulted from the fact that livestock production was the part of agriculture that generated the most greenhouse gases.

Keywords:
agriculture, EU, greenhouse gases, pollution reduction, methane, carbon dioxide

Emisja gazów cieplarnianych przez rolnictwo w krajach UE

Streszczenie

Celem głównym pracy było ukazanie zależności emisji gazów cieplarnianych przez rolnictwo z rozwojem gospodarczym i parametrami produkcji rolniczej w krajach Unii Europejskiej. W sposób celowy wybrano do badań wszystkie kraje członkowskie Unii Europejskiej. Okres badań dotyczył lat 2004-2017. Źródłami materiałów były dane

EUROSTAT, literatura przedmiotu. Do analizy i prezentacji materiałów zastosowano metody opisową, tabelaryczną, graficzną, wskaźniki dynamiki o podstawie stałej, współczynnik koncentracji Giniego, analiza koncentracji za pomocą krzywej Lorenza, współczynniki korelacji liniowej Pearsona. Rolnictwo jest jednym z ważniejszych działów gospodarki odpowiedzialnych za emisję gazów cieplarnianych. W latach 2004-2017 emisja wynikająca z tego działu nieznacznie zmniejszyła się w UE. Występowało duże zróżnicowanie pomiędzy krajami. Państwa rozwijające się gospodarczo zwiększały emisję, zaś rozwinięte utrzymywały ją na podobnym poziomie. Emisja gazów cieplarnianych była mocno skoncentrowana w kilku państwach UE. Były to państwa z najbardziej rozwiniętym rolnictwem. W latach 2004-2017 nie zaszły żadne zmiany w poziomie koncentracji emisji. Poziom emisji gazów cieplarnianych z rolnictwa był uzależniony od sytuacji gospodarczej i w zakresie rolnictwa w kraju. Prawidłowości były w wielu przypadkach prostoliniowe, jak dla relacji emisji gazów cieplarnianych z rolnictwa z wartością produkcji zwierzęcej, pogłowiem bydła, czy zużyciem nawozów mineralnych i produkcją obornika. Ten ścisły związek wynikał z faktu, że produkcja zwierzęca była tą częścią rolnictwa, która generowała najwięcej gazów cieplarnianych.

Słowa kluczowe:
rolnictwo, UE, gazy cieplarniane, redukcja emisji zanieczyszczeń,
metan, dwutlenek węgla