Leszek **SIECZKO** • Zofia **KOLOSZKO-CHOMENTOWSKA**

RELATIONSHIPS BETWEEN ECONOMIC AND ECOLOGICAL INDICATORS AND GREENHOUSE GAS EMISSIONS: THE PERSPECTIVE OF FARMS IN POLAND AT THE REGIONAL LEVEL

Leszek **Sieczko** (ORCID: 0000-0002-9325-643X) – *Department of Biometry, Warsaw University of Life Sciences – SGGW*

Zofia **Koloszko-Chomentowska** (ORCID: 0000-0002-3937-9594) – *Department of Management Economy and Finance, Bialystok University of Technology*

Correspondence address:
Nowoursynowska Street 159, 02-787 Warsaw, Poland
e-mail: leszek_sieczko@sggw.edu.pl

ABSTRACT: Aligning farms with the European Green Deal necessitates precise identification and analysis of the interplay between primary economic factors and ecological dimensions. This study presents detailed research findings on the correlation between ecological indicators, CH_4 and N_2O emissions, and economic metrics within a regional framework. The research draws on data from farms participating in the European Agricultural Accounting Network (FADN) spanning 2010-2019. The resultant analysis underscores substantial correlations among the examined parameters. Regions characterised by heightened agricultural production intensity report elevated agricultural income. However, this is coupled with increased environmental impact and heightened greenhouse gas emissions, particularly among farms engaged in animal production. Mazowsze, Podlasie, Wielkopolska, and Slask exhibit notable progress in pro-environmental initiatives. In the Pomorze and Mazury regions, expenditures on fertilisation and plant protection remain close to the average, culminating in an efficient equilibrium of organic matter in the soil and minimal CH_4 and N_2O emissions per hectare.

KEYWORDS: greenhouse gas emission, soil organic matter, farm income

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Introduction

One important area of the EU's activity is the fight against climate change and the achievement of climate neutrality by 2050. These goals were outlined in a document titled the European Green Deal (EGD). Among the EGD's priorities is the "farm to fork" strategy, which is intended to guarantee safe food produced with the application of sustainable practices (Vanham & Leip, 2020; Taning et al., 2021; Riccaboni et al., 2021).

Protection of biodiversity and climate change, as highlighted in the EGD, are strategic measures of the EU. Implementation of this concept requires financial and institutional engagement (Barcaccia et al., 2020; Sikora, 2020; Cortignani et al., 2022). Implementing the principles of the European Green Deal (EGD) into agricultural practice is also a new challenge for agricultural holdings. This is associated with changes in agricultural practice, which should contribute to protecting resources and preserving the natural environment (European Commission, 2020; Sikora, 2020). On the other hand, the socioeconomic aspect of agriculture as a source of income for farmers and their families is highlighted. Hence, both high-quality food produced by methods safe for the environment and the economic security of agricultural families are very heavily accented.

The negative impact of agricultural production on the environment manifests, above all, in the emission of greenhouse gases (GHG), mainly nitrous oxide (N_2O) and methane (CH_4) (Emmerling et al., 2020; Nowakowicz-Dębek et al., 2020; Tongwane & Moeletsi, 2018).

Agricultural production is responsible for over 10% of total carbon dioxide emissions within the EU-28 area (Solazo et al., 2016). According to data from the Ministry of Climate in 2019, agriculture in Poland was responsible for 8.4% of greenhouse gas emissions (KOBiZE, 2021). Over half of the total emissions from agriculture in Poland are associated with animal husbandry (Wiśniewski, 2018).

The economic dimension of relationships between agriculture and climate change has been confirmed in studies. However, the results of these studies are not unambiguous. Khan et al. (2018) observed a slight reduction in GHG emissions as a result of the increase in value added in agriculture and renewable energy. In the case of studies by Zafeiriou et al. (2018), the results are quite different. The authors studied the relationship between greenhouse gas emissions from agriculture and income per resident in the agricultural sector in different EU member states. The results indicated that if CO_2 emissions increase, so too does income from agriculture, which was confirmed in the case of Spain, although a linear dependency was not observed.

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According to studies, the reduction of greenhouse gas emissions from agriculture should be considered on the background of changes in farmers' income situation (Milne et al., 2015). The "farm to fork" strategy confirms that research and innovation are the critical factors accelerating the transition to healthy and sustainable food systems, which combine environmental and economic objectives (Riccaboni et al., 2021). At the same time, the varying results obtained in research conducted until now justify the need for continuing research at the level of individual agricultural holdings as the elementary links in the food chain.

This paper fits into the concept of the EGD and broadens knowledge in this scope. In the assessment of this paper's authors, such research is necessary and should account for the broadest possible spectrum of indicators of environmental and economic equilibrium at the level of an agricultural holding. This gives a broader picture of the dependencies occurring between a farmer's choice as to applied agricultural practices and the benefits flowing from the protection of biodiversity. This will make it easier to achieve the objectives defined in the EGD concept.

The goal of this paper is to investigate dependencies between environmental indicators, methane and nitrous oxide emissions, and economic indicators at the level of agricultural holding in different regions of Poland. This territorial reference is justified because, as research shows, agri-environmental practices and the economic situation of agricultural holdings are regionally differentiated (Cortignani & Dono, 2019). Learning about these differences will make it possible to implement more directed actions according to the given region in order to provide a stimulus in the direction of sustainable development.

Methodology

Data concerning agricultural holdings used in the analysis come from the FADN system and are published by the Institute of Agricultural and Food Economics – National Research Institute (Polski FADN). Despite the fact that it mainly concerns the economic situation of agricultural holdings, it is also used for environmental analyses (Wilk, 2007; Piekut & Machnacki, 2011; Syp & Osuch, 2017; Koloszko-Chomentowska et al., 2021). Different groups of indicators of environmental equilibrium are known in the literature, and their selection depends on data availability (Castoldi & Bechini, 2010; Belanger et al., 2015; Escribano et al., 2014; Paracchini et al., 2015; Prus, 2017; Harasim, 2013).

The following were taken into account in the group of agri-environmental indicators: livestock density (Lu·ha-1),$^{-1}$), balance of soil organic matter (t·ha^{-1}) (Harasim, 2013) and consumption of mineral fertilisers and plant

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protection products (PLN·ha^{-1}) (Sobczynski, 2008). Organic matter is of significant importance in shaping the fertility of soils. The balance of soil organic matter was estimated based on organic matter degradation and reproduction coefficient (after Harasim, 2013). The coefficients for medium soils were adopted. Greenhouse gas emissions (methane and nitrous oxide) were estimated according to the methodology proposed by Wiśniewski (2018). Such a solution is consistent with the methodology and standard indicators of the Intergovernmental Panel on Climate Change (IPCC, 2006) and takes into account emissions indicators development by the National Centre for Emissions Management (KOBiZE). The detailed methodology for calculating methane and nitrous oxide emissions is presented in another paper (Koloszko-Chomentowska et al., 2021). This is a simplified solution. However, it allows for the evaluation of the influence of agricultural practices on the environment. The method also has a practical aspect, as pointed to by Dick et al. (2008).

The following indicators were applied for evaluation of the economic situation of agricultural holdings: net value added (PLN·AWU^{-1}), family farm income per 1 ha of farmland (PLN), financial surplus (PLN) and rate of property reproduction (%). Farms' capabilities of self-financing development are evaluated based on the financial surplus (Sobczyński, 2008).

In order to determine the prospects of farms' operation, the fixed assets reproduction rate was calculated. This is one of the methods of evaluating the reproduction of fixed assets and the development of farms.

Data comes from the years 2010-2019. Farms from four regions were taken into account in analyses, and in the FADN system, these Polish regions are listed as 785 Pomorze and Mazury, 790 Wielkopolska and Slask, 795 Mazowsze and Podlasie, 800 Malopolska and Pogorze. The number of farms varies from year to year, which is due to the selection of the sample for the FADN system. Every year, some farms remain outside of FADN's field of observation, and other farms enter the sample.

The arithmetic means, and standard deviation from the four studied regions were taken for presentation of results from 10 years of observation. The significance of differences in mean values between the studied regions was determined using the Tukey test at a significance level of 0.05. Based on economic and environmental indicators from the described farms and calculated values of emissions of the selected greenhouse gases, an attempt was made to present the variability of these indicators in the observed years. Fourteen features describing economic and agrarian properties of farms and the number of farms participating in FADN studies in individual regions were taken as the variables subject to reduction in analysis (Table 1). Mean values and standard deviations were given for the whole country.

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The number of farms is not a feature associated with emissions and should not be taken for analysis in normal studies with repetitions; however, in this case, FADN studies were based on a variable number of farms, and hence, this feature could justify variability within the very short period of one year. The set of input data included 14 features representing the dimensions of the described farms in four regions over 10 years, which were treated as objects in the analysis (Table 1). Principal components analysis (PCA) was applied (Seber, 1984; Morrison, 1990). To facilitate the interpretation of results, the varimax rotation method was applied.

Results

Where the region was the factor, variance analysis showed a significant differentiating influence for all features at the level < 0.01 (Table 1). Above all, regions differed significantly in terms of the average area of farmland of a farm. The largest farms are found in regions Pomorze and Mazury, and the smallest in regions Małopolska and Pogórze.

The basic economic category is family farm income, on which farms' developmental capabilities depend. In terms of this feature, similarities can be observed between region – Pomorze and Mazury and Wielkopolska and Slask (Table 1).

The level of income per 1 ha farmland did not differ significantly in these regions. The level of income in these regions was lower than the average level of family farm income in all of the studied farms by 18.1% and 15.7%, respectively (Table 1). In the other two regions, income per 1 ha farmland was higher than in all studied farms, by 18.5% and 15.2%, respectively. Subsidies for operational activity played a large role in shaping farm income. This had an influence on self-financing capabilities. Surplus I (subsidies taken into account) and surplus II (after correction by subsidies) in farms of all regions were positive, although their amounts differed. However, it should be noted that the amount of the surplus without subsidies did not cover the unpaid labour input of the farmer and their family. As for the economic results of farms, it should be noted that with the increase in net value added and financial surplus, CH_4 and N_2O emissions increased. These results are consistent with those of Zafeirou et al. (2018) and Syp and Osuch (2017).

The level of greenhouse gas emissions was regionally differentiated. The most CH_4 per 1 ha was emitted by farms from the region Mazowsze and Podlasie. This region differed significantly from the others in terms of the emission of this gas. Region Wielkopolska and Slask and Malopolska and Pogorze can be acknowledged as similar in terms of methane emission (differences were not statistically significant). The lowest (statistically significant) level of methane emission per 1 ha of farmland was in the region Pomorze and

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Mazury. In the case of nitrous oxide, the highest level of N_2O emissions per 1 ha farmland was in the region Wielkopolska and Slask, and the lowest was inthe region Pomorze and Mazury. Both Pomorze and Mazury and Malopolska and Pogorze are regions with the lowest CH_4 and N_2O emissions. These results confirm the results of Kistowski and Wiśniewski (2020).

Table 1. Basic statistics for the years 2010-2019 with the marking of homogeneous groups for the studied regions*

Specification	Pomorze i Mazury	Wielkopolska i Slask	Mazowsze i Podlasie	Malopolska i Pogorze	Mean	Standard deviation
Economic indicators						
X1 – Number of farms	1898.4[b]	4298.8[c]	4356.5[c]	1379.7[a]	2983.4	1382.2
X2 – Utilised agricultural area [ha]	38.88[d]	26.44[c]	15.57[b]	10.70[a]	22.898	11.015
X3 – Farm Net Value Added [PLN $\cdot$AWU^{-1}]	44923.1[d]	37547.8[c]	24591.7[b]	18348.4[a]	31352.8	11127.0
X4 – Family Farm Income [PLN$\cdot$ha^{-1}]	1623.4[a]	1670.5[a]	2282.7[b]	2348.1[b]	1981.2	489.43
X5 – Financial Surplus I [PLN]	90561.7[d]	71921.5[c]	53233.4[b]	39613.5[a]	63832.5	20256.0
X6 – Financial Surplus II [PLN]	40839.5[c]	38148.2[c]	31528.7[b]	24920.8[a]	33859.3	8023.9
X7 – The rate of re-investment of assets [%]	-0.282[b]	-0.119[b]	-0.701[b]	-1.556[a]	-0.6645	0.77833
Ecological indicators						
Y1- Stocking density [LU$\cdot$ha^{-1}]	0.852[a]	1.667[d]	1.461[c]	1.066[b]	1.2615	0.32679
Y2 – Fertilizers and crop protection [PLN$\cdot$ha^{-1}]	874.02[c]	1039.77[d]	677.64[a]	692.38[a]	820.95	167.96
Y3 – Soil organic matter balance [t$\cdot$ha^{-1}]	10.289[c]	10.616[c]	7.606[b]	4.766[a]	8.319	2.5501
Sources of GHG						
Z1 – Emissions CH_4 [kg $\cdot$y^{-1}]	1340.40[c]	1294.65[c]	999.52[b]	490.88[a]	1031.4	355.56
Z2 – Emissions CH_4 [kg $\cdot$ha^{-1}]	34.39[a]	49.01[b]	64.12[c]	46.22[b]	48.43	11.16
Z3 – Emissions N_2O [kg $\cdot$y^{-1}]	1786.58[c]	2044.31[d]	1120.0[b]	639.74[a]	1397.66	572.45
Z4 – EmissionsN_2O [kg $\cdot$ha^{-1}]	45.865[a]	77.417[d]	71.936[c]	59.60[b]	63.705	12.754

* In respect to each variable, homogeneous groupings within the analysed regions were denoted with average letters (a – d) employing the HSD Tukey statistic with a significance level set at alpha = 0.05.

Source: authors' work based on Polski FADN data [20-06-2022].

Animal production is also a source of nitrogen excreted in faeces. In terms of N_2O emissions, region Wielkopolska and Slask is distinct. This region is characterised by a high level of pig production. During the studied period, the number of pigs per farm was the highest in the country (38.45 heads), and 56.8% of N_2O emissions came from raising pigs. It should be noted that, in the case of pig-raising, the number of heads of livestock decreased successively starting from 2014. This was due to the appearance of African Swine Fever (ASF). These changes were reflected in greenhouse gas emissions.

Mineral fertilisation is also a source of nitrous oxide. Data on nitrous oxide emissions from the application of mineral fertilisers indicates that the greatest emission concerned farms of the Wielkopolska and Slask region (0.76 kg N_2O ·ha^{-1}) and Mazowsze and Podlasie region (0.73 kg N_2O ha^{-1}). This is the result of intensive fertilisation of cultivated plants, with the predominance of plants cultivated as fodder.

The studied regions also differed in terms of environmental evaluation. One of the indicators of environmental equilibrium is livestock density. Farms from region Pomorze and Mazury (0.852 LU·ha^{-1}) were characterised by the lowest livestock density, while region Wielkopolska and Slask (1.667 LU·ha^{-1}) was characterised by the highest livestock density. This is a reflection of the distribution of animal production in the country.

In the case of expenditures for mineral fertilisers and plant protection products, the lowest value was noted in farms of region Mazowsze and Podlasie, and it was 17.5% lower than the average in the entire studied population of farms. In the Malopolska and Pogorze region, consumption of these means of production was at a slightly higher level, but these differences were not significant. The greatest expenditures for these means of production occurred in farms of region Wielkopolska and Slask (26.6% more than the average for all studied farms). The highest consumption of mineral fertilisers and plant protection products decidedly occurred in region Wielkopolska and Slask. This is a region of intensive agriculture.

Another indicator of environmental equilibrium is the balance of soil organic matter. This indicator was positive in all regions, which signifies the reproduction of organic matter. Farms of region Wielkopolska and Slask were characterised by the highest reproduction. High reproduction also occurred in farms of region Pomorze and Mazury. In both regions, the organic matter balance was greater than the average from all studied farms. In the two remaining regions Mazowsze and Podlasie and Malopolska and Pogorze, organic matter reproduction was lower than the average for the entire studied population of farms.

Statistical analysis confirmed the dependency between greenhouse gas emissions, environmental indicators and economic results (Figure 1). As value added increased, so too did the value of CH_4 and N_2O emissions, as well as the use of mineral fertilisers and plant protection products. Net value added was positively correlated with CH_4 ($r=0.880^{**}$) and N_2O ($r=0.863^{**}$) emissions, as well as with the value of consumed mineral fertilisers and plant protection products, and with organic matter reproduction ($r=0.683^{*}$ and $r=0.528^{*}$). A positive correlation also occurred between family farm income (PLN·ha^{-1}) and methane emission per 1 ha farmland (r=0.390*). A negative

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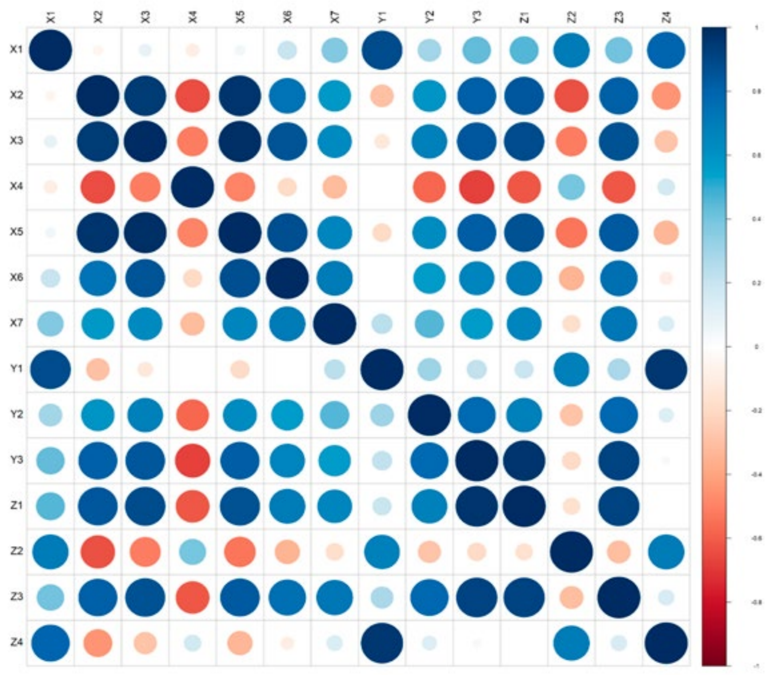
correlation occurred between family farm income and consumption of mineral fertilisers and plant protection products (r=-0.576*), as well as reproduction of organic matter (r=-0.518*). Other financial indicators (variables: X_5, X_6i X_7) describing the developmental capabilities of agricultural holdings were positively correlated with CH_4 and N_2O emissions as well as with the area of farmland and value-added. Variables X_5, X_6 and X_7 were also significantly positively correlated with environmental indicators, with the exception of livestock density (variable Y_1).



absolute values of the factor greater than 0.312 are significant at the level of 0.05
absolute values of the factor greater than 0.403 are significant at the level of 0.01

Figure 1. Pearsons' correlation matrix

Source: authors' work based on Polski FADN data [20-06-2022].

The reduction of 14 dimensions, represented in the form of the primary features introduced into the analysis, distinguished the three principal components responsible for 89.94% of the total variability. The first component was responsible for 40.82% of total variability, and the features most strongly correlated with it were farmland area, net value added, financial surplus and asset reproduction rate, as well as organic matter balance and CH_4 and N_2O emissions in kg per year. The second component explains 26.94% of the total variability. The features most strongly correlated with it were environmental

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indicators such as organic matter balance and CH_4 and N_2O emissions per 1 ha farmland. The total explanation of variability by the first two components amounts to 67.76%. The third component explained 22.18% of total variability and was most strongly correlated with family farm income (PLN·ha^{-1}), mineral fertiliser consumption (PLN·ha^{-1}), and organic matter balance (t·ha^{-1}).

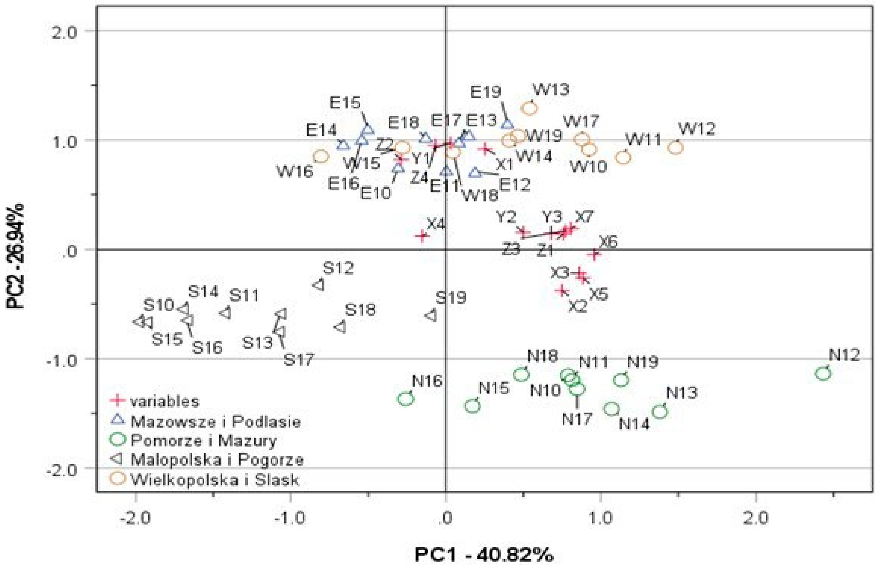

Figure 2. Relationships of the locations of the examined economic indicators (X1, ..., X7), ecological indicators (Y1, ..., Y3), sources of GHG (Z1, ..., Z4) for farms located in regions: Mazowsze and Podlasie (E), Pomorze and Mazury (N), Malopolska and Pogorze (S), Wielkopolska and Slask (W) in the researched years 2010-2019 in the space of the first two components PC1 and PC2. Individual regions in years are marked with a letter in brackets next to the name and the last two digits of the year. for example: Mazowsze and Podlasie as E10 – E19

Figure 2 is a synthesis of the presented results. It presents the studied farms in individual regions in years within the space of the first component (PC1), which concentrates economic indicators most strongly, and within the space of the second component (PC2), the concentration of GHG emission indicators. Regions positively correlated with PC1 reach high economic indicators, which are associated with this component. The left part of the chart contains regions with lower indicators. The Y axis (PC2) shows features associated with GHG emissions. Regions Wielkopolska and Slask and Mazowsze and Podlasie, where intensive animal production is conducted, have the greatest influence on GHG emissions and are positively correlated with this component. Regions negatively correlated with PC2 are characterised by low

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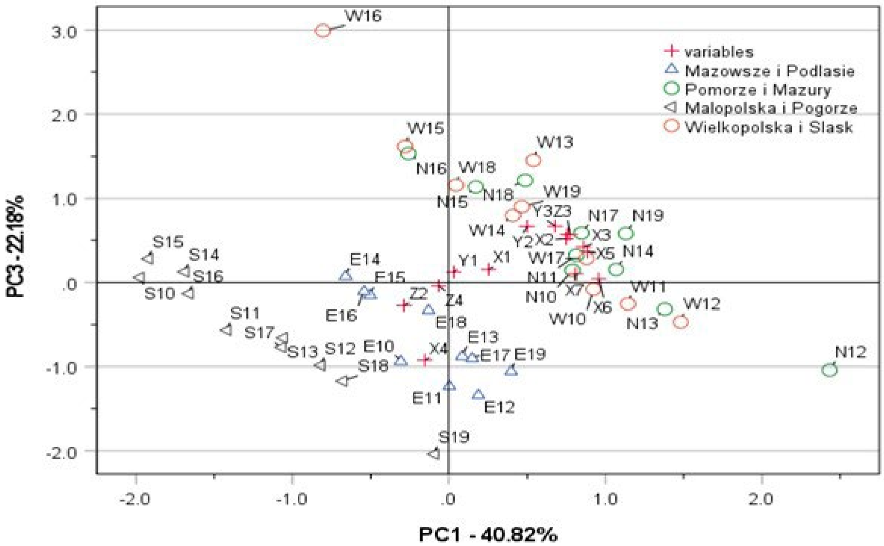
livestock density and, hence, by low GHG emissions. Similar results were obtained in the research of Wysocka-Czubaszek et al. (2018); 51% CH_4 and 37% N_2O are emitted by three voivodeships of intensive agriculture, including the voivodeships of the Masovia and Podlasie regions, leading milk and beef producers, and the Wielkopolska and Silesia regions, characterised by both intensive animal and plant production.

Figure 3 shows the distribution of regions within the space of the first component, PC1 and the third component, PC3, with which economic indicators that directly influence GHG emissions are more strongly related.



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Conclusions

The results of the conducted research indicate regional differences in environmental practices and the economic situation of farms. This is important information in the context of implementing the sustainable agriculture development strategy. For strategies to reduce the negative effects of agricultural production on the environment to be effective, the specificity of production in individual regions must be taken into account. There are regions in

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which farms successfully achieve the economic objective, but environmental rules are not always followed. The regions where the highest priority is placed on pro-environmental measures are Mazowsze, Podlasie, Wielkopolska and Slask. Similar results were obtained by Kistowski and Wiśniewski (2020).

Our study has revealed that farms in the Pomorze and Mazury regions, allocating expenditures for fertilisation and plant protection at levels approximating the mean, demonstrate the most effective organic matter equilibrium in the soil, coupled with the lowest specific emissions of CH_4 and N_2O per hectare. This region encompasses farms characterised by extensive land holdings and the highest values of farm-added worth.

This research also has practical value. It makes it possible to evaluate the impact of agricultural practices on the environment in a relatively simple way and their verification at the farm level.

Policies ensuring sustainable development of agriculture and ecosystem services will have critical importance in the strategy of maintaining the expected level of production and economic results without risk to environmental integrity. Promoting the benefits flowing from the application of environment-friendly practices may increase the probability of selection of such technologies that will make it possible to realise both environmental and economic objectives. The "farm to fork" strategy, as one of the central pillars of the European Green Deal, maybe the fundamental stimulus for reviewing the deficiencies and weaknesses of Polish agriculture.

The authors are aware of the limitations arising from this analysis. These limitations are the insufficient availability of indispensable data and problems with determining boundary values for many indicators for the evaluation of the level of equilibrium. The choice of research objects is also not without significance. These are commercial farms, achieving higher results than average farms in Poland. This limits generalisation and conclusions with regard to the entire population of agricultural holdings. Further studies should be expanded by other indicators depending on the availability of data.

The contribution of the authors

The article is a collaboration between two authors.

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