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Article

Greenhouse Gas Emissions in the Agricultural and Industrial Sectors—Change Trends, Economic Conditions, and Country Classification: Evidence from the European Union

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Abstract: The decrease in the level of greenhouse gas (GHG) emissions from industry and agriculture is one of the biggest challenges that European Union (EU) countries have to face. Their economic development should occur under the conditions of limiting the pressure on the environment. The agricultural and industrial sectors play a key role in ensuring food security, technological progress, job security, social well-being, economic competitiveness, and sustainable development. The main purpose of this article was to identify and compare the level, trends, and variability in greenhouse gas emissions from industry and agriculture in EU countries in 2010–2019, to create classes of countries with similar gas emissions, and to analyze the average values of their economic conditions. The original contribution to the article was to investigate whether there is a relationship between the level of greenhouse gas emissions and the economic development of countries and other economic indicators characterizing the sectors of industry and agriculture. Empirical data were obtained from the Eurostat and Ilostat databases. Basic descriptive statistics, classification methods, multiple regression, and correlation methods were used in the study. The industrial and agricultural sectors in EU countries emit similar amounts of greenhouse gases into the environment. In the years 2010–2019, the percentage share of emissions from these sectors in total gas emissions was growing dynamically, but no evidence was found indicating that those countries that emitted the most greenhouse gases significantly reduced their emissions in the decade under review. Moreover, EU countries are still significantly and invariably differentiated in this respect. Greenhouse gas emissions from industry and agriculture are influenced by the economic characteristics of these sectors, such as the level of GDP per capita, the scale of investment by enterprises, the expenditure on research and development, as well as employment in these sectors. The findings of this study show that total greenhouse gas emissions from all sources increase with countries' economic growth, while a higher level of support of EU countries for research and development, and a greater share of employment in both industry and agriculture, translate into higher greenhouse gas emissions from these sectors. These conclusions may be useful for decision makers in developed and developing countries, as well as those in the industrial and agricultural sectors, in controlling and verifying the possible causes of greenhouse gas emissions in terms of the need to reduce their negative role on the environment and human health.

Keywords: greenhouse gas emission; agriculture; industry; economic conditions; variation; trends

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1. Introduction

One of the negative effects of operations across all global economies is the increasing environmental pollution, contributing to global warming and consequently the global climate crisis. As recent studies [1–5] have shown, the most recent eight-year average global temperature (2015–2022) was the highest on record. Warming since the preindustrial era, defined as 1850–1900, has been estimated to be 1.5 °C. Europe, where the average temperature began to rise sharply from the 1980s, is the worst affected. The average temperature for the 60 months ending in 2019 was approximated to be 9.9 °C, which is almost 2 °C higher than the equivalent values from the second half of the 19th century. The temperature rise in Europe is about 0.9 °C higher than the equivalent global rise. Over the few past decades, Europe has been warming faster than any other continent [1,2]. A growing body of evidence suggests that the risk of extreme heat will be growing as climate change progresses, and this will pose serious public health and economic hazards, with climate change expected to affect nearly 50% of the world's societies and economies by 2035 [6,7]. For example, in the case where the world becomes warmer by 1.5 °C, some insects (6%), plants (8%), and vertebrates (4%) will lose their geographical range as a consequence. A temperature increase that is higher by 2.0 °C will double the number of extinct species and increase the number of people who have difficulties with access to water by half [8]. The results of these changes will be clearly visible in agriculture, where we will experience huge reductions in the cultivation of corn, rice, wheat, and other grains that are critical for the existence of mankind. Therefore, this will result in an increase in the number of expenditures needed to keep agricultural production on the right level, which is even more dangerous if we take into account the continuing population growth [3,9].

Many European and global initiatives are now focused on the climate crisis. The European Union recognizes the solution to the problem of the extremely high levels of greenhouse gas emissions as one of its priorities and supports the sustainable development of the economy, including the agricultural and industrial sectors. This is evidenced by the provisions of the European Green Deal [10], the Farm to Fork Strategy's objectives [11], The State of Food Security and Nutrition in the World 2022 report [12], and the inclusion of agriculture and industry sectors in the strategic plans of the CAP in EU countries. The final document of the World Summit organized in Glasgow in 2021 during the UN climate conference (COP26) [13] pointed to the need to reduce coal emissions, raised the issue of climate justice, announced increased funding for developing countries, and linked climate protection with the protection of the environment and biodiversity.

The current climate crisis is the result of the detrimental effects of increasing the concentrations of greenhouse gases [6,14–18], which are generated naturally and anthropogenically in the atmosphere. Of all of the long-lived greenhouse gases that are emitted as a result of human activity, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have the greatest impact on climate change [2,19–25]. The main sources of anthropogenic gas emissions are the energy sector (inter alia gases that are emitted to the atmosphere due to burning solid, liquid, and gaseous fuels and gas leaks), transport and industry (emissions that result from industrial activities, e.g., production of concrete, lime, and steel, as well as the transport of passengers and cargo), agriculture (emissions connected with food production, e.g., soil fertilization and animal production, as well as emissions and removals of greenhouse gases that result from the changes in use, e.g., turning forests into agricultural lands), and landfills (emissions resulting from processes that occur on landfills of solid and liquid waste). The increased intensification of industrial processes and agricultural production, along with the development of tourism and consumerism in developed countries, are often prioritized, and external environmental costs are often ignored [26–28]. Therefore, the hope for change lies in the gradual steps countries are taking to reduce the burden on the natural environment. But are all EU countries really effective in taking action to reduce the emissions of harmful pollutants, and are they effectively managing greenhouse gas emissions from industry and agriculture (resulting from the intensive production of food and non-food goods)? Knowing that economic conditions play a dominant role in many countries, we also sought to answer the question of whether greenhouse gas emissions in industry and agriculture are increasing, along with GDP growth, corporate investment or government subsidies, expenditure on research and development in industry and agriculture, and also the scale of employment in these sectors. The results of this study may fill the research gap in this area.

To answer these questions, the first aim of this article was to assess and compare the levels of and changes in greenhouse gas emissions from industry and agriculture in EU countries in 2010–2019, in particular, the emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The second objective was to classify EU countries into groups of similar levels of greenhouse gas emissions from industry and agriculture and to characterize them on the basis of some calculated average characteristics. The third objective was to determine the impact of selected economic indicators of greenhouse gas emissions from industry and agriculture, such as GDP per capita, the level of business investments, research and development (R&D) expenditures in these sectors, or income and stocking density in agricultural production. In addition, we investigated whether the level of greenhouse gas emissions is influenced by the level of employment in the sectors of industry, agriculture, and services.

This article contributes to the literature by providing a diagnostic and comparative assessment of the issues studied and describing the causal relationship between the economic indicators and GHG emissions from industry and agriculture in EU countries. The importance of this issue has been highlighted by the authors in their previous research presented at an international conference [29]. It is well known that the production and consumption of energy contribute the most to greenhouse gas emissions [30]. The average share of GHG emissions from energy in % of total emissions for EU countries in 2019 was as much as 77%, while industrial processes and product consumption accounted for 9%, and agriculture accounted for 10% [31]. The remaining smaller share of GHG emissions belongs to the waste management sector (3%) [32]. In this regard, it should be emphasized that the study and assessment of the levels of and changes in GHG emissions resulting from the agricultural and industrial sectors, and the relationship between these emissions and economic conditions, can be important for the policymakers and help to develop effective policies that mitigate the impact of human activities and will contribute to reducing GHG emissions while maintaining economic growth.

2. Literature Review

Industry, agriculture, processing, and consumption, mainly of food, contribute to a variety of side effects concerning human health and the environment [32–35]. The significant contribution of industry and agriculture to the generation of negative externalities for the natural environment and society is a major concern for the EU Member States, from the perspective of both efficiency and equity [27,36]. The external costs of these sectors that place a burden on the natural environment, caused by human activity, are also often overlooked, and producers are commonly limited when it comes to how much they can reduce gas emissions over the entire production cycle. Therefore, the classic equitable solution is to "internalize" externalities through taxes levied from activities that cause negative effects and consequently generate costs for society as a whole [37].

While the climate implications of fossil fuel combustion have attracted much attention, a recent study by the United Nations Intergovernmental Panel on Climate Change [4,38] shows that industrial and agricultural production and food consumption have an increasing impact on the environment and public health. Globally, food systems have become heavily industrialized and are now a threat to both environmental sustainability and human health [39]. Therefore, green industry and agriculture, as well as the responsible management of food demand, are crucial for fulfilling the UN Agenda for Sustainable Development by 2030 and the environmental commitments under the UN Paris Agreement [40–43].

Carbon dioxide (CO_2) is the most important and harmful gas based on the volume of total anthropogenic greenhouse gas (GHG) emissions. As much as 80% of CO_2 emissions come from burning fossil fuels. In 2017, the estimated annual emission of CO2 from fossil fuels in the world was 36 gigatons of coal (Gt CO_2), and the biggest contributors were China, the USA, India, and the EU [19]. According to the ESOTC [2], the annual increase in atmospheric concentrations of carbon dioxide (CO_2) amounts to about 0.6%/year. Such high CO_2 concentrations as in 2020 and 2021 have not been seen in the world for millions of years [1]. This increase is mainly caused by CO_2 emissions from the burning of fossil fuels (oil, coal, and natural gas), industrial activities, and deforestation. As with CO_2, methane CH_4 levels have also increased by about 0.4%/year since 2007. The CH_4 flux on the ground is a combination of anthropogenic emissions (e.g., agriculture, fossil fuels, municipal waste, and sewage) and natural emissions (from wetlands and fires). Methane is the second most important greenhouse gas after CO_2 and is responsible for about 23% of the total radiative forcing [20]. In contrast, the main source of nitrous oxide (N_2O) is the microbial nitrification and denitrification processes that occur naturally in soil, freshwater systems, and oceans [44]. However, it should be noted that human activity has also contributed to the emissions of this gas, through operations such as the use of nitrogen fertilizers and manure spreading in agriculture, industrial processes, wastewater treatment, and the combustion of fossil fuels and biomass [45].

The literature on the assessment of GHG emissions in specific sectors such as agriculture, industry, energy, transport, construction, or tourism is quite extensive [15,46,47], and as can be observed, the methods of analysis are diverse, with authors mainly attempting to analyze the potential for GHG emission reductions [17,24,25,46,48,49], the past changes and future trends in GHG emissions, environmental impacts, and mitigation actions [16,47]. Sector-specific studies have shown that the best strategy to grow GDP with less environmental impact is to develop some advanced technologies [47].

The increase in emissions of harmful greenhouse gas, ammonia, and other environmental pollutants, including particulate matter and heavy metals, is mainly attributable to the processes of intensification and concentration of agricultural production [50–52]. However, the results of empirical studies are not obvious. For example, Veysset et al. [53] highlighted that large, diversified farms (with mixed livestock farming systems) have a more negative environmental impact than medium-sized, specialized (beef production) farms. The literature emphasizes that the fundamental threat to the climate goals and objectives of the Paris Agreement is the increasing use of nitrogen fertilizers in agricultural production and global food production. The increasing demand for food and animal feed in the future will further drive the increase in environmental pollution [54,55]. The significant impact of the level of agricultural potential on the natural environment has also been observed by other authors [24,25,56,57]. For years, the successive strategic action plans of the European Union have emphasized the sustainable and balanced economic, social, and environmental development of the Member States. Industry and agriculture disrupt this because they represent a real threat to the environment, and the release of pollutants into the atmosphere by these sectors is a major environmental and economic concern. Therefore, the idea of sustainable process management in industry and agriculture addresses environmental risks and social concerns, especially in highly developed countries [15,51,58–63].

The EU's main political priority for tackling climate change is the European Green Deal [64,65]. It envisages a further reduction in emissions by at least 55% by 2030, as part of the climate target plan. The main objective of the European Green Deal is to achieve net-zero greenhouse gas emissions by 2050; promote circular economies; and increase societal responsiveness, mainly by reducing gas emissions, investing in green technologies, and protecting the environment. This law aims to ensure that all EU Member States contribute to this goal and that all sectors of the economy and society play their part [58]. The Economic Commission for Europe [63] proposed the adoption of a GHG emission reduction pathway for 2030–2050 to measure progress and provide predictability to public authorities, businesses, and citizens. The action plan includes driving investment in green technologies, stimulating innovation, promoting decarbonization, and fostering global partnerships to improve standards. Sustainable production and the use of raw materials, primary and secondary, underpin the successful attainment of the Green New Deal goals, a US-born initiative inspired by the "New Deal" [66].

3. Methodological Approach

The analyses were based on the available indicators monitoring the implementation of sustainable development goals gathered by the European Statistical Office and the International Labour Organization [31,67]. In order to achieve the objectives of the article, some indicators were selected and collected, and consequently, a database was created in MS EXCEL and STATISTICA 13.3 PL software. The selection of the indicators was based on the expert method, which consisted of holding discussions with independent experts on the validity of variable selection. In the final analysis, only complete independent X and dependent Y variables with data for all the EU countries were included; therefore, some industrial gases, such as HFC, PFC, SF6, and NF3, were omitted due to missing values, being fully aware of their significant importance for the global climate policy, which was highlighted in the Kyoto Protocol. For the evaluation of the issues addressed, the following indicators were taken into account:

- Indicators characterizing the total greenhouse gas emissions by industry (P) and agriculture (A) as a % of the total emissions (Y_{01P}, Y_{05A}) and, in particular, the release of gases such as carbon dioxide CO_2 (Y_{02P}, Y_{06A}), methane CH_4 (Y_{03P}, Y_{07A}), and nitrous oxide N_2O (Y_{04P}, Y_{08A}), and the total greenhouse gas emissions in tonnes per capita (Y_{09}) (dependent variables);
- Economic indicators such as GDP per capita (X_{01}), the share of business investment in GDP (X_{02P}), R&D expenditures in the corporate sector (X_{03P}) and agriculture (X_{04A}), and the agricultural factor income per annual work unit (X_{05A}), as well as the stocking rate (X_{06A}) (independent variables);
- Indicators characterizing employment in the sectors of industry (X_{07P}), agriculture (X_{08A}), and services (X_{09U}) (independent variables) (Table 1).

Table 1. Indicators included in the analysis of greenhouse gas emissions from industry and agriculture in the 27 EU countries in 2010–2019.

Variable	Year	Variable Name
Variables characterizing the total emissions of greenhouse gas, emissions of carbon dioxide CO_2, methane CH_4, and nitrous oxide N_2O from industry (industrial processes and product applications)		
Y_{01P}	2010–2019	Greenhouse gas emissions from industrial processes and product applications in % of the total greenhouse gas emissions (CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, and NF_3 in CO_2 equivalent)
Y_{02P}	2010–2019	CO_2 emissions from the industrial processes and product applications in % of total CO_2 emissions
Y_{03P}	2010–2019	CH_4 emissions from the industrial processes and product applications in % of total CH_4 emissions
Y_{04P}	2010–2019	N_2O emissions from the industrial processes and product applications in % of total N_2O emissions
Variables characterizing total emissions of greenhouse gas, emissions of carbon dioxide CO_2, methane CH_4, and nitrous oxide N_2O from agriculture		
Y_{05A}	2010–2019	Greenhouse gas emissions from agriculture in % of total greenhouse gas emissions (CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, and NF_3 in CO_2 equivalent)

Table 1. *Cont.*

Variable	Year	Variable Name
Y_{06A}	2010–2019	CO_2 emissions from agriculture in % of total CO_2 emissions
Y_{07A}	2010–2019	CH_4 emissions from agriculture in % of total CH_4 emissions
Y_{08A}	2010–2019	N_2O emissions from agriculture in % of total N_2O emissions
General variable characterizing greenhouse gas emissions		
Y_{09}	1990–2019	Greenhouse gas emissions in tonnes per capita
Variables characterizing economic conditions of industry and agriculture		
X_{01}	2000–2021	Real GDP per capita in EUR
X_{02P}	2000–2020	Share of business investment in % of GDP
X_{03P}	2000–2020	Gross domestic expenditures on R&D in the corporate sector in % of GDP
X_{04A}	2004–2020	Government support to agricultural research and development in EUR per capita
X_{05A}	2001–2020	Agricultural factor income in EUR per annual work unit (AWU)
X_{06A}	2005–2016	Stocking rate—number of livestock animals per ha
Variables characterizing employment in the industry, agriculture, and services sectors		
X_{07P}	2010–2020	Share of employees in the industrial sector in % of all working people
X_{08A}	2010–2020	Share of employees in the agricultural sector in % of the total working population
X_{09S}	2010–2020	Share of people employed in the service sector in % of all working people

Source: own work based on Eurostat (2023). Your key to European statistics. Retrieved from https://ec.europa.eu/eurostat/data/database (accessed on 24–25 March 2023); Ilostat (2023). Retrieved from https://ilostat.ilo.org/data/ (accessed on 24–25 March 2023).

The studied period covered the years 2010 to 2019. Twenty-seven European Union states were analyzed. (We used the following abbreviations for the names of the EU Member States, compliant with ISO 3166 Alpha-2 codes developed by the International Organization for Standardization (ISO 2019): Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), Czechia (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Greece (GR), Spain (ES), Ireland (IE), Lithuania (LT), Luxembourg (LU), Latvia (LV), Malta (MT), the Netherlands (NL), Germany (DE), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Sweden (SE), Hungary (HU), and Italy (IT).) The collected indicators were subdivided into dependent variables (Y) and independent variables (X). Such division of indicators was used to verify the existence of any associations between selected economic indicators, such as GDP per capita, investment outlays, expenditures on research and development, as well as employment in industry, agriculture, and services (assumed as a cause of gases emissions), and dependent variables characterizing the share of greenhouse gas emissions generated due to industrial production and agricultural processes (assumed as a result of the existing economic conditions). All empirical data were subjected to statistical analysis prior to the commencement of detailed analyses and the implementation of the assumed goals. Mean values, standard deviation, kurtosis, and asymmetry were calculated, and the normal distribution was analyzed using the Shapiro–Wilk test [68]. In order to be able to achieve the first objective of the study, i.e., to assess and compare the levels of and changes in greenhouse gas emissions from industry and agriculture in the EU countries in 2010–2019, in particular, CO_2, CH_4, and N_2O, the basic descriptive statistics of the investigated EU countries were calculated. Inter alia the indices of the relative increase or decrease (P_w) in %, absolute increase or decrease (P_a) in %, coefficients of variation (V_s) in %, and correlation coefficients (r_{xy}) were calculated [69,70]. The calculation of the relative increase or decrease (P_w) was performed to evaluate the percentage change in GHG emissions in 2019, compared with the base year 2010 ($P_w = t_{2019} \times 100/t2_{010} - 100$), and the absolute increase (P_a) was calculated to evaluate the difference between gas emissions in 2019 and 2010 ($P_a = t_{2019} - t_{2010}$). Positive values of indicators P_w and P_a indicate an increase in the level of emissions, whereas negative values indicate a decrease in emissions. To assess variations in the studied countries, the coefficient of variation (V_s) was determined as $V_s = \frac{S}{\overline{x}} \times 100\%$, where $\overline{X}$ and S represent, respectively, the arithmetic mean and standard deviation. The variation in gas emission levels among the EU countries is significant when $V_s > 10\%$. In order to enable the implementation of the second objective, consisting of creating classes of EU countries with similar levels of greenhouse gas emissions from industry and agriculture, the values of the first quartile (Q1), the second quartile (Q2) (medians), and the third quartile (Q3) were calculated. The purpose of these calculations was to create classes of countries with different levels of emissions (class I—low emission level, class II—medium lower, class III—medium upper, and class IV—high level of gas emissions). The analyses were conducted using the variables that characterize the general level of greenhouse gas emissions from industry (Y_{01P}) and agriculture (Y_{05A}). Then, the class averages of both gas emissions and the countries' economic characteristics were calculated in the separated classes. Multiple regression analysis was also performed [71,72], as well as a relationship analysis using a simple linear correlation coefficient (r_{xy}). These calculations, in turn, helped to determine the impact of the selected economic indicators on greenhouse gas emissions from industry and agriculture, which was the third objective of the study.

4. Results

4.1. Comparison of Greenhouse Gas Emissions from Industry and Agriculture in the European Union Countries: Diversity and Changes in 2010–2019

Based on the findings of our study, agriculture accounted for a slightly larger share of total GHG emissions ($Y_{05A}2019 = 10.3\%$) than the industry ($Y_{01P}2019 = 9.1\%$). The EU countries varied significantly in terms of the release of gases into the environment, as confirmed by the calculated coefficients of variation (V_s) (industry, $V_s2019 = 44.1\%$; agriculture, $V_s2019 = 55.0\%$). A small decrease in variation between the countries in terms of GHG emissions was observed after 2016. The relatively highest share of GHG emissions from the industry as a % of total emissions was found throughout the analyzed period in Slovakia ($Y_{01P}2010$, 20.7%; $Y_{01P}2019$, 21.6%), while the country at the opposite extreme, with the lowest emissions, was Estonia ($Y_{01P}2010$–2018, from 2.5% to 3.1%) and, in 2019, Denmark (3.9%). On the other hand, Ireland emitted the most greenhouse gas from agriculture ($Y_{05A}2010$, 28.5%; $Y_{05A}2019$, 32.4%), and Malta emitted the least ($Y_{05A}2010$, 2.5%; $Y_{05A}2019$, 2.8%) (Table 2).

Table 2. The statistical comparison of GHG emissions from industry (Y_{01P}) and agriculture (Y_{05A}) in 2010–2019 in EU countries.

Greenhouse Gas Emissions from Industry in % of Total Emissions (Y_{01P})						**Greenhouse Gas Emissions from Agriculture in % of Total Emissions (Y_{05A})**					
Statistics/Year	**2010**	**2015**	**2017**	**2018**	**2019**	**Statistics/Year**	**2010**	**2015**	**2017**	**2018**	**2019**
EU(27)	8.5	8.8	9.0	9.0	9.1	EU(27)	8.9	9.9	9.9	10.0	10.3
Y_{01P} min Estonia	2.5	2.8	3.0	3.1	3.9 *	Y_{05A} min Malta	2.5	3.0	3.0	3.0	2.8
Y_{01P} max Slovakia	20.7	22.2	22.6	22.5	21.6	Y_{05A} max Ireland	28.5	30.8	31.6	32.4	32.4
V_s	49.9	47.0	47.0	45.5	44.1	V_s	56.4	55.2	56.3	56.2	55.0

Key: Y_{01Pmin}—minimum value for the country, Y_{01Pmax}—maximum value for the country, V_s—coefficient of variation in % for EU countries, * 2019 Denmark. Source: own calculations based on Eurostat (2023). Your key to European statistics. Retrieved from https://ec.europa.eu/eurostat/data/database (accessed on 24–25 March 2023).

As illustrated in Figure 1, in addition to Slovakia, the largest share of GHG emissions from industry in 2019, defined as a percentage of total emissions, occurred in Austria, Belgium, and Lithuania, and it exceeded 15%. Compared with other EU countries, Malta did not emit the most greenhouse gas from industry. Data for this country, on the other hand, show that the share of emissions from this sector increased almost three times during 2010–2019. The introduction and monitoring of mitigation measures were inevitable in this country, which resulted in a positive and decreasing trend from 2016. The lowest share of total GHG emissions from industry in 2019 was found in Estonia, Denmark, Luxembourg, Ireland, the Netherlands, and Poland, where it did not exceed 7%.

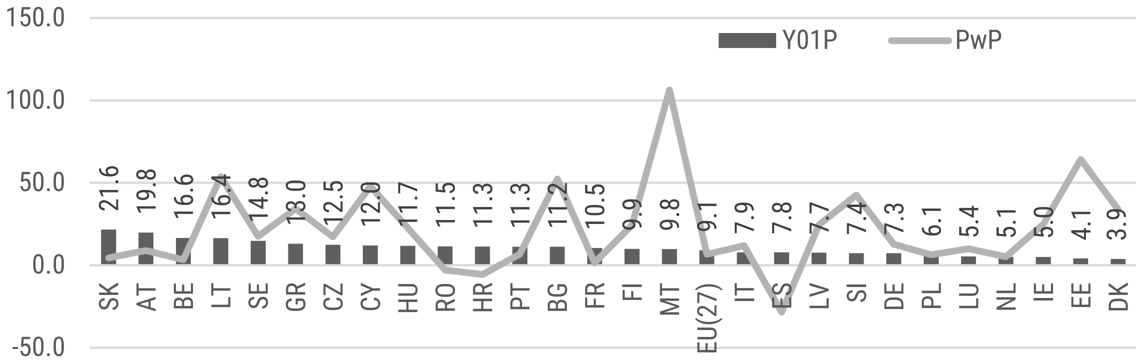

Figure 1. The ranking of EU countries according to their greenhouse gas emissions from industry in % of total emissions (Y_{01P}) in 2010–2019 and the fixed-base index (P_{wP}). Source: as in Table 2.

By analyzing the graphical summary of the ranking of the EU countries in terms of GHG emissions from industry in 2019 and the trend of change (P_{wP}) in 2019 compared with that in 2010, it cannot be unambiguously concluded that the countries that emitted the largest amount of gases in 2019 at the same time achieved the largest increase or decrease in these emissions between 2010 and 2019. Concurrently, no unambiguous changes, increase or decrease in emissions, were observed for countries with the lowest share of gas emissions from industry. These differences and the lack of significant changes in emissions can be explained by the fact that each EU Member State is characterized by a different scale of industrial development and level of application of modern production processes and technologies. From 2010 to 2019, only three EU countries saw a decrease in GHG emissions from industry (Spain, Croatia, and Romania), and these were by no means the countries with the highest emissions. This means that in the analyzed period, as many as 24 EU countries saw an increase in GHG emissions from the industrial sector, and the largest increase occurred in countries that were the top emitters, e.g., Malta, Cyprus, Belgium, and Lithuania (Figures 1 and 2).

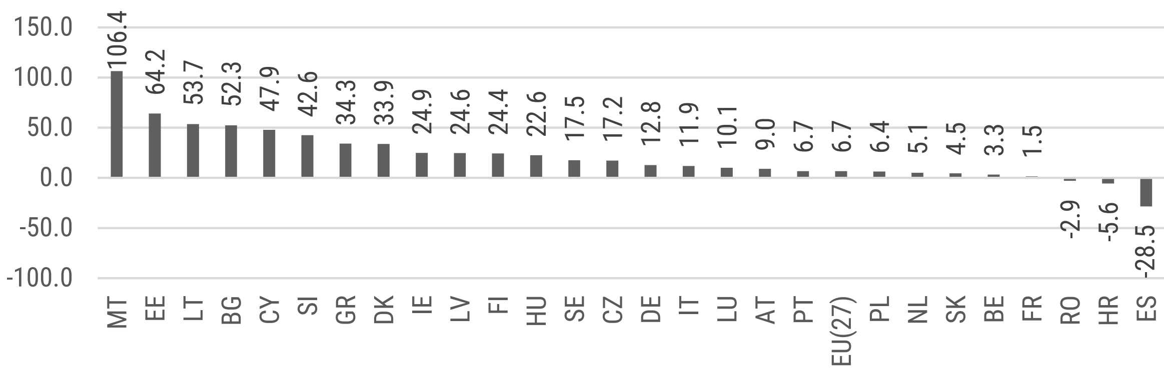

Figure 2. The ranking of EU countries according to P_{wP}—the index of change in greenhouse gas emissions from industry in 2010–2019. Source: as in Table 2.

In turn, the largest emitters of GHG from agriculture in % of total EU gas emissions in 2019 were Ireland (32.4%), Denmark (23.0%), Lithuania (20.5%), and Latvia (18.9%), and it is advisable that these countries in particular effectively implement the corrective actions set out in the EU plans and objectives for the coming years that are related to the sustainable management of industrial and agricultural sectors. At the other extreme are Malta, Cyprus, Luxembourg, Slovakia, Czechia, and Italy, where the share of GHG emissions from agriculture was less than 7% of total emissions. As in the case of industrial release, there is again no clear link between the ranking of countries according to GHG emissions from agriculture in the EU and the trend of changes in P_{WA}, i.e., an increase or decrease in the emissions in 2019 compared with 2010 (Figure 3). Of the greatest concern is the fact that between 2010 and 2019, in all 27 EU countries, we could observe an increase in emissions. The largest increase in gas emissions from agriculture in the analyzed period was observed in Estonia (70.4%), Denmark (40.2%), Finland (38.3%), and Slovakia (31.2%). Cyprus, on the other hand, had the lowest relative GHG emissions after 2010 and underwent the smallest increase in emissions over the studied period (Figure 4).

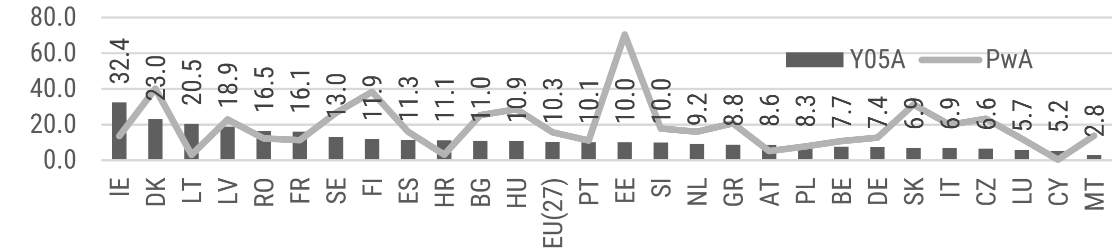

Figure 3. The ranking of the EU countries according to their greenhouse gas emissions from agriculture in % of total emissions (Y_{05A}) in 2010–2019 and based on the fixed-base index (P_{wA}). Source: as in Table 2.

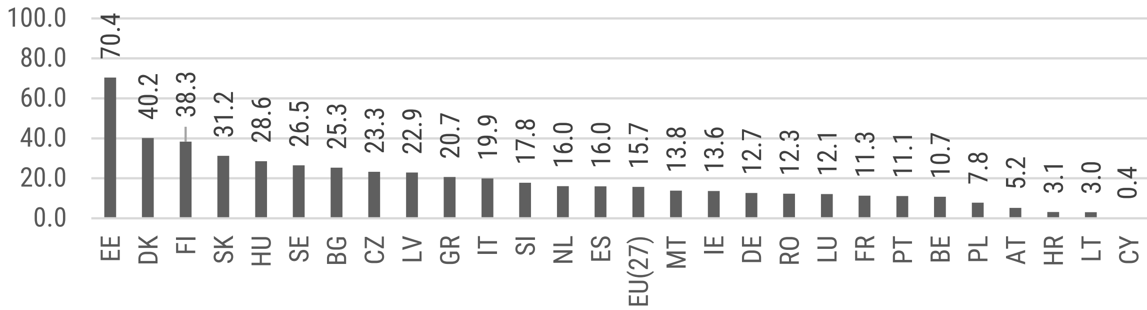

Figure 4. The ranking of the countries according to P_{wA}—the index of changes in greenhouse gas emissions from agriculture in 2010–2019. Source: as in Table 2.

4.2. Comparison of CO_2, CH_4, and N_2O Emissions from Industry and Agriculture in the European Union Countries: Diversity and Changes in 2010–2019

The EU countries emit significantly more carbon dioxide (CO_2) from production processes and product applications than from agricultural activities. In 2019, EU CO_2 emissions from the industry accounted for 8.1% of total CO_2 emissions, while emissions from agriculture accounted for merely 0.3%. CO_2 emissions from agriculture practically remained at a similar level for a decade, while CO_2 releases from production processes increased by P_{aPCO2} = 0.9 percentage points, and P_{wPCO2}2019 was 13.0%. Based on the calculated coefficients of variation (V_s) (V_{sP}2019 = 56.7%; V_{sA}2019 = 85.3%), it can be concluded that the EU countries varied significantly in terms of CO_2 emissions and this variation did not change. The distance between the countries emitting the most and the least CO_2 from both industry and agriculture was also invariably high and remained at a similar level for years. The leading country emitting the most CO_2 from industry was Slovakia (Y_{02P}2019 = 23.10%), whereas Ireland emitted the most CO_2 from agriculture

(Y_{06A}2019 = 1.2%). At the other extreme was Malta, with a share of CO_2 emissions from the industry of Y_{02P}2019 = 0.3%. The smallest emissions from agriculture over the entire analyzed period of 2010–2019 can be found in several countries, such as Greece, Cyprus, and the Netherlands, whose share of CO_2 in % of total CO_2 emissions was zero (Table 3).

Table 3. The statistical data of carbon dioxide (CO_2) emissions from industry (Y_{02P}) and agriculture (Y_{06A}) in 2010–2019 in EU countries.

Carbon Dioxide (CO_2) Emissions from the Industry in % of CO_2 Emissions(Y_{02P})						**Carbon Dioxide (CO_2) Emissions from the Agriculture in % of CO_2 Emissions (Y_{06A})**					
Statistics/Year	**2010**	**2015**	**2017**	**2018**	**2019**	**Statistics/Year**	**2010**	**2015**	**2017**	**2018**	**2019**
EU(27)	7.2	7.5	7.8	7.9	8.1	EU(27)	0.3	0.3	0.3	0.3	0.3
Y_{02P} min Malta	0.1	0.5	0.3	0.4	0.3	Y_{06A} min *	0.0	0.0	0.0	0.0	0.0
Y_{02P} max Slovakia	20.4	23.5	24.0	24.0	23.1	Y_{06A} max Ireland	1.3	1.2	1.1	1.4	1.2
V_s	61.1	61.9	60.6	57.7	56.7	V_s	113.1	87.2	81.8	94.0	85.3

Key: as in Table 2. * Y_{06A} min in three countries: Greece, Cyprus, and the Netherlands. Source: Table 2.

The next greenhouse gas that has a negative impact on the environment is methane (CH_4). Industry plays a negligible role in the emission of this gas, whereas agriculture is the main contributor. As the data collected for the EU countries (27) show, CH_4 emissions from industry accounted for Y_{03P}2019 = 0.4% of total CH_4 emissions, while from agriculture, these emissions accounted for as much as Y_{07A}2019 = 54.1%. As seen from the data in Table 4, CH_4 emissions from industry are relatively low and, after 2010, remained at a similar level or increased significantly in the case of agricultural activities (P_{aY07A} = 5.0 pkt. proc.; P_{wY07A} = 10.2%). The calculated coefficients of variation (V_s) also indicate that there was a significant variation between the EU countries, which remained at a similar level for years. Methane emissions from industry were not observed in countries such as Denmark, Estonia, Ireland, and Greece, while the leading country in terms of methane emissions was the Netherlands, whose value of the variable Y_{03P} increased after 2010 and was equal to 2.0% in 2019. Conversely, methane emissions from agriculture were the lowest in Malta (Y_{07A}2019 = 22.4%), and compared with 2010, emissions in this country decreased by about 3.9 percentage points. Ireland is at the other extreme. It is a country with the highest methane emissions from agriculture among all the EU countries. In 2019, the share of CH_4 emissions from agriculture was Y_{07A} = 93.2% (Table 4).

Table 4. The statistical data of methane (CH_4) emissions from industry (Y_{03P}) and agriculture (Y_{07A}) in 2010–2019 in EU countries.

Methane (CH_4) Emissions from the Industry in % of Total CH_4 Emissions (Y_{03P})						**Methane (CH_4) Emissions from the Agriculture in % of Total CH_4 Emissions (Y_{07A})**					
Statistics/Year	**2010**	**2015**	**2017**	**2018**	**2019**	**Statistics/Year**	**2010**	**2015**	**2017**	**2018**	**2019**
EU(27)	0.4	0.4	0.4	0.4	0.4	EU(27)	49.1	52.2	53.0	53.5	54.1
Y_{03P} min *	0.0	0.0	0.0	0.0	0.0	Y_{07A} min Malta	26.4	25.5	24.2	23.5	22.4
Y_{03P} max Netherlands	1.7	1.9	1.9	1.9	2.0	Y_{07A} max Ireland	94.6	92.3	92.8	93.0	93.2
V_s	149.7	154.7	148.7	147.7	152.0	V_s	36.2	36.0	36.1	35.8	35.7

Key: as in Table 2. * Y_{03P} min in at least nine countries: Denmark, Estonia, Ireland, Greece, Lithuania, Luxembourg, Romania, Slovakia, and Finland. Source: Table 2.

In the EU Member States, similarly to methane, nitrous oxide (N_2O) also primarily originates from agricultural activities. The share of N_2O emissions from industry in 2019 was 4.4%, while agriculture accounted for as much as 79.4% of total N_2O emissions. It should be emphasized that, within the analyzed period of 2010–2019, a positive trend of decrease in N_2O emissions from industry was observed ($R_{Y04}P = -4.0$ p.p.; $Is_{Y04P} = -47.3\%$). The calculated coefficients of change P_w and P_a indicated a reduction in the share of industry in N_2O emissions between 2010 and 2019 by almost half. Unfortunately, such conclusions cannot be drawn for nitrous oxide emissions from agriculture. Not only is agriculture a major emitter of N_2O, but over the analyzed period, this sector accounted for even more N_2O emissions, as confirmed by the calculated coefficients ($P_{aY08A} = +4.0$ p.p.; $P_{wY08A} = +5.3\%$). Latvia was the country that emitted very little N_2O from industry, while Cyprus was at the other extreme ($Y_{04P}2019 = 18.2\%$). In contrast, agricultural activities resulted in the lowest N_2O emissions in Italy ($Y_{08A}2019 = 58.7\%$), and the highest, just like with methane, was observed in Ireland, where agriculture accounted for 92.2% of N_2O emissions. As in the case of the previously analyzed gases, the EU(27) countries also differed significantly in their N_2O emissions, especially in the case of N_2O emissions from industry, and after 2010, the variation consistently remained at a similar level in terms of N_2O emissions from agriculture and decreased in terms of these emissions from industry (Table 5).

Table 5. The statistical data of nitrous oxide (N_2O) emissions from industry (Y_{04P}) and agriculture (Y_{08A}) in 2010–2019 in EU countries.

Nitrous Oxide (N_2O) Emissions from Industry in % of Total N_2O Emissions						**Nitrous Oxide (N_2O) Emissions from Agriculture in % of Total N_2O Emissions**					
Statistics/Year	**2010**	**2015**	**2017**	**2018**	**2019**	**Statistics/Year**	**2010**	**2015**	**2017**	**2018**	**2019**
EU(27)	8.4	4.8	4.5	4.2	4.4	EU(27)	75.4	79.2	79.4	79.4	79.4
Y_{04P} min Latvia	0.2	0.0	0.0	0.0	0.2	Y_{08A} min Italy	55.4	58.7	59.1	58.6	58.7
Y_{04P} max Cyprus	38.8	20.4	19.1	18.0	18.2	Y_{08A} max Ireland	91.9	92.5	92.4	92.6	92.2
V_s	109.8	107.8	105.3	98.0	95.2	V_s	15.2	10.7	10.2	9.8	10.9

Key: as in Table 2. Source: Table 2.

4.3. Relationships between GHG Emissions from Industry and Agriculture and Their Changes in 2010–2019

As the data in Table 6 show, there were significant relationships between some of the dependent Y variables characterizing the share of GHG emissions from industry and agriculture and the coefficients determining changes in gas emissions (P_w and P_a). As for the EU(27) countries, there was a significant positive correlation between the total GHG emissions from industry in % of total emissions and carbon dioxide (CO_2) emissions from industry in % of total CO_2 emissions ($r_{xy} = +0.96$). The EU(27) countries that emitted more methane (CH_4) from industry in % of total CH_4 emissions at the same time emitted significantly more nitrous oxide N_2O ($r_{xy} = +0.50$). In the EU(27) countries, there was a significant positive correlation between total GHG emissions from agriculture as a % of total emissions and emissions of the other specified gases (r_{xy} for the relationship with emissions of CO_2: $r_{xy} = 0.76$, CH_4: $r_{xy} = 0.46$, and N_2O: $r_{xy} = 0.70$), while countries emitting more CO_2 from agriculture simultaneously emitted significantly more nitrous oxide ($r_{xy} = 0.59$) and methane ($r_{xy} = 0.38$) (but the correlation was too small and did not exceed the significance threshold).

Table 6. Correlation r_{xy} between the variables characterizing the level of greenhouse gas emissions from industry (Y_P) and agriculture (Y_A) in the EU(27) countries in 2019 and their absolute increases (P_a) and relative increases (P_w) in 2010–2019.

Correlations r_{xy}–Emission from Industry					**Correlations r_{xy}–Emission from Agriculture**				
Variable	Y_{01P}	Y_{02P}	Y_{03P}	Y_{04P}	**Variable**	Y_{05A}	Y_{06A}	Y_{07A}	Y_{08A}
Y_{05P}	1.00	0.96 *	−0.16	0.03	Y_{05A}	1.00	0.76 *	0.46 *	0.70 *
Y_{06P}	0.96 *	1.00	−0.17	−0.02	Y_{06A}	0.76 *	1.00	0.38	0.59 *
Y_{07P}	−0.16	−0.17	1.00	0.50 *	Y_{07A}	0.46 *	0.38	1.00	0.09
Y_{08P}	0.03	−0.02	0.50 *	1.00	Y_{08A}	0.70 *	0.59 *	0.09	1.00
P_{wY05P}	−0.12	−0.19	−0.15	−0.06	P_{wY05A}	0.05	0.05	0.04	0.20
P_{wY06P}	−0.33	−0.24	−0.19	−0.14	P_{wY06A}	0.20	0.29	−0.03	0.17
P_{wY07P}	0.22	0.24	0.42	−0.11	P_{wY07A}	−0.24	−0.15	−0.01	−0.06
P_{wY08P}	−0.29	−0.30	0.05	0.27	P_{wY08A}	−0.12	−0.09	−0.25	−0.04
P_{aY05P}	0.25	0.14	−0.08	−0.06	P_{aY05A}	0.62 *	0.52 *	0.35	0.54 *
P_{aY06P}	0.30	0.35	−0.20	0.03	P_{aY06A}	0.18	0.33	−0.04	0.25
P_{aY07P}	−0.03	−0.02	0.80	0.14	P_{aY07A}	−0.22	−0.20	0.34	−0.19
P_{aY08P}	−0.59 *	−0.60 *	0.20	−0.20	P_{aY08A}	−0.06	−0.09	−0.23	0.04

* The correlation coefficients marked by an asterisk are significant with $p < 0.05$; N = 27 (missing data were deleted on a case-to-case basis). Source: Table 2.

In the EU(27) countries, there was no significant relationship between GHG emissions from industry and agriculture (Y) and the change (increase or decrease) in these emissions between 2010 and 2019, as measured by the relative index P_w. As the results of the analyses show, in the EU(27) countries with relatively higher GHG emissions from industry, the combined and individual emissions of CO_2 and CH_4 revealed a larger difference (change) in GHG emissions from 2010 to 2019, with the correlation being significant for the Y_{03P} level and relative change in methane emissions (P_{aY03P}) (r_{xy} = 0.80). Similar positive correlations were observed for gas emissions from agriculture and differences in emissions between 2010 and 2019, with significant correlations in this case only for total greenhouse gas emissions (r_{xy} = +0.62) (Table 6).

4.4. Classification of EU Countries in Terms of GHG Emissions from Industry and Agriculture and Their Economic Conditions: Characteristics of Class Averages

Using the classification method, the EU countries were divided into four classes based on their GHG emissions from industry and agriculture. These four classes were defined as low (class I), medium-lower (class II), medium-higher (class III), and high (class IV) levels of greenhouse gas emissions.

The EU Member States Denmark, Estonia, Ireland, the Netherlands, Luxembourg, Poland, and Germany were included in class I with low levels of greenhouse gas emissions from industry. The class average of industrial gas emissions in these countries was only 5.3% of total emissions. Among all the four classes, these are the countries with the highest real GDP per capita (EUR 50,019), the highest share of business investment (17.5% of GDP), and gross domestic expenditure on research and development in the business sector (at the level of 1.2% of GDP). At the other extreme, countries classified in class IV had high greenhouse gas emissions from industry, with a share of 16.4%. These countries are Czechia, Greece, Sweden, Lithuania, Belgium, Austria, and Slovakia. It was found that in this group of countries, the gross domestic R&D expenditures in the enterprise sector were the highest among all the four classes, at 1.4% of GDP, while the share of business investments in GDP was 14.3% and was also of the highest level. In addition, it should be emphasized that the level of GHG emissions from industry in individual classes increased with the increase in employment in the industrial sector and the decrease in employment in services (Table 7).

Table 7. Classification of EU countries in terms of GHG emissions from industry and the selected economic conditions of this sector.

Specification	Class Name, GHG Emission Level, and Economic Conditions			
	Class I—Low	**Class II—Lower Middle**	**Class III—Upper Middle**	**Class IV—High**
	Countries Qualified for the Class			
	Denmark Estonia Ireland Netherlands Luxembourg Poland Germany	**Slovenia Latvia Spain Italy Malta Finland France**	**Bulgaria Portugal Croatia Romania Hungary Cyprus**	**Czechia Greece Sweden Lithuania Belgium Austria Slovakia**
	Class Averages			
Greenhouse gas emissions from industrial processes and product applications in % of total greenhouse gas emissions (X_{01P})	5.3	8.7	11.5	16.4
Real GDP per capita in EUR (X_{01})	50,019	29,000	15,980	29,394
Share of business investments in % of GDP (X_{02P})	17.5	12.9	13.1	14.3
Gross domestic expenditures on R&D in the corporate sector in % of GDP (X_{03P})	1.2	1.0	0.6	1.4
Share of employees in the industrial sector in % of all working people (X_{07P})	21.4	23.5	27.1	25.3
Share of employees in the agricultural sector in % of the total working population (X_{08A})	3.3	3.8	7.8	4.2
Share of people employed in the service sector in % of all working people (X_{09S})	73.0	72.3	65.0	69.2

Source: own calculations based on Eurostat (2023). Your key to European statistics. Retrieved from https://ec.europa.eu/eurostat/data/database (accessed on 24–25 March 2023); Ilostat (2023). Retrieved from https://ilostat.ilo.org/data/ (accessed on 24–25 March 2023).

In the case of greenhouse gas emissions from agriculture, the classification of countries was different than that in terms of GHG emissions from industry. This fact was confirmed not only with the classification method but also with a regional analysis of the relationship between the level of GHG emissions by the surveyed countries from industry (Y_{01P}) and agriculture (Y_{05A}). The relationship between the variables at the level of $r_{xy} = -0.23$ was insignificant. Malta, Cyprus, Luxembourg, Czechia, Italy, Slovakia, and Germany were included in class I, with low greenhouse gas emissions from agriculture. Greenhouse gas emissions from agriculture in this class accounted for only 5.9% of the total emissions. Sweden, France, Romania, Latvia, Lithuania, Denmark, and Ireland were grouped in class IV with high levels of gas emissions from agriculture. The share of greenhouse gas emissions from agriculture in this class accounted for as much as 20.1% of the total emissions. Interestingly, both class I (low emissions) and class IV (high emissions) countries were characterized by the highest and comparably similar levels of real GDP per capita (EUR 37,867 and EUR 36,171, respectively). It should be noted that in class IV, with high agricultural gas emissions, government support for agricultural research and development amounted to as much as EUR 8.2 per capita, while in the other three classes (I, II, and III), the support was only EUR 5 per capita. In turn, the income of agricultural production factors per annual work unit was comparable in classes I, II, and IV and amounted to EUR 20,000 on average. In class III, the income was lower, at EUR 15.5 thousand. However, there were significant differences in the number of animals. It was found that in classes I and II, with low and medium-lower levels of gas emissions from agriculture, there were twice as many livestock per 1 ha as in classes III and IV with medium-higher and high levels of emissions. In the case of employment in agriculture, a significant gap could be clearly observed between the countries in class I (with the lowest GHG emissions from agriculture) with the percentage of employed in agriculture at the level of 2.1% and countries in class IV (with the highest GHG emissions) with the percentage of employees in this sector being as much as 6.5% (Table 8).

Table 8. Classification of EU countries in terms of greenhouse gas emissions from agriculture and the selected economic conditions of this sector.

Specification	Class Name, GHG Emission Level, and Economic Conditions			
	Class I—Low	Class II—Lower Middle	Class III—Upper Middle	Class IV—High
	Countries Qualified for the Class			
	Malta Cyprus Luxembourg Czechia Italy Slovakia Germany	Belgium Poland Austria Greece Netherlands Slovenia Estonia	Portugal Hungary Bulgaria Croatia Spain Finland	Sweden France Romania Latvia Lithuania Denmark Ireland
	Class Averages			
Greenhouse gas emissions from agriculture in % of total greenhouse gas emissions (Y_{05A})	5.9	8.9	11.1	20.1
Real GDP per capita in EUR (X_{01})	37,867	29,767	21,355	36,171.4
Government support for agricultural research and development in EUR per capita (X_{04A})	5.0	5.0	5.3	8.2
Agricultural factor income in EUR per annual work unit (AWU) (X_{05A})	20,785	20,376	15,518	20,054.7
Stocking rate—number of livestock animals per ha (X_{06A})	1.2	1.4	0.5	0.7
Share of employees in the industrial sector in % of all working people (X_{07P})	24.9	24.2	26.1	22.2

Table 8. *Cont.*

Specification	Class Name, GHG Emission Level, and Economic Conditions			
	Class I—Low	Class II—Lower Middle	Class III—Upper Middle	Class IV—High
	Countries Qualified for the Class			
	Malta Cyprus Luxembourg Czechia Italy Slovakia Germany	Belgium Poland Austria Greece Netherlands Slovenia Estonia	Portugal Hungary Bulgaria Croatia Spain Finland	Sweden France Romania Latvia Lithuania Denmark Ireland
	Class Averages			
Share of employees in the agricultural sector in % of the total working population (X_{08A})	2.1	5.0	5.1	6.5
Share of people employed in the service sector in % of all working people (X_{09S})	72.1	68.3	68.7	70.9

Source: as in Table 7.

4.5. The Impact of the Selected Economic Conditions on GHG Emissions from Industry and Agriculture: Analysis of Correlation and Multiple Regression

An additional objective of this study was to determine whether there are correlations between economic conditions and GHG emissions. As can be seen in Figure 5, a significant positive correlation at the level of r_{xy} = +0.697 was observed between variables Y_{09} (GHG emissions in tons per capita) and X_{01} (GDP per capita) (Figure 5). Based on this coefficient, it can be concluded that wealthier EU(27) countries, with higher economic development, have significantly higher GHG emissions in tonnes per capita (Figure 5).

However, after using an indicator measuring the share of GHG emissions from industry and agriculture in % of total emissions, it was found that the resulting correlations with economic conditions were no longer so evident. In the case of indicators describing the share of emissions from industry in % of the total emissions for total greenhouse gas (Y_{01P}), CO_2 (Y_{02P}), CH_4 (Y_{03P}), and N_2O (Y_{04P}); indicators characterizing economic conditions, such as GDP per capita in EUR (X_{01}); the share of business investments in % of GDP (X_{02P}); and the gross domestic expenditure on R&D in the corporate sector in % of GDP (X_{03P}), there were no significant correlations. The only significant correlation was found between CO_2 emissions from industry and the level of business investments in % of GDP (r_{xy} = 0.52). Therefore, it can be concluded that economic conditions such as GDP per capita, the share of business investments, or government support for R&D in the corporate sector in the EU(27) countries are not correlated with the total greenhouse gas emissions for CH_4 or N_2O from industrial processes and product manufacturing. It was found that the higher the level of business investments in % of GDP in a given country, the higher the carbon dioxide emissions (CO_2) are (Table 9).

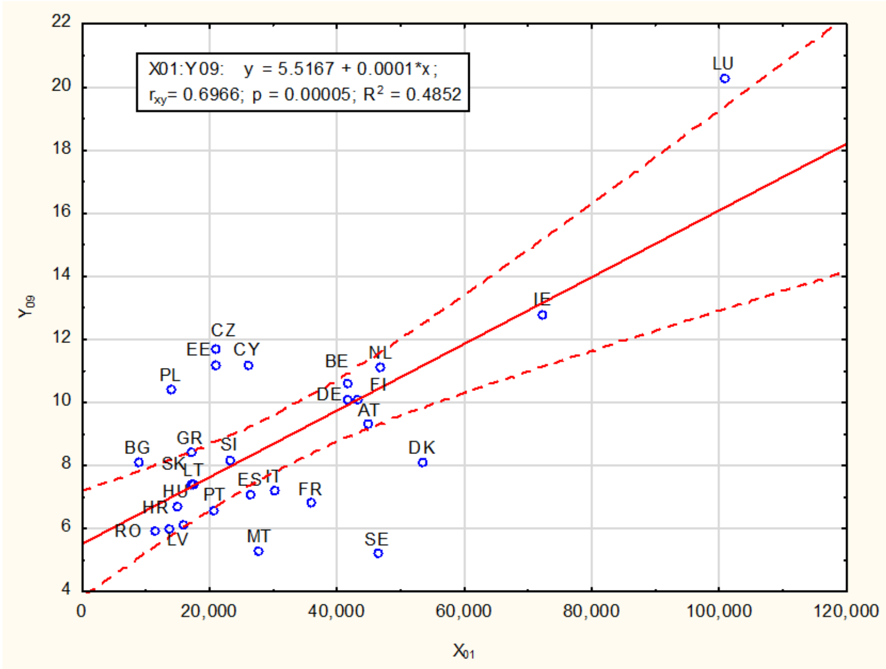

Figure 5. Scatterplot for the variable X_{01} (GDP per capita) and variable Y_{09} (greenhouse gas emissions in tonnes per capita) X_{03} (data for the EU countries (27) in 2019). Key: r_{xy}—linear correlation coefficient; R^2—coefficient of determination; solid line—best-fit line; dashed lines—limits of the confidence interval. Source: as in Table 2.

Table 9. Correlations r_{xy} between variables characterizing the level of greenhouse gas emissions from industry (Y_P) and agriculture (Y_A)in EU in 2019 and economic factors (X).

Correlations r_{xy}—Emission from Industry				Correlations r_{xy}—Emission from Agriculture				
Variable	X_{01}	X_{02P}	X_{03P}	**Variable**	X_{01}	X_{04A}	X_{05A}	X_{06A}
Y_{05P}	−0.13	0.38	0.04	Y_{05A}	0.18	0.60 *	−0.02	−0.09
Y_{06P}	−0.08	0.52 *	0.07	Y_{06A}	0.28	0.63 *	0.07	−0.10
Y_{07P}	0.40	0.10	0.33	Y_{07A}	0.80 *	0.52 *	0.57 *	0.45 *
Y_{08P}	0.11	−0.02	0.15	Y_{08A}	−0.05	0.39	−0.05	−0.25

* The correlation coefficients marked by an asterisk are significant with $p < 0.05$; N = 27. Source: as in Table 2.

The analysis of the level of greenhouse gas emissions from agriculture and the relationship between the level of these emissions and economic conditions revealed more significant correlations. A significant positive correlation was observed between the level of GDP per capita and the share of CH_4 methane emissions from agriculture (r_{xy} = 0.80). Significant, positive correlations were also found between the government support for research and development (R&D) in agriculture (X_{04A}) and the share of agriculture in total GHG emissions (Y_{05A}) (r_{xy} = 0.60) in carbon dioxide emissions (Y_{06A}) (r_{xy} = 0.63), methane (Y_{07A}) (r_{xy} = 0.52), and nitrous oxide (Y_{08A}) (r_{xy} = 0.39). In addition, significantly more methane emissions from agriculture were observed in the EU(27) countries with relatively higher agricultural factor income in EUR per annual work unit (AWU) X_{05A} (r_{xy} = 0.57) and significantly higher stocking rate X_{06A} (r_{xy} = 0.45) (Table 9).

The conclusions obtained on the basis of the analysis of class average groups of the EU countries (class I, II, III, and IV) regarding the level of employment in the sectors of industry, agriculture, and services were confirmed during the study of dependencies (Table 10). Although the calculated correlation coefficients were insignificant (below the assumed significance level of $p < 0.05$), their values led us to similar conclusions as before. The greater the level of greenhouse gas emissions from industry (Y_{01P}) was, the greater the employment in this sector (r_{xy} = 0.27) was. In terms of agriculture (Y_{05A}), the level of GHG emissions also increased with the level of employment (r_{xy} = 0.24). On the other hand, the general level of GHG emissions from all sources (Y_{09}) increased with the level of employment in services (r_{xy} = 0.30).

Table 10. Correlations between GHG emissions from industry (Y_{01P}), agriculture (Y_{05A}), and from all sources (Y_{09}) depending on employment in individual sectors (industry X_{07P}, agriculture X_{08A}, and services X_{09S}): sectoral analysis.

Variables	**Correlations r_{xy}**		
	X_{07P}	**X_{08A}**	**X_{09S}**
Y_{01P}	0.27	0.06	−0.19
Y_{05A}	−0.12	0.24	0.03
Y_{09}	−0.31	−0.31	0.30

Source: as in Table 7.

In order to verify (confirm or reject) the conclusions drawn on the basis of the applied classification method on the impact of economic conditions on the level of greenhouse gas emissions from industry and agriculture, multiple regression analysis was performed (Tables 11 and 12).

Table 11. The impact of the selected economic conditions on GHG emissions from industry: summary of multiple regression of the Y_{01P} dependent variable.

N = 27	**Dependent Variable Regression: Y_{01P}: r_{xy}= 0.376; R^2 = 0.142 Corrected R_2 = ----- F(4,21) = 0.866; *p* < 0.501; Standard Error of Estimation (SEE): 4.735**					
	b*	**SEE from b***	**b**	**SEE from b**	**t(21)**	***p***
Free word	–	–	10.23	5.93	1.72	0.10
X_{01}	−0.33	0.33	0.00	0.00	−1.02	0.32
X_{02P}	−0.03	0.23	−0.02	0.14	−0.12	0.90
X_{03P}	0.22	0.23	1.51	1.54	0.98	0.34
X_{07P}	0.07	0.29	0.05	0.19	0.25	0.80

Key: r—linear correlation coefficient; r^2—coefficient of determination; F—F statistics; t—Student's t statistics; b—coefficient b for the independent variable; b*—BETA coefficient (standardized b coefficient); *p*—critical significance level. Source: as in Table 7.

Table 12. The impact of selected economic conditions on greenhouse gas emissions from agriculture: summary of multiple regression of the Y_{05A} dependent variable.

N = 27	**Dependent Variable Regression: Y_{05A}: r_{xy} = 0.785; R^2 = 0.617 Corrected R^2 = 0.526 F(5.21) = 6.768; *p* < 0.001 Standard Error of Estimation (SEE): 4.3558**					
	b*	**SEE from b***	**b**	**SEE from b**	**t(21)**	***p***
Free word	–	–	3.75	2.95	1.27	0.22
X_{01}	0.26	0.17	0.00	0.00	1.50	0.15
X_{04A}	0.75	0.16	1.05	0.23	4.65	0.00
X_{05A}	−0.22	0.20	0.00	0.00	−1.07	0.30
X_{06A}	−0.17	0.17	−1.24	1.18	−1.05	0.31
X_{08A}	0.37	0.17	0.55	0.25	2.18	0.04

Key: r—linear correlation coefficient; r^2—coefficient of determination; F—F statistics; t—Student's t statistics; b—coefficient b for the independent variable; b*—BETA coefficient (standardized b coefficient); *p*—critical significance level. Source: as in Table 7.

Multiple regression analysis was carried out for the dependent variable Y_{01P} (greenhouse gas emissions from industrial processes and product applications in % of total greenhouse gas emissions), and we found no significant evidence of an impact on the share of gas emissions from this sector when taking into account the selected economic conditions such as the value of GDP, the level of business investment, R&D spending, and employment in the business sector. The coefficient of determination with $R^2 = 0.14$ indicated a poor fit of the regression function to the empirical data. This means that there are other factors not included in this study that determine GHG emissions from the industrial sector to a greater extent (Table 11).

On the other hand, the multiple regression analysis carried out for the dependent variable Y_{05A} (greenhouse gas emissions from agriculture in % of total greenhouse gas emissions) proved that the economic indicators characterizing the EU countries that were included in this study, such as GDP, government support for research and development in the agricultural sector, the income of agricultural factors of production, stocking density, and the percentage of employed individuals in agriculture accounted for 61% ($R^2 = 0.61$) of the variability of the Y_{05A} dependent variable. There was a relatively high fit of the regression function to the empirical data (Table 12). At the same time, the conclusions obtained using the previously used classification method were confirmed. Greenhouse gas emissions from agriculture were significantly higher in countries with relatively higher government support for R&D in the field of agriculture and a higher percentage of people employed in agriculture.

5. Discussion

Greenhouse gas emissions and the relationship between the level of emissions and the economic development of countries have been studied by many authors. As most studies indicate, highly developed countries significantly contribute to the emissions of harmful pollutants [19,24,25,55,73–75]. As emphasized by Janiszewska and Ossowska [56] and Matyka [76], countries with a high level of agricultural potential, characterized, inter alia, by high land productivity and a favorable agrarian structure, are distinguished by a stronger pressure on the environment. On the other hand, countries with lower agricultural pressure on the environment are at the same time characterized by low and medium agricultural potential, not particularly favorable agrarian structure, as well as land productivity and yields that significantly diverge from the EU average. This means that the significant intensification and concentration of agricultural production, combined with high levels of fertilization and high stocking rates, may have many adverse environmental consequences.

There are many studies in the literature that verify the environmental Kuznets curve (EKC) hypothesis [77], which states that there is an inverted U-shaped curve relationship between GDP per capita and greenhouse gas emissions or other indicators that describe environmental degradation [15,78,79]. Industrialization increases the negative impact of economic activity on the environment up to a certain point, after which this impact decreases with further economic growth. In other words, it is assumed that, in the long term, as a country develops, the quality of its environment improves. However, empirical studies for particular types of pollutants (e.g., greenhouse gas emissions) cast doubt on the existence of the effect postulated by the environmental Kuznets curve. A study of Tunisia by Fodha and Zaghdoud [78] showed that there is a long-term inverted U-shaped curve relationship between CO_2 emissions and GDP, and there is a monotonically increasing relationship between CO_2 emissions and GDP.

Grossman and Krueger [80] studied the relationship between per capita income and various environmental indicators and found no evidence that environmental quality consistently deteriorates with economic growth. Instead, for most indicators, economic growth led to an initial phase of deterioration followed by a phase of improvement. The team of Jovanović et al. [15], on the other hand, confirmed the Kuznets environmental curve (EKC) hypothesis, i.e., an inverted U-shaped curve relationship between GDP per capita and CO_2 emissions, in European economies. Similar conclusions for EU countries were drawn by Wawrzyniak [81], which confirm the environmental Kuznets curve hypothesis for this group of countries. However, she emphasizes that there is no basis for generalizing the obtained results to other types of pollution or other countries. In contrast, a study of 43 developing countries by Narayan and Narayan [82] revealed that carbon emissions in the Middle East and South Asia declined in the long term, as economic development increased, while the results of a study for the Middle East by Ozcan [79] provided some evidence contrary to the EKC hypothesis. The casual and long-term relationship between GHG emissions and the economic growth of Canadian industrial sectors was also studied by Hamit-Haggar [14]. Their study showed that there was a nonlinear relationship between GHG emissions and economic growth, according to the environmental Kuznets curve. A nonlinear relationship between agricultural carbon emissions and per capita income in the agricultural sector in different EU countries was also demonstrated by Zafeiriou et al. [83]. They confirmed the existence of a strong relationship because of the nonlinear autoregression cointegration that existed in all cases.

The previously mentioned authors most commonly identified economic growth as the cause of gas emissions, while other researchers treated a certain level of economic development in the future as an effect of the current impact of industry and agriculture on environmental degradation [6]. Researchers have also investigated the differences in the impact of, e.g., agroeconomic factors, on GHG emissions, with a subdivision into highly developed and developing economies [15]. A similar issue regarding the relationship between environmental effects, as well as economic and financial development in EU countries, was also addressed by Ziolo et al. [84]. These researchers found that the relationship between financial sustainability and environmental degradation is more significant for convergent economies than in developed countries, but it is closer for developed countries and reduces GHG emissions in convergent economies.

Based on the data collected for the EU countries, our findings show that countries with higher subsidies for research and development in agriculture emit more GHG from this sector. Different conclusions were obtained by other researchers concerning other countries. The relationship between agricultural subsidies and global greenhouse gas emissions was studied by Laborde et al. [85]. These researchers revealed that while governments have provided incentives for high-carbon agriculture for years, this support has little impact on global GHG emissions from agricultural production. However, according to a study by Yasmeen et al. [86], investments in research and development for agriculture increased the efficiency of agricultural production by 1% while reducing carbon dioxide emissions. In contrast, in our study, the data for EU countries showed a significant impact of the level of subsidies for research and development in agriculture on the increase in CO_2 emissions. The reason lies in the group of objects/countries included in the analysis, which was also noted by Yasmeen et al. [86]. Thus, the effectiveness of government management of greenhouse gas emissions, especially CO_2, can be both positive and negative, depending on whether they are developed or developing countries.

European countries are struggling with the process of demographic shrinking in rural areas (e.g., there are villages with a constant regression of population, the so-called vanishing villages). One of the negative phenomena is an acceleration in the rate of aging among the rural population, which is a consequence of selective migrations and a low birth rate. As a result of the population loss, the farm size structure is slowly improving. Paradoxically, population decline contributes to the improvement in the spatial structure of villages; they become more compact because, first of all, the number of farms located far from the concluded layout of the rural settlement is reduced. However, Genstwa [87] emphasized that the share of the urbanized area of a given region has a significant impact on the environment and the emission of air pollutants. The increase in the share of urbanized lands contributes to the decrease in the share of agricultural lands, forests, and other natural areas, which is a direct cause of environmental degradation. On the other hand, the increase in economic activity resulting from the urbanization process results in an increase in pollutant emissions and contributes to the deterioration of the environment.

Sadowski [88] and Świtek et.al. [57] pointed out that the volume of gas emissions is related to production factors in agriculture. The development of advanced digital technologies, in which the young generation is perfectly versed, may be the answer to humanity's problems, including the adverse effects of climate change and environmental pollution. Advanced digital technologies have been used to integrate individual actors in the food supply chain. However, transformations in the food production market occur slowly. Agriculture is the "least digitized sector of the economy", according to a McKinsey Global Institute report [89]. On a global scale, however, Europe is one of the leaders in developing digital agriculture [90].

In conclusion, most empirical studies focus on using data at the aggregated level to investigate levels and trends in GHG emissions and the relationship between emissions and economic development. Some of these studies use time series data for different time periods, which are known to produce unreliable and inconsistent results. Therefore, as it was indicated above, there are many works on this issue, but the results obtained are inconsistent and diverse. This leads to difficulties in comparing the results obtained and conclusions.

6. Conclusions

Industry and agriculture in the EU(27) countries play a significant role as the sectors contributing to greenhouse gas emissions, and the impact of these economic sectors on environmental pollution has further increased in recent years. Agriculture accounted for a slightly larger share of total GHG emissions (10.3%) than industry (9.1%). The industrial sector contributed to considerably more carbon dioxide (CO_2) emissions than agriculture, while agriculture was the main contributor of methane (CH_4) and nitrous oxide N_2O emissions. During the analyzed period of 2010–2019, no progress was observed in any effective reduction in the concentration levels of these harmful gases from industry and agriculture, and the EU(27) countries continued to vary significantly in terms of their GHG emissions. The largest GHG emissions from industry were observed in Slovakia, Austria, and Belgium, and the lowest were in Denmark, Estonia, and Ireland. On the other hand, Ireland, Denmark, and Lithuania were the largest emitters of greenhouse gas from agriculture, while Malta, Cyprus, and Luxembourg had the least greenhouse gas emissions from this sector.

When analyzing the correlation between the Y_{09} indicator, presenting the total greenhouse gas emissions in tonnes per capita of the 27 EU countries, and the GDP per capita (X_{01}), it can be concluded that there is a significant relationship between these variables, which means that the higher economic development of a country contributes to a higher level of greenhouse gas emissions. However, when assessing the indicators that only describe the share of GHG emissions from industry and agriculture as a % of total emissions, no highly significant correlations were found, and there were insignificant relationships. Based on the analyses of dependencies and classification methods, it was confirmed that the structure of employment in the EU countries affected the level of greenhouse gas emissions by the individual sectors. Greenhouse gas emissions from agriculture increased with the percentage of employment in agriculture, and emissions from industry also increased with the percentage of employment in the industrial sector, while employment in the service sector affected the scale of the total greenhouse gas emissions from all sectors.

In the industrial sector, there was a positive causal relationship between CO_2 and GHG emissions in total based on the individual EU countries and the share of business investment in % of GDP. In turn, countries with higher GDP and expenditure on research and development in the enterprise sector contributed to relatively more methane emissions. In contrast, more confirmed associations were found between gas emission indicators and economic conditions in the agricultural sector. Methane (CH_4) emissions from agriculture significantly increased with all the economic indicators included in the study, namely GDP per capita, government support for agricultural R&D, agricultural income, or the stocking rate. The most disturbing finding is the significant positive causal relationships between all the GHG emissions studied and the government support for agricultural R&D, meaning that higher government support leads to more GHG emissions. Based on this result, it can be hypothesized that rural areas in the EU, which are supposed to play a special environmental role in the Common Agricultural Policy, are the main threat to the climate and that successful governmental support for R&D contributes effectively to this situation.

In conclusion, at a time of climate crisis, the need to protect the natural environment, in particular air, should be a priority for all economic units, from farms to businesses and households. Effective management aimed at reducing greenhouse gas emissions can be implemented if research is available on the current status and causes. The results of the presented research indicate the existence of differences in the level of GHG emissions from industry and agriculture in individual EU countries, as well as a cause-and-effect relationship between the economic conditions of these countries and the level of emissions. This relationship was more clearly visible in the agricultural sector than in the industry. There were time constraints in our work. The 10-year period of research may not cover the full range of variability and trends in GHG emissions from industry and agriculture. Some processes and phenomena may have long-term or seasonal effects, so it is important to study them over a sufficiently long period to obtain more representative results. Further studies and analyses that take into account longer observation periods should be carried out to better understand long-term changes in GHG emissions.

We hope that the results presented in this article will lead to further discussion among scholars undertaking research into the presented topic for the first time by providing them with a literature reference; entities from the industry and agriculture sectors, in terms of the identification of the levels of GHG emissions, their variation, and the possibility to decrease their intensity; scientists helping them to develop their research; and government bodies deciding on future ways of the industry and agriculture development in order to help them to better understand trends and economic factors influencing the variation in GHG emissions in the EU countries. Regular research on these issues is important from the point of view of building awareness among decision makers, from the largest business entities to individual consumers. This knowledge can contribute to the competitiveness of different sectors as long as the development of greener and more sustainable management and production practices is supported.

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