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Relationship Between Organic Farmland Expansion and Greenhouse Gas Emissions in Europe: Implications for the Implementation of the Sustainable Development Goals

Związek pomiędzy ekspansją ekologicznych gruntów rolnych a emisją gazów cieplarnianych w Europie w kontekście wdrażania Celów zrównoważonego rozwoju

Serhii Kozlovskyi[1*], Ivan Zayukov[2], Volodymyr Kozlovskyi[3], Oleksandr Tregubov[4], Sviatoslav Storchak[5], Viktor Mishchenko[6], Ruslan Lavrov[7]

[1]Vasyl' Stus Donetsk National University, Vinnytsia, Ukraine
[*]E-mail (Corresponding Author): s.kozlovskyy@donnu.edu.ua,ORCID: 0000-0003-0707-4996
[2]Vinnytsia Institute of Trade and Economics of State University of Trade and Economics, Vinnytsia, Ukraine
E-mail: i.zayukov@vtei.edu.ua, ORCID: 0000-0002-7225-2827
[3]Vinnytsia National Technical University, Vinnytsia, Ukraine
E-mail: v@vin.ua, ORCID: 0000-0002-0955-4347
[4]Vasyl' Stus Donetsk National University, Vinnytsia, Ukraine
E-mail: a.trigubov@donnu.edu.ua, ORCID: 0000-0002-0397-5570
[5]Vasyl' Stus Donetsk National University, Vinnytsia, Ukraine
E-mail: s.storchak@donnu.edu.ua, ORCID: 0009-0009-2119-3351
[6]Vasyl' Stus Donetsk National University, Vinnytsia, Ukraine
E-mail: v.mishchenko@donnu.edu.ua, ORCID: 0009-0008-7802-3700
[7]T.H. Shevchenko National University, Chernihiv Colehium, Chernihiv, Ukraine
E-mail: lavrus2017@gmail.com, ORCID: 0000-0002-9655-4467

Abstract

The global community is endeavouring to achieve the ambitious Sustainable Development Goals. A significant aspect of the implementation of the Goals is the introduction of organic production in agriculture. This will contribute, among other things, to zero hunger (Goal 2); the provision of humanity with alternative energy sources (Goal 7); the development of innovative solutions (Goal 9); the motivation of the population to consume responsibly, including food (Goal 12); the combating of climate change (Goal 13); and the preservation of ecosystems both on land and below water (Goals 14-15). An important area of implementation of all the seventeen goals is the introduction of organic production in agriculture. This will contribute to providing the population with food; improving public health; overcoming the problems related to hunger, poverty, poor health, limited clean drinking water, energy shortages, depletion of natural resources, climate change, and pollution of both aquatic and terrestrial ecosystems. The EU-27 countries need to reduce greenhouse gas emissions to zero by 2050, which exacerbates the issue. For this reason, the paper hypothesizes that organic farmland expansion will potentially result in an increase in greenhouse gas emissions. Accordingly, the purpose of the paper is to conduct empirical research into the impact of organic farmland expansion on the increase in greenhouse gas emissions in the EU. The correlation and regression analysis based on the use of available Eurostat statistics for the period 2014-2021 for selected individual European countries demonstrated that the majority of European countries exhibit a high degree of correlation. According to data from all EU Member States (27), the relationship is strong and directly proportional. It was found that with an increase in the area of organic farmland by 1% in the EU27, greenhouse gas emissions will increase by 0.00000025 thousand tons. The calculations revealed that ceteris paribus, greenhouse gas emissions are influenced by the expansion of organic farmland by 62.4%. Among the European countries under study, similar trends are observed in Denmark, Germany, Estonia, Spain, the Netherlands, Portugal, Romania, Finland, Switzerland, and the United Kingdom. Meanwhile, in Lithuania and the Netherlands, the relationship is inversely proportional. Weak correlation, as evidenced by the calculated correlation coefficient, is observed in such European countries as Bulgaria (0.05); Poland (0.02); Slovakia (0.05). To implement the Sustainable Development Goals, it is recommended to take measures to change the culture of food consumption; to use agricultural technologies, methods, equipment, machinery and mechanisms more efficiently; and to rationally use the waste.

Key words: sustainable development, organic production, greenhouse gases, model, correlation and regression analysis, economic security, food security, agricultural sector, ecology, international economics, Europe
JEL Classification: G33, C45, M11.

Streszczenie

Społeczność globalna dąży do osiągnięcia ambitnych Celów Zrównoważonego Rozwoju. Istotnym aspektem realizacji Celów jest wprowadzenie produkcji ekologicznej w rolnictwie. Przyczyni się to między innymi do zerowego głodu (Cel 2); zapewnienia ludzkości alternatywnych źródeł energii (Cel 7); opracowania innowacyjnych rozwiązań (Cel 9); motywacji ludności do odpowiedzialnej konsumpcji, w tym żywności (Cel 12); walki ze zmianą klimatu (Cel 13); oraz zachowania ekosystemów zarówno na lądzie, jak i pod wodą (Cele 14-15). Ważnym obszarem realizacji wszystkich siedemnastu celów jest wprowadzenie produkcji ekologicznej w rolnictwie. Przyczyni się to do zapewnienia ludności żywności; poprawy zdrowia publicznego; przezwyciężenie problemów związanych z głodem, ubóstwem, złym stanem zdrowia, ograniczoną ilością czystej wody pitnej, niedoborami energii, wyczerpywaniem się zasobów naturalnych, zmianami klimatu i zanieczyszczeniem ekosystemów wodnych i lądowych. Kraje UE-27 muszą zredukować emisję gazów cieplarnianych do zera do 2050 r., co jest dodatkowym wyzwaniem. Z tego powodu w artykule postawiono hipotezę, że ekspansja ekologicznych gruntów rolnych potencjalnie doprowadzi do wzrostu emisji gazów cieplarnianych. W związku z tym celem artykułu jest przeprowadzenie badań empirycznych nad wpływem ekspansji ekologicznych gruntów rolnych na wzrost emisji gazów cieplarnianych w UE. Analiza korelacji i regresji oparta na wykorzystaniu dostępnych statystyk Eurostatu za okres 2014–2021 dla wybranych poszczególnych krajów europejskich wykazała, że większość krajów europejskich wykazuje wysoki stopień korelacji. Zgodnie z danymi ze wszystkich państw członkowskich UE (27) związek ten jest silny i wprost proporcjonalny. Stwierdzono, że wraz ze wzrostem powierzchni ekologicznych gruntów rolnych o 1% w UE27 emisja gazów cieplarnianych wzrośnie o 0,00000025 tys. ton. Obliczenia wykazały, że ceteris paribus emisja gazów cieplarnianych pod wpływem ekspansji ekologicznych gruntów rolnych może wzrosnąć o 62,4%. Wśród badanych krajów europejskich podobne tendencje obserwuje się w Danii, Niemczech, Estonii, Hiszpanii, Holandii, Portugalii, Rumunii, Finlandii, Szwajcarii i Wielkiej Brytanii. Tymczasem na Litwie i w Holandii zależność jest odwrotnie proporcjonalna. Słabą korelację, o czym świadczy obliczony współczynnik korelacji, obserwuje się w takich krajach europejskich jak Bułgaria (0,05); Polska (0,02); Słowacja (0,05). Aby wdrożyć Cele Zrównoważonego Rozwoju, zaleca się podjęcie działań mających na celu zmianę kultury konsumpcji żywności; efektywniejsze wykorzystanie technologii, metod, sprzętu, maszyn i mechanizmów rolniczych; racjonalne wykorzystanie odpadów.

Słowa kluczowe: zrównoważony rozwój, produkcja organiczna, gazy cieplarniane, modelowanie, analiza korelacji i regresji, bezpieczeństwo ekonomiczne, bezpieczeństwo żywnościowe, sektor rolniczy, ekologia, gospodarka międzynarodowa, Europa

1. Introduction

In 2015, the United Nations (UN) adopted the Global Goals, also known as the Sustainable Development Goals (SDGs), which are to be achieved by 2030. The SDGs encompass a range of objectives, including ending poverty and hunger; good health and quality education; gender equality; clean water and sanitation; renewable energy; decent work and economic growth; innovation and infrastructure; reducing inequality; sustainable cities and communities; responsible consumption; combating climate change; conservation of marine ecosystems; conservation of terrestrial ecosystems; peace and justice; partnership for sustainable development (UNDP, 2024). According to UN experts, organic farming is not only an important form of agriculture but also allows for the implementation of the vast majority of the Sustainable Development Goals, which are interconnected and complementary (Nature & More, 2024). For example, when considering one of the most important Sustainable Development Goals, Goal 13: Climate action, the Intergovernmental Panel on Climate Change examined

the relationship between climate change, soil and agriculture. The IPCC concluded that agriculture and other related sectors are responsible for 23% of human greenhouse gas emissions (Nature & More, 2024).
For example, Sustainable Development Goal 15: Life on land can be achieved by expanding the area of organic land. This will not only lead to zero hunger (Goal 2), but will also to the restoration of biodiversity (on land and in water), restore the population of beneficial insects, birds, etc., which will reduce the number of pests and improve the overall environmental situation. Humanity is currently facing the challenge of extremely high greenhouse gas (GHG) emissions, mainly due to the expansion of agricultural land to meet the ever-growing demand for food (Maraveas et al., 2023). Agriculture is of paramount importance in ensuring food security and is aimed at reducing hunger and ensuring social and economic development in any country. For example, global cereal production increased from 0.88 billion tons in 1961 to 3.06 billion tons in 2022 (Ritchie et al., 2022). That is, grain production increased by 2.5 times over the past 60 years. The expansion of agricultural areas under cultivation, population growth, and yield growth, especially when using intensive methods, technologies, and automation in the agricultural sector, have been the main factors contributing to the growth of food production globally, with a particular focus on grain production. A striking example is the US, whose total agricultural production tripled in 2017 compared to 1948. This was achieved not through the expansion of cultivated areas and increased labour input, but through the implementation of innovations in animal and crop genetics, chemical agents, equipment and effective farm management (U.S. Department of Agriculture, 2020). One of the factors behind the expansion of farmland is the rapid growth of the world's population. In 2022, there were about 8 billion people on Earth, which is three times as many as in 1950. In addition, by 2050, the world's population is expected to grow to 10.4 billion people (The Guardian, 2022). That is, we can hypothetically assume that a threefold increase in population is likely to have led to an expansion of farmland by the same amount. Further population growth and extensive agriculture will lead to the expansion of farmland to produce more food. Intensive agriculture can prevent the expansion of such areas, which is an important factor in sustainable development.
In the modern world, the concept of sustainable development involves overcoming the problems of hunger and climate change. This requires solving the dual problem associated with the development of agriculture because, on the one hand, agriculture provokes climate change by emitting GHGs into the atmosphere. Unfortunately, over the past 120 years, emissions of such GHGs as carbon dioxide (CO_2) have quadrupled, with annual emissions (CO_2), including changes in land use from 1850 to 2022, growing much more in some countries (Fig 1).

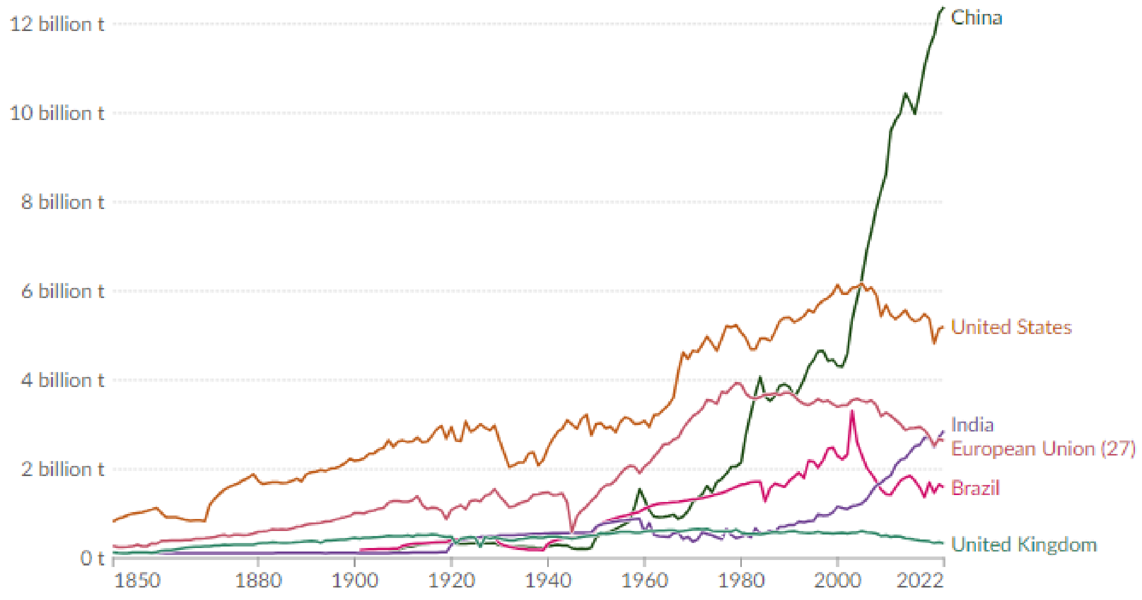

Figure. 1. Annual emissions (CO_2), including land use changes in selected countries for 1850-2022, million tons, source: (Ritchie et al., 2022).

Fig. 1 shows that the largest annual emissions (CO_2), including land use changes in 2022, are recorded in China – by more than 12 million tons, in the United States – by about 5 million tons; in India and the EU – by about 3 million tons. The largest increase was recorded in China over the period 1850-2022 – more than 12 times. On average, agriculture accounts for about 20-25% in the structure of emission sources (CO_2).
On the other hand, climate change has an extremely strong impact on agricultural development. Traditional farming methods (using chemical fertilizers, pesticides, energy-consuming machinery that consumes much energy, expanding agricultural areas, etc.) need to be radically changed in view of the constant population growth and climate change. Without these measures, environmental problems will aggravate, farmland will degrade, which

will result in an increase in food security risks. Therefore, the primary objective of humanity is to return to fundamental environmental values, in particular, to strive *not significantly harm the environment* (Avasiloaiei et al., 2023).

It is important and timely to maximize the use of resources, in particular in agriculture, reduce GHG emissions, and ensure biodiversity. An important area of resource efficiency in agriculture is the introduction of organic agriculture. This will minimize the use of chemical fertilizers and pesticides, increase soil fertility and yields, and reduce environmental pollution, including GHG emissions (Selvan et al., 2021; Koziuk et al., 2020).

Thus, the introduction of organic agriculture is an important factor in sustainable development. Therefore, the hypothesis of the article is to test the claim that the expansion of organic farmland could potentially lead to an increase in GHG emissions. The purpose of the article is to empirically study the impact of the expansion of organic farmland on the increase in GHG emissions in the EU. This will make it possible to understand whether the increase in the area of organic agricultural production will lead to a change in GHG emissions and, on this basis, to develop recommendations that will allow the national policies of European countries to reduce greenhouse gas emissions, which will be an important factor in achieving the Sustainable Development Goals.

2. Literature review

Organic agriculture plays an instrumental role in ensuring the implementation of the Sustainable Development Goals. According to the scientific report *Organic Agriculture and the Sustainable Development Goals*, developed and published by scientists at the University of Twente in the Netherlands (Nature & More, 2024), organic farming has a positive impact on at least eight of the seventeen Sustainable Development Goals, including Goal 2: Zero Hunger; Goal 3: Good health and well-being; Goal 6: Clean water and sanitation; Goal 8: Decent work and economic growth; Goal 12: Responsible consumption and productiton; Goal 13: Climate action; Goal 14: Life below water; Goal 15: Life on land. Furthermore, using organic land management technologies and expanding farmland globally, particularly in Europe, will foster the realisation of other Sustainable Development Goals. For example, Goal 2: Zero hunger, is a crucial objective in the present era, which cannot be attained without the implementation of Goal 1: No poverty, etc. Owing to the growing global population, there is a need to increase food production. The world's population is expected to grow to 9.1 billion people by 2050 (Population Matters, 2022). This, in turn, leads to an increase in the area of farmland to grow the required number of crops and increase livestock production. As a result, a significant amount of GHGs is generated, including carbon dioxide (CO_2), nitrogen oxide (N_2O), and methane (CH_4), which are the most dangerous ones and severely affect the Earth's climate change (Chataut et al., 2023). GHGs themselves have a detrimental impact on agriculture, in particular through droughts, floods, forest fires, and other natural hazards (Bhavsar et al., 2023).

The EU countries have developed indicators for reducing GHG emissions by 55% by 2030, and they expect to achieve *zero* emissions by 2050 (Filipovic et al., 2022). Thus, at the European level, the problem of GHG emissions in agriculture can be solved, which will become a powerful reserve for its development (Verschuuren, 2022). According to statistical data (Statista, 2024), in 2020, the distribution of GHG emissions in various sectors of the economy was as follows, in particular: power generation – 32%; transport – 15.3%; industry – 13.10%, agriculture – 12.3%. Thus, agriculture accounts for a fairly large share in the overall structure of GHG emissions, or every 8th unit of GHG emissions, which exacerbates the problem of global climate change and sustainable development. The largest source of GHG emissions in agriculture is livestock (intestinal fermentation and manure) (Arcipowska et al., 2019).

Agriculture (AA) is not only a source of GHGs, but also a consumer and a neutralizer of them (Zaman et al., 2021). For example, the application of manure increases N_2O emissions by an average of 32.7%, while the application of synthetic nitrogen fertilizers increases N_2O emissions by an average of 58.2% (Zhou et al., 2017).

Consumer demand for more environmentally friendly food has increased significantly in the EU. The market for organic agricultural products must adhere to standards, in particular environmental ones, which include, among other things, a ban on the use of synthetic fertilizers and pesticides. This will help reduce GHG emissions not only in the agricultural sector, but also in the overall structure of emissions (Gomiero et al., 2011). Organic agriculture is based on a comprehensive strategy for food production and agricultural operations. It is important to use environmentally friendly technologies in crop and livestock production; conservation and cost-effective use of resources; compliance with all animal welfare rules and standards; motivation to preserve biodiversity, etc.

The fact that organic farming contributes significantly to the reduction of GHG emissions, in particular (CO_2), is confirmed by the research conducted by many scientists across the globe. To illustrate, according to (Smith et al., 2000), the production of organic agricultural food in crop production, in particular, when growing carrots, reduces the amount of energy consumed by 50% compared to conventional methods of cultivation; for onions – by 65%. Scientists (Fritsche et al., 2007) found that GHG emissions (CO_2) from growing such crops as tomatoes, in particular, were one third lower (from 15 to 31%) than when using traditional cultivation technology. The use of compost and manure compared to synthetic fertilizers can significantly save energy resources and reduce GHG emissions (Bos et al., 2014; Kozlovskyi et al., 2017; Kozlovskyi et al., 2019).

The production of organic crops, in particular vegetables, can significantly reduce global GHG emissions. Thus, according to (Scialabba & Muller-Lindenlauf, 2010), this reduction can be up to 20%, in particular, due to the refusal to use nitrogen fertilizers. The potential ability of organic agriculture to neutralize carbon can reduce GHG emissions in agriculture by up to 72% (Avasiloaiei, et al., 2023; Kozlovskyi, 2010; Kozlovskyi et al., 2010).
A study conducted in Italy showed that organic agriculture has a significantly lower carbon footprint (due to reduced use of synthetic fertilizers and pesticides and lower energy use) than conventional agriculture (Chiriacô et al., 2017). A corresponding study was conducted in China, where organic farming managed to minimize GHG emissions by 13.4% compared to conventional farming methods (Zhou et al., 2019), and, accordingly, according to (Zikeli et al., 2014), emissions can be reduced by 20% to 50%.
Investigated is the relationship between organic farming and GHG emissions in the US states. Organic farming is defined as a system of livestock and crop production that does not use off-farm inputs to maintain a *healthy* interaction between soil biological activity, cycles, and biodiversity (Squalli & Adamkiewicz, 2018). The data was analyzed for the period 1997-2010. It was found that a one percent increase in the agricultural area under organic farming would potentially reduce GHG emissions by 0.049% (Squalli & Adamkiewicz, 2018).
There is no consensus among scholars who study the relationship between organic farming and the environment, in particular, on the difference between organic and conventional farming methods. For example, researchers (Wood et al., 2006) emphasize that there is a positive relationship between organic farming and the environment, researchers (Cooper et al., 2011) argue that the relationship is negative, and scientists (Syvasalo et al., 2006) believe that there is no statistically significant difference between organic and conventional farming methods. At the same time, there are studies that explain that organic agriculture plays a crucial role in partially neutralizing GHGs (Mattila et al, 2022), in particular by binding them in agricultural soil, which has a positive impact on climate change (Paustian et al, 2019).
A study by scientists (Adewale et al., 2016) who analyzed the carbon footprint of agricultural production, in particular vegetables on a small farm, showed that organic farming can reduce the carbon footprint and therefore GHG emissions by 34%. Moreover, there is evidence of a reduction in (CO_2) when using organic farming compared to conventional farming methods (Gomiero et al., 2008). In addition, according to (Kustermann, Hulsbergen, 2008), the energy consumption per hectare of land in organic farming is about 2.75 times lower than in conventional farming.
A review of the literature related to the problem of GHG emissions, in particular (CO_2), generated in agriculture has led to the conclusion that it is relevant and timely. The analyzed literature sources show that organic production in agriculture can significantly solve this problem. It is related to climate change, world population growth, and the expansion of agricultural areas for food production. Solving this problem will help to achieve the Sustainable Development Goals, in particular: overcoming hunger and reducing the negative impact on climate change. Therefore, this paper proposes to conduct an empirical study of the impact of the expansion of organic farmland on GHG emissions in the EU.

3. Methodology

The study involves the following steps: to analyze GHG emissions and areas of organic farmland in European countries (Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, Norway, Switzerland, European Union – 27 countries) in 2014-2021 based on the statistical database of the official Eurostat website (the latest statistics as of 01.06.2024 in Eurostat for indicators are given for 2021); to calculate the rates of growth (decline) in GHG emissions in European countries in 2021 compared to 2014; to calculate the rates of increment (decrement) in GHG emissions in European countries in 2021 compared to 2014; to estimate the ratio of GHG emissions in European countries in 2021 compared to the average value for the EU countries (27); to calculate the rates of growth (decline) in the use of organic farmland in European countries in 2021 compared to 2014; to calculate the rates of increment (decrement) in the use of organic farmland in European countries in 2021 compared to 2014; to work out correlation and regression equations to determine the impact of the expansion of organic farmland on GHG emissions for the countries under study and assess their adequacy and statistical reliability. To visualize the data obtained from the correlation and regression analysis to determine the impact of the expansion of organic farmland in Europe on GHG emissions for the countries under study.
The impact of expanding the area of organic farmland (x) on GHG emissions (Y) was determined using correlation and regression analysis. Indicator (Y) – GHG includes CO_2; N_2O in CO_2 equivalent; HFC in CO_2 equivalent; PFC in CO_2 equivalent; SF_6 in CO_2 equivalent; NF_3 in CO_2 equivalent, and is measured in thousand tons. Indicator (x) is the area of organic crops by agricultural production methods and crops, in particular: arable land, cereals for grain production (including seed), cereals (except rice) for grain production (including seed); wheat and spelt; vital winter mixtures (olive); barley; oat and spring grain mixtures (grain mixtures except olive); mixtures of grain corn and corn cobs; dry legumes and protein crops for grain production (including seeds and mixtures of cereals

and legumes); root crops; industrial crops; plants harvested green from arable land; fresh vegetables (including melons); strawberries; permanent meadows; perennial crops; fruits from temperate climates; grapes; olives. The correlation-regression analysis in assessing the impact of (x) on (Y) involves the construction of a correlation equation (formula 1): (Chatterjee at al, 2013):

$$Y_x = b_0 + b_1 x, \quad (1)$$

where Y_x – linear equation;
b_0, b_1 – equation parameters (coefficients);
x – influencing factor.
The algorithm of correlation and regression analysis to identify the impact of the expansion of organic farmland (x) on GHG emissions (Y) is shown in Fig. 2.

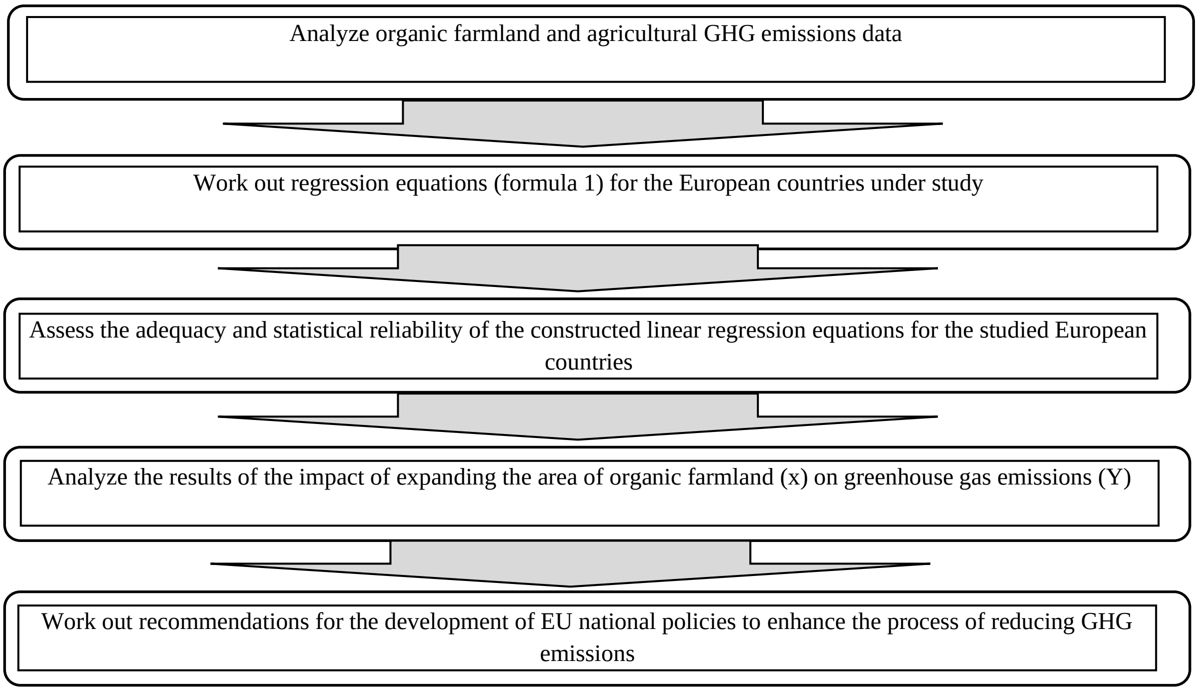

Figure. 2. Algorithm for detecting the impact of the expansion of organic farmland (x) on GHG emissions (Y)

The unknown parameters of the regression equation (b0, b1) are found using the least squares method. For this purpose, a system of normal equations for European countries was built. The closeness of the relationship was estimated using a linear correlation coefficient. The proportion of variation in the studied outcome variable (Y) due to the influence of the factors (x) included in regression equation 1 is determined by the coefficient of determination (D). The reliability of the multiple correlation coefficient (as well as the correlation equation as a whole) was assessed by calculating the F-criterion (F). In addition to the closeness of the relationship, the following indicators were used to assess the adequacy of the regression equation (1) to real processes: sample correlation coefficient (z), standard error (Se), the lower limit of the confidence interval of the correlation coefficient (rL), the upper limit of the confidence interval of the correlation coefficient (rU). The above indicators were calculated using MS Excel.

4. Results and discussion

This section provides a statistical analysis of European countries, in particular: Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, Norway, Switzerland, European Union – 27 countries) based on Eurostat data of the studied indicators – the area of organic farmland and GHG emissions. Calculated were the rates of growth (decline) and the rates of increment (decrement) in GHG emissions in European countries in 2021 compared to 2014; assessed was the ratio of GHG emissions in European countries in 2021 compared to the average value for the European Union (27 countries); calculated were the rates of growth (decline) and the rates of increment (decrement) in the use of organic farmland in European countries in 2021 compared to 2014 were. The impact of the expansion of organic farmland on GHG emissions for the countries under study is investigated. Correlation and regression equations were worked out to determine the impact of the expansion of organic farmland on GHG emissions for the countries under study; the level of their adequacy and statistical reliability was assessed. The data obtained from the correlation and regression analysis are visualized and proposals are made to achieve the Sustainable Development Goals in terms of food security, hunger and environmental biodiversity.

4.1. Analyzing statistics on GHG emission in European countries

The statistical data for analyzing GHG emissions in individual European countries is taken from the official Eurostat website (Eurostat, 2021). The calculation of the growth (decline) rates of GHG emissions in European countries in 2021 compared to 2014 is shown in Fig. 3.

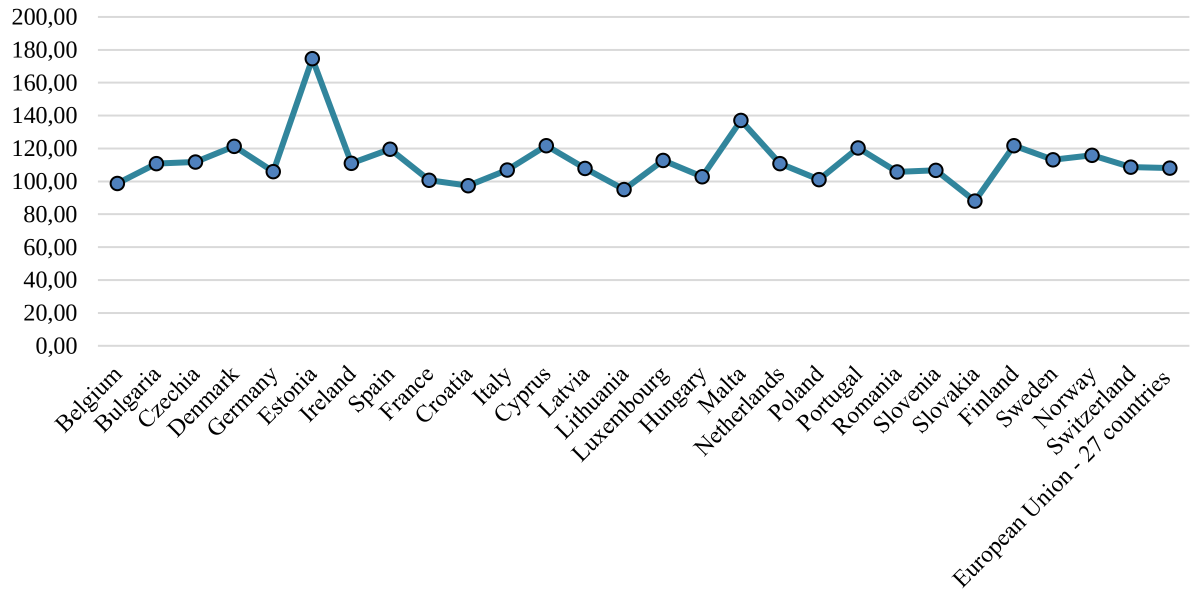

Figure 3. Calculation of growth (decline) rates of GHG emissions in European countries in 2021 compared to 2014, %, source: calculated by the authors according to (Eurostat, 2021).

The information in Fig. 3 shows that in 2021, compared to 2014, there was an increase in GHG emissions in almost all of the above European countries except for the countries where the rate of decline was recorded: Belgium (98.78%); Croatia (97.32%); Lithuania (95.05%); Slovakia (88.06%). Figure 4 shows the increment (decrement) rates of GHG emissions in European countries in 2021 compared to 2014.

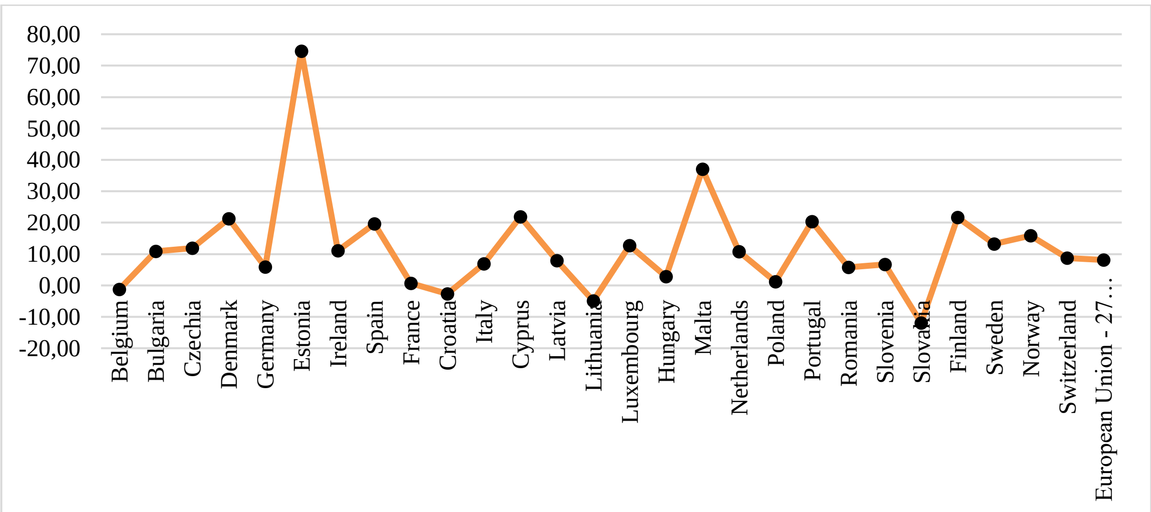

Figure 4. Calculation of the rate of increment (decrement) in GHG emissions in European countries in 2021 compared to 2014, %, source: calculated by the authors according to (Eurostat, 2021).

Thus, Fig. 4 shows that in 2021, compared to 2014, the highest growth rate of GHG emissions was recorded in Estonia – 74.65%. The following European countries have the highest respective growth rates: Malta – 37.04%; Cyprus – 21.82%; Finland – 21.70%; Denmark – 21.27%; Portugal – 20.39%; Spain – 19.59%; Norway – 15.85%.

That is, their emissions have increased significantly, which is a negative trend in terms of achieving the Sustainable Development Goals. The following countries have made significant progress in reducing GHG emissions (reduction rates): Slovakia – minus 11.94%; Lithuania – minus 4.95%; Croatia – minus 2.68%; Belgium – minus 1.22%. A correlation between GHG emissions in European countries in 2021 and the average for the EU (27) is shown in Fig. 5.

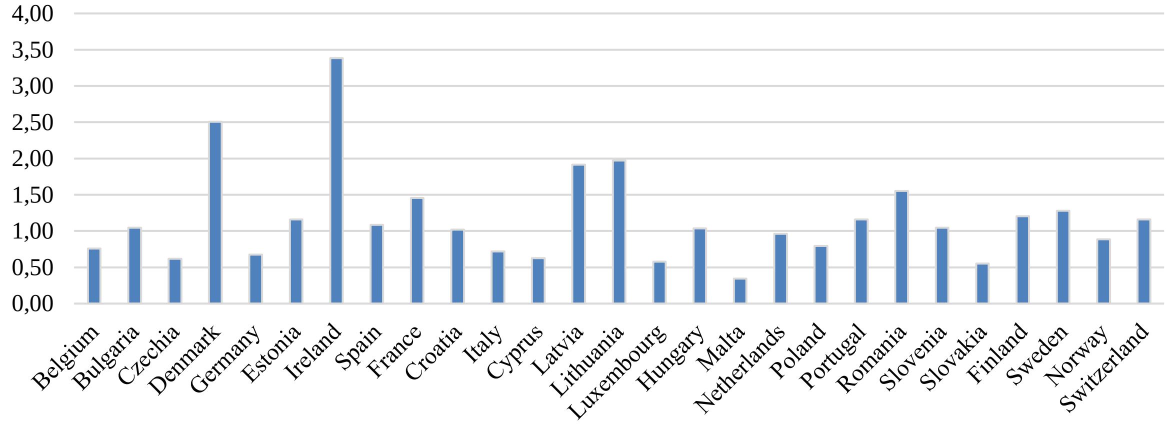

Figure 5. The ratio of GHG emissions in European countries in 2021 compared to the average value for the European Union (27), source: calculated by the authors according to (Eurostat, 2021).

The ratio of GHG emissions in European countries in 2021 compared to the average value for the European Union (27) shows that the lowest value is recorded in the following countries: Malta – 0.35%; Slovakia – 0.55; Luxembourg – 0.58; Czech Republic – 0.62; Cyprus – 0.63. The corresponding excess was recorded in the following countries: Ireland – 3.38; Denmark – 2.50; Lithuania – 1.97; Romania – 1.55; France – 1.46%.

4.2. Analyzing the use of organic farmland in European countries

The calculation of the growth (decline) in the use of organic farmland in European countries in 2021 compared to 2014 is shown in Fig. 6.

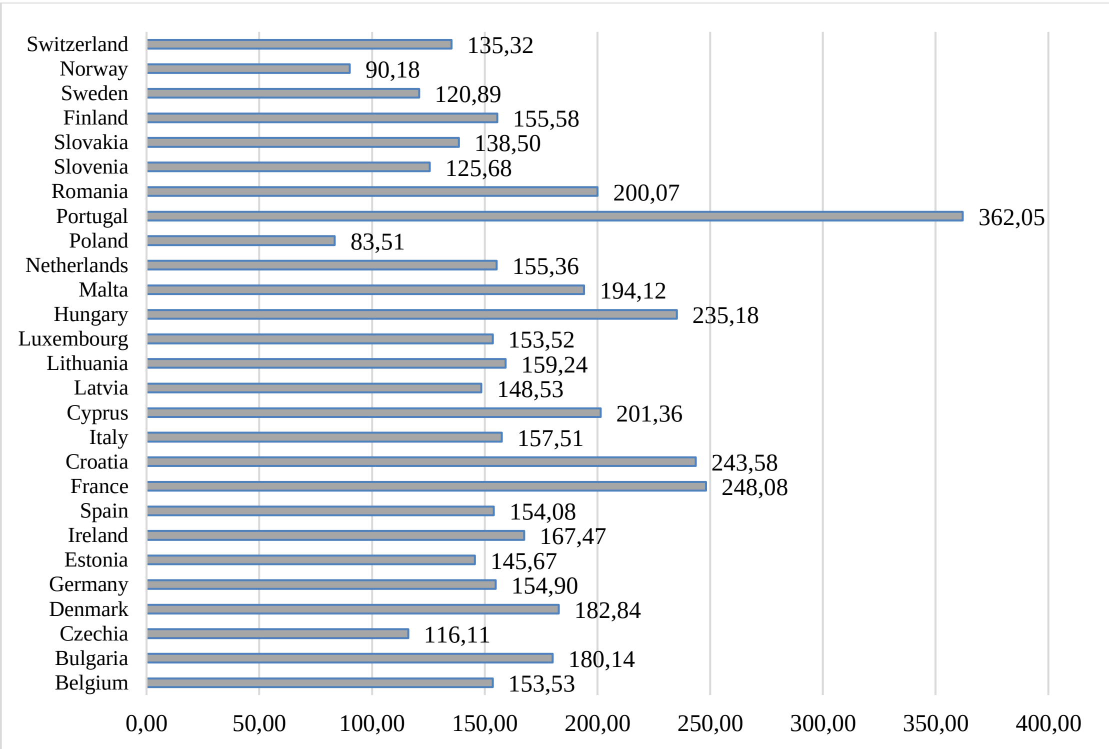

Figure 6. Calculation of the rates of growth (decline) in the use of organic farmland in European countries in 2021 compared to 2014, %, source: calculated by the authors according to (Eurostat, 2021).

Therefore, the calculated rates of growth (decline) in the use of organic farmland in European countries in 2021 compared to 2014 show that the prevailing majority of countries shown in Fig. 6 expanded the area of their farmland for the production of organic products. Thus, the highest respective growth rates were recorded in the following countries: Portugal – 362.05%; France – 258.08%; Croatia – 243.58%; Hungary – 238.15. Among the above countries (Poland and Norway), there is a decline in the rate of growth. Figure 7 shows the calculation of the increment (decrement) in the use of organic farmland in European countries in 2021 compared to 2014.

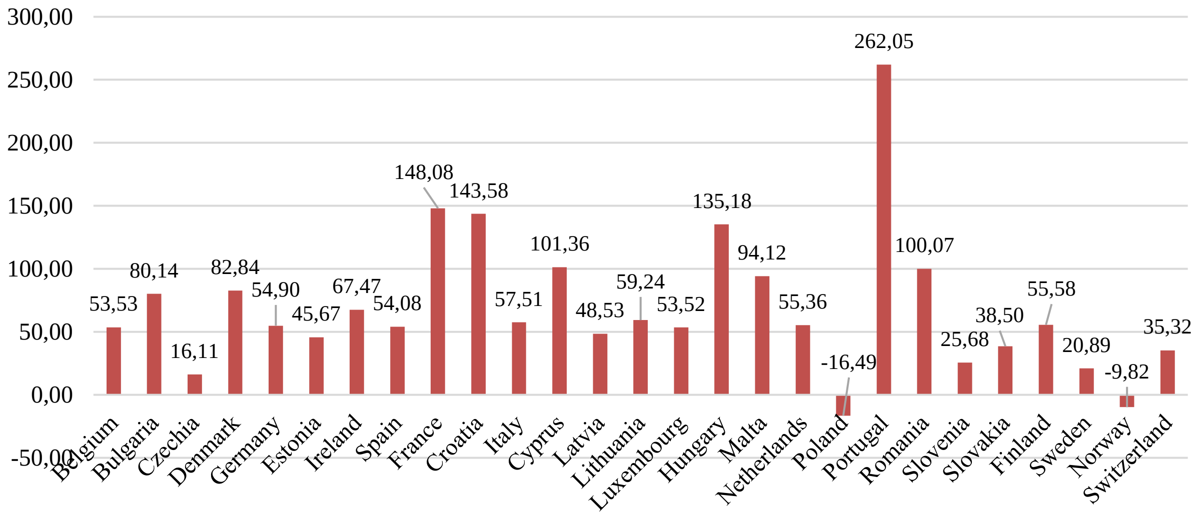

Figure 7. Calculation of the increment (decrement) in the use of organic farmland in European countries in 2021 compared to 2014, %, source: calculated by the authors according to (Eurostat, 2021).

The data in Fig. 7 shows that Portugal, which increased the use of organic areas by 2.62 times, is the leader among the countries that expanded the area of organic farmland in Europe in 2021 compared to 2014. It is followed by France, Croatia and Hungary – by about 1.5 times each. Cyprus, respectively, increased them by 101.36%; Romania by 100.07%; Malta by 94.12%; Bulgaria and Denmark by more than 80%; Ireland by 67.47%; Belgium, Germany, Spain, Luxembourg and Finland by more than 50%. Countries such as Poland and Norway reduced the use of organic land in 2021 compared to 2014 by 16.49% and 9.82%, respectively.

4.3. Impact of expanding the area of organic farmland on GHG emissions

In order to study the impact of the expansion of organic farmland (x) on GHG emissions (Y), a correlation and regression analysis was utilized to build regression equations (formula 1) and summarize the results in Table 1.

The study of the impact of the expansion of organic farmland (x) on GHG emissions (Y), based on the correlation and regression analysis, revealed a relationship between (x) and (Y). This relationship is ambiguous for individual European countries. In general, if we take the average values of the EU member states (27), the relationship between the expansion of organic farmland and GHG emissions is quite strong. If we take into account only one factor of influence – the expansion of organic farmland on GHG emissions (Y) in the EU27 countries, then, as the correlation and regression equation (Table 1) shows, with an increase in the area of organic farmland by 1%, GHG emissions increased by 0.00000025 thousand tons. The constructed correlation-regression equation on average for the EU-27 countries (Table 1) is characterized by the following parameters: r = 0.790; D = 0.624; Fisher's coefficient (F = 3.149) is greater than the normative (tabular) value (Ft = 2.447); that is, (F > Ft); z = 1.07; Se = 0.45; C_95% = 1.96; rL = 0.19; rU = 0.96. Thus, GHG emissions (ceteris paribus) are 62.4% influenced by the expansion of organic farmland in the EU-27, and the remaining 37.6% are influenced by other factors. This equation shows that this influence is positive and directly proportional, and the correlation-regression equation built for the EU-27 countries on average is objective and corresponds to real economic processes and phenomena.

Among the European countries listed in Table 1, similar trends are observed in the following countries: Denmark, Germany, Estonia, Spain, the Netherlands, Portugal, Romania, Finland, Switzerland, and the United Kingdom. For example, for Germany, the correlation-regression equation (Table 1) is characterized by the following parameters: r = 0.88; D = 0.774; Fisher's coefficient (F = 4.602) is greater than the normative (tabular) value (Ft = 2.447); that is, (F > Ft); z = 1.39; Se = 0.45; C_95% = 1.96; rL = 0.47; rU = 0.98. Thus, GHG emissions in Germany (ceteris paribus) are 77.4% influenced by the expansion of organic farmland, and the remaining 22.6% are influenced by other factors. This equation shows that this influence is positive and directly proportional, and the correlation-regression equation for Germany is objective and corresponds to real economic processes and phenomena.

With a 1% increase in the area of organic farmland, GHG emissions could potentially increase by 0.00000140 thousand tons.

Table 1. Study of the impact of expanding the area of organic farmland (x) on GHG emissions (Y), source: compiled based on statistical data (Eurostat. 2021).

Country	r	D	F	F_t	z	S_e	C_95%	rL	rU	Equation
Belgium	0.30	0.090	0.773		0.31			-0.51	0.83	Y = 7.53 + 0.00000595x
Bulgaria	0.05	0.003	0.128		0.05			-0.68	0.73	Y = 10.58 + 0,00000124x
Czechia	0.66	0.436	2.174		0.80			-0.08	0.93	Y = 3.13 + 0,00000627x
Denmark	0.84	0.706	3.800		1.22			0.33	0.97	Y = 16.43 + 0,00003276x
Germany	0.88	0.774	4.602		1.39			0.47	0.98	Y = 5.20 + 0,00000140x
Estonia	0.71	0.504	2.465		0.89			0.01	0.94	Y = -3.81 + 0,00006646x
Ireland	0.44	0.194	1.214		0.48			-0.38	0.89	Y = 27.64 + 0,00008346x
Spain	0.77	0.593	2.915		0.77			0.13	0.96	Y = 4.37 + 0,00000275x
France	0.50	0.250	1.419		0.55			-0.31	0.89	Y = 14.58 + 0,00000048x
Croatia	-0.59	0.348	1.802		-0.68			-0.92	0.19	Y = 11.46 − 0,00000497x
Italy	0.62	0.384	1.912		0.72			-016	0.92	Y = 5.43 + 0,00000110x
Cyprus	0.62	0.384	1.920		0.72			-0.16	0.92	Y = 4.01 + 0,00031431x
Latvia	0.31	0.096	0.795		0.32			-0.51	0.83	Y = 16.98 + 0,00000924x
Lithuania	-0.69	0.476	2.360		-0.86			-0.94	0.02	Y = 24.71 − 0,00001404x
Luxembourg	0.43	0.185	1.163	2.447	0.46	0.45	1.96	-0.40	0.87	Y = 4.92 + 0,00017564x
Hungary	0.45	0.203	1.233		0.48			-0.37	0.88	Y = 10.46 + 0,00000169x
Malta	0.33	0.109	0.852		0.34			-0.49	0.89	Y = 3.07 + 0,00781421x
Netherlands	0.80	0.640	3.310		1.11			0.23	0.96	Y = 6.98 + 0,00004330x
Poland	-0.02	0.0004	0.057		-0.02			-0.72	0.69	Y = 8.45 − 0,00000014x
Portugal	0.75	0.56	2.806		0.98			0.10	0.95	Y = 9.10 + 0,00000460x
Romania	0.75	0.56	2.802		0.98			0.10	0.95	Y = 15.44 + 0,00000242x
Slovenia	0.46	0.211	1.286		0.50			-0.36	0.88	Y = 7.78 + 0,00005923x
Slovakia	-0.05	0.003	0.118		-0.05			-0.73	0.68	Y = 6.37 − 0,00000074x
Finland	0.76	0.578	2.846		0.99			0.11	0.95	Y = 6.96 + 0,00001673x
Sweden	0.59	0.348	1.813		0.69			-0.19	0.92	Y = 5.93 + 0,00001178x
Norway	-0.83	0.689	3.591		-1.18			-0.97	-0.29	Y = 19.53 − 0,00023164x
Switzerland	0.74	0.548	2.720		0.96			0.08	0.95	Y = 8.04 + 0,00002304x
European Union - 27 countries	0.79	0.624	3.149		1.07			0.19	0.96	Y = 7.05 + 0,00000025x

In such countries as Lithuania and the Netherlands, an inverse relationship between the expansion of organic farmland and GHG emissions is observed. For example, in Norway, with a 1% increase in organic farmland, GHG emissions will decrease by 0.00023164 thousand tons. GHG emissions (ceteris paribus) are 68.9% influenced by the expansion of organic farmland in the Netherlands, and the remaining 31.10% are influenced by other factors. Using Lithuania as an example, with a 1% increase in the area of organic farmland, GHG emissions will decrease by 0.00001404 thousand tons. The corresponding factor of influence on Y, ceteris paribus, is 47.6%, and the remaining 52.40% is influenced by other factors. The visualization of the results of the study of the impact of the expansion of organic farmland on GHG emissions according to the data (Table 1) is shown in Fig. 8. It shows the interpretation of the correlation coefficient, which shows the level of strength of the relationship: r>0.01<0.29 – weak positive correlation, r>0.30<0.69 – moderate positive correlation, r>0.70<1.00 – strong positive correlation, r-0.01<-0.29 – weak negative correlation, r>-0.30<-0.69 – moderate negative correlation, r>-0.70<-1.00 - strong negative correlation. Weak correlation is indicated in green in Fig. 8, moderate correlation is indicated in yellow, and strong correlation is indicated in orange.

Thus, a positive and strong relationship between the expansion of organic farmland and GHG emissions in European countries in 2014-2021 was recorded in the following countries: Germany (0.88); Denmark (0.84); the Netherlands (0.80); Spain (0.77); Portugal and Romania (0.75); Switzerland (0.74); Estonia (0.71). For these countries, it can be said that given one factor of influence – the area of organic farmland – the relationship is close and reliable, which has an impact on GHG emissions in Europe. An inverse but close and reliable relationship was recorded in Norway (*minus* 0.83). That is, with the growth of agricultural areas for the production of organic products, GHG emissions will decrease.

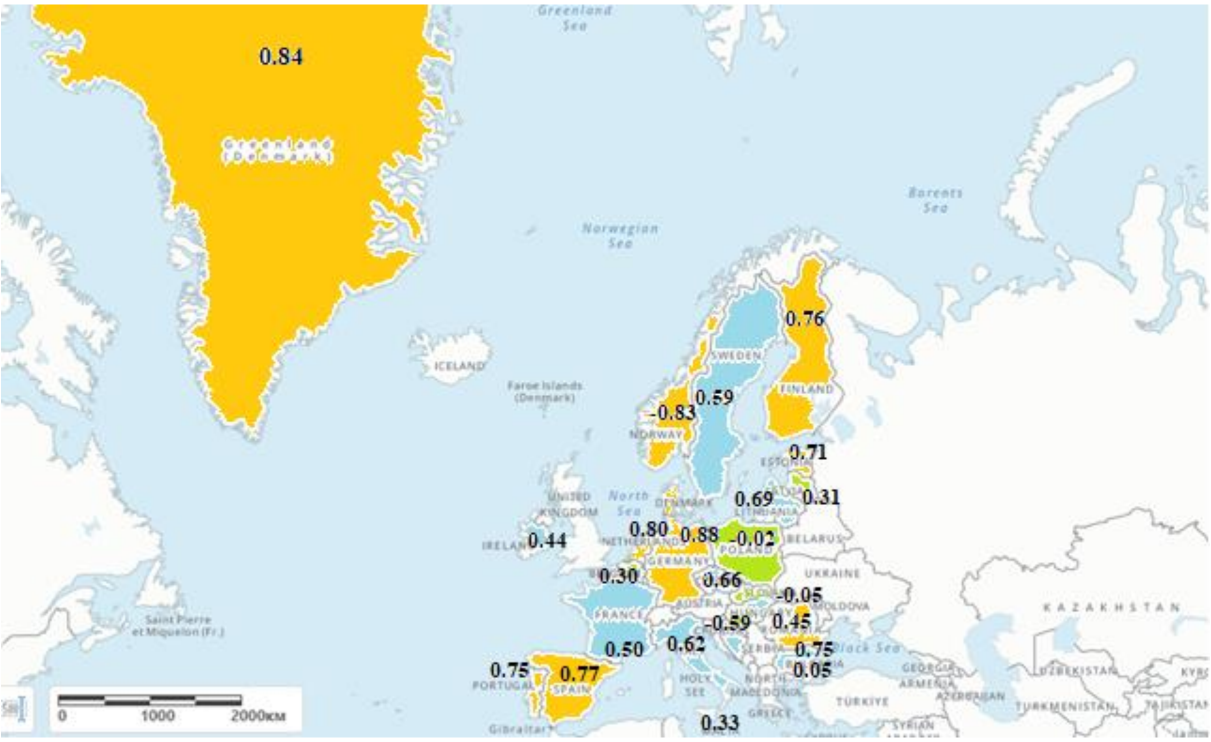

Figure 8. Visualization of the degree of relationship between the expansion of organic farmland and GHG emissions in European countries in 2014-2021, source: calculated by the authors according to (Eurostat, 2021).

4.4. Discussion of results

Today, the study of the relationship between the expansion of organic farmland and GHG emissions in the world, particularly in Europe, is relevant, controversial, and promising. After all, an important factor of sustainable development is overcoming hunger, ensuring environmental safety, etc., which requires a change in emphasis in the management of the agro-industrial complex, in particular in the field of agriculture. It is crucial to acknowledge that all seventeen Sustainable Development Goals are of paramount importance. However, agriculture plays a pivotal role in addressing global challenges, including hunger, climate change and biodiversity loss. In practice, as evidenced by the results of numerous studies referenced in the literature review, there is no consensus regarding the most effective means of addressing specific Sustainable Development Goals through the introduction of organic agriculture. In essence, the issue under study is directly or indirectly pertinent to each of the 17 Sustainable Development Goals. This issue is the subject of considerable debate, but it is nevertheless worth noting that, according to the data (Nature & More, 2024), organic farming has a positive impact on at least eight of the seventeen Sustainable Development Goals, including Goals 2, 3, 6, 8, 12, 13, 14 and 15. Agriculture as an important sector of the economy produces GHG emissions (CO_2, N_2O, CH_4) into the atmosphere (Chataut et al., 2023; Arcipowska et al., 2019; Verschuuren et al., 2022; Zaman et al., 2021; Gomiero et al., 2011), which affects climate change and is an obstacle to further sustainable development. The EU countries have set an ambitious goal to reduce GHG emissions by 55% by 2030 and to achieve zero GHG emissions by 2050 (Filipovic et al., 2022). At the same time, an important priority should be to change traditional farming methods to organic ones, which are environmentally friendly. This raises the question of whether it is possible to provide the world's ever-growing population with food with the existing agricultural areas and the use of organic farming (World Population Statistics, 2019).

On the one hand, many researchers believe that growing crops using organic approaches will reduce GHG emissions and that there is a positive relationship between organic farming and the environment (Smith et al., 2000; Fritsche et al., 2007; Bos et al., 2014; Scialabba & Muller-Lindenlauf, 2010; Avasiloaiei, et al., 2023; Chiriacô et al., 2017; Squalli & Adamkiewicz, 2018; Squalli & Adamkiewicz, 2018; Mattila et al., 2022; Paustian et al., 2019; Gomiero et al., 2008; Kustermann, Hulsbergen, 2008; Wood et al., 2006). At the same time, a plethora of researchers argue that the correlation is negative, and scientists (Syvasalo et al., 2006) believe that there is no statistically significant difference between organic and conventional farming methods. The issue of reducing GHG emissions through the expansion of organic farmland remains important and controversial.

Some studies emphasize that a one percent increase in agricultural area for organic farming would potentially reduce GHG emissions by 0.049% (Squalli & Adamkiewicz et al., 2018). Other studies argue that such expansions are dangerous. For example, a large-scale increase in the agricultural area for organic farming is likely to increase GHG emissions (CO_2) and reduce the global carbon sequestration capacity (Omotoso, A., & Omotavo, 2024). In addition, there are studies claiming that to realize the ambitious goal of transitioning to 100% organic farming, a significant expansion of farmland will be needed (van der Werf et al., 2020; Smith et al., 2019). The expansion of the relevant areas can provoke detrimental impacts on the ecosystem, in particular through deforestation, water drainage, etc. (Tscharntke et al., 2021); land degradation and soil erosion (Rahmann et al., 2017). In addition, these processes can also negatively affect socioeconomic processes, in particular, farmers are likely to encounter difficulties when realizing their land tenure (Zoomers et al., 2017); farmers' limited financial resources and lack of access to credit for land acquisition (Rahmann et al., 2017); forced migration of residents to other places and deterioration of their financial, economic and social situation (D'Odorico et al., 2017).

Thus, there is no consensus on this dilemma in the reviewed literature. Therefore, the paper formulates and tests the hypothesis of an empirical study of the impact of the expansion of organic farmland on the increase in GHG emissions in European countries. Based on the use of statistical data on European countries and correlation and regression analysis, the results obtained show that in general, an increase in the area of organic farmland will increase greenhouse gas emissions. The relationship is ambiguous for individual European countries. But, on average, for the E-27 countries, this impact is positive and directly proportional, strong, and the constructed correlation-regression equation is objective and corresponds to real economic processes and phenomena. It was found that the impact of one factor – the expansion of organic farmland by 62.4% affects greenhouse gas emissions in the EU-27 countries. Provided that the area of organic farmland increases by 1%, GHG emissions will potentially increase by 0.00000025 thousand tons in the EU-27.

In order to minimize the impact of GHG emissions from agriculture, it is necessary to focus on intensive factors, rather than on extensive factors such as the expansion of land for organic land use. (Ondrasek et al., 2023; Chataut et al., 2023; Omotoso A., & Omotavo, 2020; Smith et al., 2019; Selvan et al., 2021). Owing to this, it be possible to optimize the amount of resources used, improve the *health* of the soil, ensure environmental friendliness and food safety, and improve the well-being of people, animals, and plants. At the same time, when using organic farming, strategies should be used to change consumer attitudes, in particular in the field of nutrition; increase the efficiency of technologies, methods and equipment, machinery and mechanisms in the field of agriculture; rational use of food waste (Basnet et al., 2023), etc.

6. Conclusion

There are a number of significant advantages associated with organic agriculture in comparison to conventional farming methods. If managed effectively, organic agriculture has the potential to achieve socio-economic and environmental efficiency in line with the Sustainable Development Goals. In particular, this applies to the implementation of the following goals: Goal 2: Zero Hunger; Goal 3: Good health and well-being; Goal 6: Clean water and sanitation; Goal 8: Decent work and economic growth; Goal 12: Responsible consumption and production; Goal 13: Climate action; Goal 14: Life below water; Goal 15: Life on land. Moreover, indirectly, the expansion of farmland will have a multiplier effect on other Sustainable Development Goals. Based on the purpose of the study, the impact of the expansion of organic farmland on GHG emissions in European countries was identified. The study of this relationship between one influencing factor – the expansion of organic farmland and the resultant indicator – GHG emissions in European countries – revealed common features and differences between the considered European countries: Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Ireland, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, Norway, Switzerland, European Union – 27 countries in 2014-2021 based on the statistical database of the official Eurostat website.

The common thread in the study is that, in general, there is a strong relationship between the expansion of organic farmland and GHG emissions in European countries. According to the data of all EU member states (27), the relationship is strong. The correlation and regression analysis conducted in the study allowed us to build linear regression equations. Based on this, a conclusion was made that with an increase in the area of organic farmland by 1%, GHG emissions will increase in the EU27 by 0.00000025 thousand tons. The constructed correlation-regression equation for the EU-27 countries is objective and corresponds to real economic processes and phenomena. It was found that GHG emissions constituted 62.4% and were affected by the selected factor – the expansion of organic farmland. Among the individual European countries studied in the article, similar trends were recorded, in particular in Denmark, Germany, Estonia, Spain, Portugal, Romania, Finland, Switzerland, and the United Kingdom. In such countries as Lithuania and the Netherlands, an inverse relationship between the expansion of organic farmland and GHG emissions is observed. For example, in Norway, with a 1% increase in organic farmland, GHG emissions will decrease by 0.00023164 thousand tons. In Lithuania, with an increase in organic farmland by 1%, greenhouse gas emissions will decrease by 0.00001404 thousand tons.

The relationship between the expansion of organic farmland and GHG emissions in European countries, as evidenced by the calculated correlation coefficient, is weak in Bulgaria (0.05); Poland (0.02); and Slovakia (0.05).

Thus, the paper confirms the research hypothesis that, in general, an increase in the area of organic farmland will increase GHG emissions Therefore, to implement the Sustainable Development Goals, in particular, to overcome hunger, ensure food security, and create conditions for environmental development, it is necessary, along with the gradual expansion of organic farmland, to take measures to change the culture of food consumption; to increase the efficiency of agricultural technologies, methods and equipment, machinery and mechanisms; to rationally use the waste; to be mindful about food consumption, etc.

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