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# Economic and Climate Efficiency of Agriculture in the EU

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## 1. Introduction

Earth's climate is warming up - the average global temperature compared to the period 1850-1900 increased by almost 1°C (274.15K) (WMO, 2017). The problem, which became apparent to most people in recent years, has already been the subject of scientific research. Their results are unequivocal - observed global temperature rise caused by the greenhouse effect. It is caused by the increase in greenhouse gas emissions from anthropogenic sources since the beginning of the industrial revolution. The use of fossil fuels and other human activities led to a situation where the $CO_2$ concentration is 143% in comparison to the level before the industrial revolution (254% for $CH_4$ and 121% for $N_2O$, respectively). The most recognized international organization in the field of climate change research – Intergovernmental Panel on Climate Change (IPCC) stated that "it is extremely likely that more than half of the observed increase in global average surface temperature is due to human-related greenhouse gas concentrations" (IPCC 2013). An increase in temperature is not the only and worst effect of climate change. This process also leads to an increase in the level of water in the oceans and an increase in the frequency of extreme weather phenomena (drought, floods, tornadoes) and many other destructive effects on life on earth.

The article aimed to determine the level of greenhouse gas emissions in agriculture and the economic and climate effectiveness of agriculture in EU countries in comparison to other sectors of the economy.

The following research questions were adopted:
What changes in greenhouse gas (GHG) emissions in agriculture have occurred in recent years?
Which countries in the EU have agriculture with the highest economic and environmental efficiency?

## 2. Research basis

### 2.1. Climate change and greenhouse gas emissions

The year 2019 was the warmest in the history of measurements in Europe, and the temperature anomaly calculated to the reference period 1980-2010 was 2°C (275.15K).

Climate change will have a major impact on natural ecosystems, which may have the ability to adapt to climate change, but not as rapidly as it is today. Climate change may also harm agricultural development, including (Sulewski & Czekaj 2015):

- plant growth and crop yields,
- changes in the frequency of atmospheric phenomena with catastrophic effects (heat, drought, floods),
- shifts of the vegetation zone of plants by 300-800 km to the north and 500 m up in the mountains,
- increased risk of fungal diseases and weeds for crops,
- increasing the area of crops requiring irrigation,
- increasing water salinity,
- fall in yields in Africa, Central America, India and Southeast Asia,
- increase in the number of people exposed to hunger by 400 million,
- increasing the frequency of forest fires,
- the disappearance of some species of animals living in the coastal zone,
- the loss of many marine mammals living in Arctic and Antarctic waters.

Given these issues, reducing greenhouse gas emissions is becoming an increasingly important problem. According to scientists' warnings, the world has less and less time to take appropriate actions. Therefore, after long negotiations, on December 12, 2015, during the Paris climate conference, nearly 200 countries adopted an agreement aimed at halting global warming. The most important provisions of the agreement are included in art. 2 Convention (United Nations 2015). It assumes maintaining a temperature rise below the 2°C limit compared to pre-industrial times and making efforts to limit the increase to 1.5°C. In art. 4 of the Convention stipulates that to achieve these objectives, countries undertake to reduce current greenhouse gas emissions as soon as possible until a balance is reached between anthropogenic emissions and the uptake of these gases. This balance is to be achieved in the second half of the 21st century. However, attempts to withdraw from some agreements and question their legitimacy are very worrying.

## 2.2. Agriculture and greenhouse gas emissions

Agriculture is responsible for almost one third of anthropogenic emissions that cause climate change, including about 50% of methane ($CH_4$) emissions and 70% of $N_2O$ emissions – mainly from the fermentation of ruminants, excrements, rice cultivation and nitrogen fertilizers (McIntyre et al. 2009). Methane is largely a by-product of agriculture (rearing of ruminants, rice cultivation), while nitrogen oxides are formed during wood burning, fossil fuels, and the use of nitrogen fertilizers. Industrial agriculture plays a shameful role in this respect (Gołębiewska & Pajewski 2016), being responsible for the excessive use of pesticides, including dichlorodiphenyltrichloroethane (DDT), poisoning of soils and waters with nitrogen compounds and the use of problematic genetically modified organisms (GMOs). It should be remembered that thanks to it the problem of food scarcity was solved (at least in developed countries).

Assuming that current trends are maintained, the reduction of greenhouse gases in agriculture by 2050 compared to 1990 is to amount to almost 50% (see Table 1) (European Commission 2011). One should bear in mind that some of the sectors as e.g. transport is one of the most important factors for development of the regions (in particular sustainable development), which enables the creation of new businesses or supports contacts with other regions (Gnap et al. 2019), nevertheless this sector is obliged for changes in greenhouse gas emission as well (Jacyna et al. 2018). Modelling of GHG gases diffusion is also an important aspect to consider, allowing to predict the spread and possibly impact of sources of GHG on the environment (Piekarski & Kowalska 2017).

**Table 1.** The planned reduction of greenhouse gas emissions by sector in EU countries in 2030-2050 compared to 1990

| Reduction of greenhouse gas emissions compared to 1990 | Gas reduction level (%) | |
|---|---|---|
| | 2030 | 2050 |
| Whole | -40 to -44 | -79 to -82 |
| By sector | | |
| Energetics | -54 to -68 | -93 to -99 |
| Industry | -34 to -40 | -83 to -87 |
| Transport | +20 to -9 | -54 to -67 |
| Residential and commercial buildings | -37 to -53 | -88 to -91 |
| Agriculture | -36 to -37 | -42 to -49 |
| Gases other than $CO_2$ | -72 to -73 | -70 to -78 |

Source: European Commission 2011, 6.

Agriculture plays an important role in the fight for climate and world stability. As a branch of the global economy, it stood at the crossroads associated with the paradigms on which its functioning is to be based.

The industrial model began to run out, as it consumed increasing expenditure, both financial and non-renewable resources, and caused more and more negative externalities. Fotyma & Krasowicz (2007) recognize the year 1992 (ecological summit in Rio de Janeiro) and the first major reform of the Common Agricultural Policy (CAP), introducing the obligation to set aside some land and to protect the environment, as the symbolic end of the era of industrial agriculture. Further actions within the EU have deepened the pro-environmental attitude of agriculture. Subsequently, agriculture was included in the climate policy, both in terms of reducing greenhouse gas emissions and their absorption (sequestration).

There are two main development paths that post-industrial agriculture can follow.

Intensive agriculture, but subjected to ecological restrictions. It is to be both competitive in terms of food prices and meet basic environmental standards (cross-compliance, animal welfare standards introduced by CAP mechanisms). It is a kind of balancing the interests of farmers, consumers and environmental issues, which do not lead to rapid changes in the modern model of agriculture.

Sustainable agriculture (Zegar 2012), which is the expression of a broader paradigm of the functioning of the world economy based on sustainable development. This approach can be used in almost all fields and departments of agriculture. However, it is very important to choose the right direction of production, adapted to natural conditions, and the correct location and scale of production. These are the basic factors differentiating sustainability and contributing to improving production efficiency, and thus achieving the objectives of sustainable agriculture (Mańko et al. 2007).

Given these assumptions, agriculture must be actively involved in the fight against climate change. It is necessary to identify the current position of agriculture and the efficiency of using traditional factors of production and greenhouse gas emissions.

## 3. Materials and methods

### 3.1. Sources for materials

The research was based on materials and secondary data from EUROSTAT. To determine the economic and climate efficiency of agriculture in European countries in 2016 the Data Envelopment Analysis (DEA) method was used.

### 3.2. Data Envelopment Analysis

The Data Envelopment Analysis method is classified as nonparametric methods for testing the effectiveness of objects. In 1978, the authors of the DEA method (Charnes et al. 1978), based on the concept of productivity formulated by Debreu and Farell, defining the measure of productivity as a quotient of a single effect and single effort, applied it to a multidimensional situation, in which there are more than one effort and more than one effect (Charnes et al. 1978). Mathematically, the DEA model can be presented in the following way (Charnes et al. 1978):

objective function:

$$\max_{u,v} \frac{\sum_{r=1}^{s} \mu_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \tag{1}$$

under the following limiting conditions:

$$\frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad (j = 0,1,\dots,n) \qquad \mu_r, v_i \geq 0 \tag{2}$$

$$\frac{\mu_r}{\sum_{i=1}^{m} v_i x_{io}} \geq \varepsilon \quad for \quad r = 0,1,\dots,s \tag{3}$$

$$\frac{v_i}{\sum_{i=1}^{m} v_i x_{io}} \geq \varepsilon \quad for \quad i = 0,1,\dots,m \tag{4}$$

where:
$s$ – number of effects,
$m$ – number of inputs,
$\mu_r$ – weights determining the importance of individual effects,
$v_i$ – weights determining the importance of individual inputs,
$y_{rj}$ – the size of the $r$-th effect ($r$ = 1, …, $s$) in the $j$-th object,
$x_{ij}$ – the size of the $i$-th type ($n$ = 1, …, $N$) in the $j$-th object; ($j$ =1, …, $n$).

The DEA method allows the study of the relationship between the level of many inputs and many effects. In the DEA model $m$ inputs and $s$ different effects boil down to single sizes of "synthetic" input and "synthetic" effect, which are then used in calculating the object efficiency index (Roll & Hayuth 1993).

The effectiveness of the object is measured relative to other objects from the studied group and takes values from the interval (0,1). In the DEA method, the objects of analysis are Decision Making Units (DMU), which can be companies, sectors, countries (Charnes et al. 1994) (see Figure 1). The subject of the analysis is the effectiveness with which a given DMU transforms its inputs into results.

Nonparametric methods, including the DEA method, are used to analyse the effectiveness of various objects. The DEA method was most commonly used to investigate the effectiveness of banks (Berger & Humphrey 1997, Brockett et al.

1997), insurance institutions (Fukuyama & Weber 2001), educational institutions (Hu & Kao 2007, Saunders 2003), hospitals (Jacobs et al. 2006, O'Neil & Dexter 2005), farms (Galanopoulos et al. 2006), as well as industries of various types.

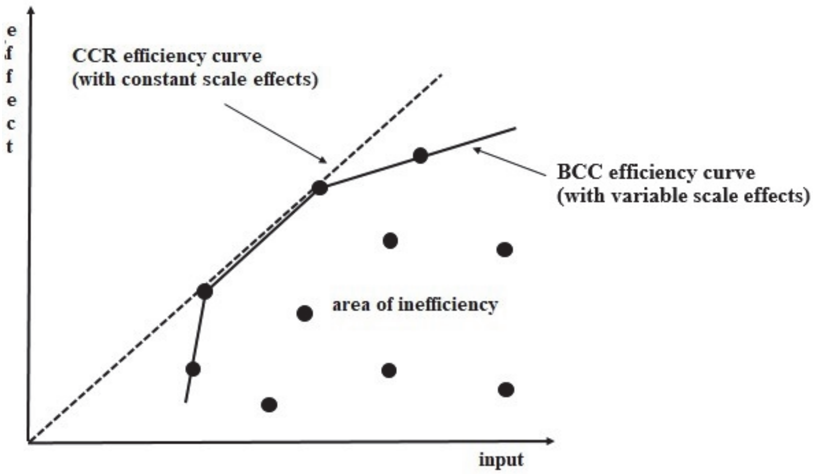


**Fig. 1.** CCR (Charnes, Cooper and Rhodes) efficiency curve (with constant scale effects) and BCC (Banker, Charnes and Cooper) efficiency curve (with variable scale effects), model with 1 effect and 1 input
Source: Charnes et al. (1994)

DEA models are increasingly used in economic and environmental analyses. This approach was presented in research, among others Ramanathan (2005), Zhou et al. (2007), Bian & Yang (2010) and Song & Wang (2014).

## 4. Results and discussion

Greenhouse gas emissions from agriculture in the entire EU in 2016 were estimated at 436 million tons of $CO_2$ per year, representing a decrease of almost 23% compared to 1990. This decline was particularly evident in the last decade of the last century, but it slowed down later. This was caused by a decrease in the use of nitrogen fertilizers, a decrease in the head of livestock and the implementation of EU environmental policy (Felman 2015). The introduction of the Nitrates Directive, which aimed to reduce water pollution by nitrogen compounds from agricultural production, also played an important role. The directive introduced quantitative and quantitative limits for the use of organic fertilizers. Also milk production quotas, limiting the size of cow population had a direct impact on stabilizing greenhouse gas emissions in agriculture (Syp 2017).

The absolute decline in emissions in agriculture is comparable to other sectors (-24% – energy, -28% – industry, -34% – waste management). The share of agriculture in total EU emissions throughout the period considered remains at the same level of 10% (see Figure 2). In the individual Member States, the changes were more diverse. In the EU, the largest greenhouse gas emitters in agriculture were France – 87 million tons and Germany – 72 million tons.

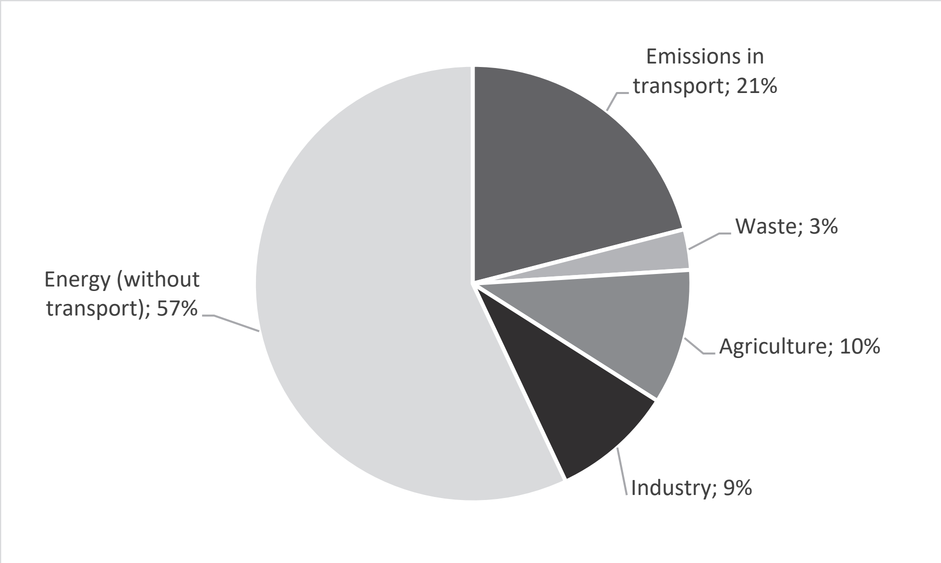


**Fig. 2.** Share of greenhouse gas emission sources in the EU in 2016
Source: Own study based on Eurostat

Except for Spain, each of the Member States reduced agricultural greenhouse gas emissions in 1990-2016 (see Figure 3). The largest absolute decrease was recorded in Germany (-18 million tons of $CO_2$), Romania (-17 million tons of $CO_2$) and Poland (-15 million tons of $CO_2$).

To assess individual elements of the EU economy, taking into account not only greenhouse gas emissions but also other variables, the DEA method was used and an attempt was made to determine the effectiveness of individual sectors of the EU economy by NACE2 category[1]. A model focused on maximizing the

[1]Statistical Classification of EconomicActivities in the EuropeanCommunity, Rev. 2 (NACE Rev. 2) (Nomenclaturestatistique des activitéséconomiquesdans la Communautéeuropéenne), the revisedclassification was adoptedat the end of 2006 – the firstreferenceyear for NACE Rev 2 statisticsis 2008.

CCR (Charnes, Cooper and Rhodes) output was adopted. Greenhouse gas emissions have been treated as an input in connection with the idea of a carbon budget. According to it, there is a limited amount of greenhouse gases that can be emitted by humanity to limit the temperature rise to a certain level [1.5-2.0°C (274.65-275.15K)] according to the Paris Agreements. With this approach, greenhouse gas emissions are a resource whose use affects the efficiency of a given sector of the economy. The following variables were used in the CCR DEA profile:

- output $y$ – gross value added (euro),
- input $x_1$ – number of employees,
- input $x_2$ – greenhouse gas emissions (tons of $CO_2$ equivalent).

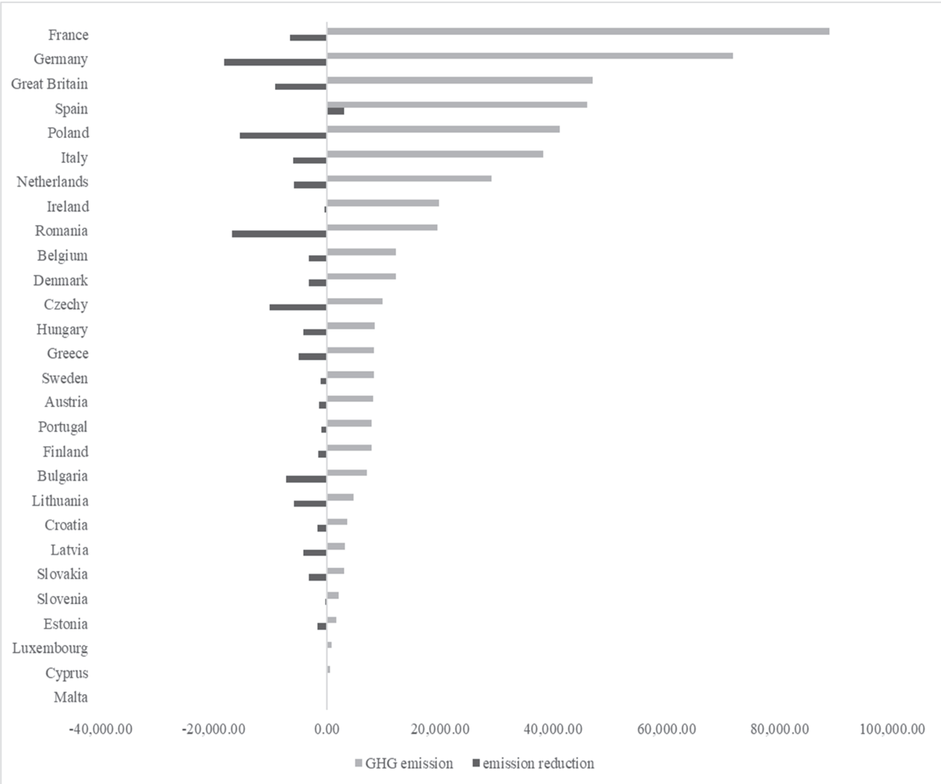


**Fig. 3.** Emissions in 2016 and changes in agricultural emissions of the Member States in 1990-2016; Source: Own study based on Eurostat

Comparing individual sectors of the economy, it should be noted that there are very large differences in their efficiency (see Figure 4). It was examined that in agriculture economic and climate efficiency was only at the level of 0.034, which is dramatically low compared to the fully effective sector. Very low efficiency was also recorded in construction (0.076) or wholesale and retail trade (0.077).

The next stage of the research was determining the level of agricultural efficiency in individual EU countries. In the initial phase of calculations, Malta and Luxembourg were eliminated, which due to their very specific structure of agriculture disturbed the obtained results. As part of the CCR DEA profile based on literature studies (Bórawski et al. 2019), the following variables were adopted:

- output $y$ – gross value added (euro),
- input $x_1$ – UAA (ha),
- input $x_2$ – number of employees,
- input $x_3$ – greenhouse gas emissions in agriculture (tons of $CO_2$ equivalent).

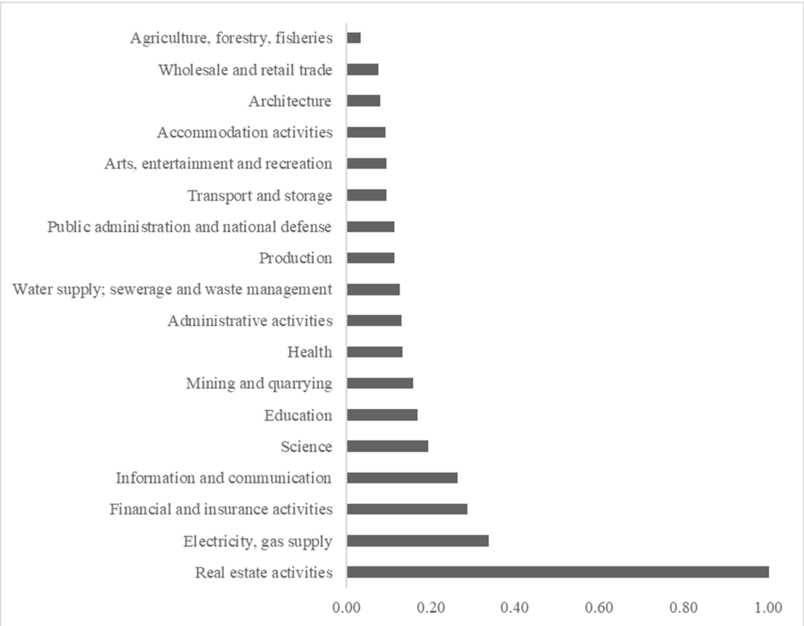


**Fig. 4.** Economic and climate efficiency of sectors of the economy in the EU (DEA)
Source: Own study based on Eurostat.

The calculations used data from the Eurostat database. The results of the calculations are presented in Figure 5. A ranking of countries was created starting from those with the least efficiency.

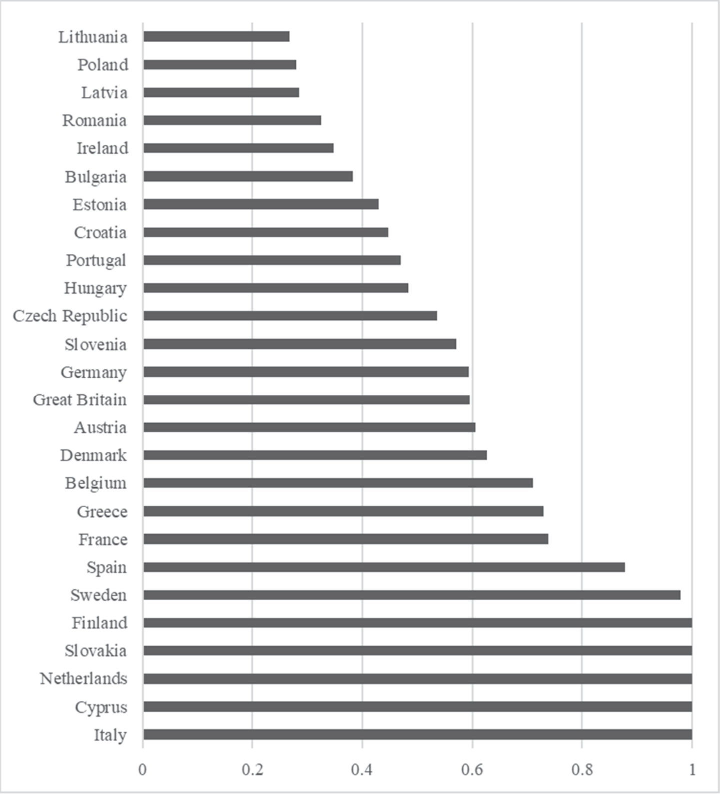


**Fig. 5.** Economic and climatic efficiency of agriculture in EU countries (DEA)
Source: Own study based on Eurostat.

The average agricultural efficiency of the studied countries was at a high level of -0.626. Considering the inputs and outputs applied, agriculture in five countries: Italy, Cyprus, the Netherlands, Slovakia and Finland should be considered as fully effective (benchmark). Polish agriculture, with an efficiency of 0.28, next to Lithuanian 0.267, was at the end of the ranking. The best countries achieve the same results as Poland, using only 28% of resources.

For future research mathematical, numerical or simulation model for the described research may be elaborated according to the structure presented in literature (e.g. Kostrzewski 2020, Kostrzewski 2017, Chamier-Gliszczyński 2017). However, it will be huge scale research which needs various types of data elaboration.

## 5. Conclusions

Climate change is a phenomenon that will affect all sectors of the European economy. Surprisingly, EU level regulations aimed at reducing GHG emissions may have a major impact on these changes. In connection with the above, it is important to determine what path agriculture has taken over the background of other departments and what is its climatic efficiency when using resources. The conducted research allowed us to accept the following conclusions:

1. In 1990-2016, agriculture accounted for around 10% of EU greenhouse gas emissions, despite the reduction of emissions by around 23% over the period considered. The constant share of agriculture resulted from a similar level of decline in emissions in other sectors of the economy.
2. During the period considered, each of the Member States, except for Spain, reduced its greenhouse gas emissions in agriculture. The largest absolute decrease was recorded in Germany (-18 million tons of $CO_2$), Romania (-17 million tons of $CO_2$) and Poland (-15 million tons of $CO_2$).
3. Agriculture has the lowest economic and climate efficiency of all sectors of the economy in the EU studied.
4. Comparing the agriculture of individual countries, it was observed that the highest economic and climate efficiency was achieved in such countries as Italy, Cyprus, the Netherlands, Slovakia and Finland. Poland, apart from Lithuania and Latvia, was among the three countries with the lowest efficiency.

The climatic efficiency of agriculture is at the lowest level among other sectors of the economy. However, it should be born in mind that it provides the most important products necessary for the functioning of society – food. All kinds of activities contributing to reducing GHG emissions in agriculture must take this into account, as well as the fact that since 1990 significant reductions have been made.

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## Abstract

The article in the theoretical part draws attention to the phenomenon of climate change and two-way relations between these changes and agriculture. Agriculture as an economic sector is extremely sensitive to any climatic disturbances. However, as a greenhouse gas (GHG) emitter, it contributes to this process. In the era of significant reductions in GHG emissions, it is becoming increasingly important to obtain the highest economic effects with the smallest external effects (e.g. GHG). The purpose of the article is therefore to determine the level of GHG emissions in agriculture and the economic and climate efficiency of agriculture in EU countries and comparison to other sectors of the economy. The DEA method was used in the study. Calculations were made based on Eurostat data.

It was found that the share of GHG emissions of agriculture in the EU represents 10-11% of all emissions in the European Union. Agriculture is the least economically and climatically effective sector of the EU economy. Comparing the agriculture of individual countries, the highest efficiency was achieved by Italy, Cyprus, the Netherlands, Slovakia and Finland, the lowest – Lithuania, Poland and Latvia.

**Keywords:**
efficiency, climate, economy, GHG, agriculture, Europe

## Efektywność ekonomiczno-klimatyczna rolnictwa w UE i Polsce

### Streszczenie

W artykule w części teoretycznej zwrócono uwagę na zjawisko zmian klimatycznych oraz dwukierunkowych relacji pomiędzy tymi zmianami a rolnictwem. Rolnictwo jako sektor gospodarki jest niezwykle wrażliwy na wszelkie zaburzenia klimatyczne. Z drugiej strony jako emitent gazów cieplarnianych (GHG) m swój udział w tym procesie. W dobie znaczących redukcji emisji GHG coraz istotniejszą kwestią jest otrzymywanie jak najwyższych efektów ekonomicznych przy jak najmniejszych efektach zewnętrznych (np. GHG). Celem artykułu jest zatem określenie poziomu emisji GC w rolnictwie oraz efektywności ekonomiczno-klimatycznej rolnictwa w krajach UE oraz w porównaniu do innych działów gospodarki. W opracowaniu wykorzystano metodę DEA. Obliczeń dokonano na podstawie danych Eurostatu. Stwierdzono, że udział emisji GC rolnictwa w UE stanowi 10-11% wszystkich emisji we Wspólnocie. Rolnictwo jest najmniej ekonomiczno-klimatycznie efektywnym sektorem gospodarki UE. Porównując natomiast rolnictwo poszczególnych krajów, najwyższą efektywność osiągnęły Włochy, Cypr, Holandia, Słowacja i Finlandia, najniższą Litwa Polska i Łotwa.

**Słowa kluczowe:**
efektywność, klimat, ekonomia, emisja gazów cieplarnianych, rolnictwo, Europa