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IS THE EU AGRICULTURE BECOMING LOW-CARBON? TRENDS IN THE INTENSITY OF GHG EMISSIONS FROM AGRICULTURAL PRODUCTION

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Abstract. GHG emissions from agriculture account for as much as 18% of the total human related emissions. In Europe, it is 12%. To reduce overall emissions, it is also necessary to reduce them from agricultural production. The study aims to assess the size and dynamics of changes in emissions from agriculture in EU countries. Based on FAO data, a trend in 1999–2019 was determined. It was also assessed how the level of emissions changed per production unit, including the extent to which these changes resulted from changes in the production volume and to what extent from the improvement of the production techniques. Overall, production increased by about 0.8% during the period under review, and GHG emissions decreased by 10.8% to 587 Mt CO_2 eq. As a result, the emission intensity decreased by 11.5% from 1.74 to 1.54 kg CO_2 eq. per 1 Int. $. There were differences in reducing emissions per unit of production between countries. The emissions per unit decreased more in the NMS with less developed agriculture, which has more significant potential to improve produc tion techniques. In more developed countries, changes were minor, and some even increased emissions per production unit. The main factor in reducing the emission intensity by 0.2 kg CO_2 eq. per 1 Int. $ was the introduction of better production techniques with a 74% share in this change; to a lesser extent, it was possi ble through better use of energy in farms (26% share).

Further reduction of the emission intensity will be relatively small. It may result from the regional intensifi cation of agriculture, the increase in production scale, and the higher level of mechanization. A more signifi cant reduction of emissions will require a reduction of production and changes in its structure, mainly limiting the production of cattle and milk and thus changes in the level and food consumption structure.

Keywords: GHG emission, agriculture, GHG emission intensity, climate change, mitigation.

JEL code: F64, O44, Q15

Introduction

The World's population has doubled since 1970. In 1970, it was 3.7 billion people, and in 2019 it reached 7.7 billion people. The annual increase is over 80 million people (UN, 2019). Similarly, food production increased, driven additionally by a higher level of consumption and a change towards more animal-based products in the diet, which means that agricultural production has more than doubled. For some animal products, it increased up to 3–4 times. Accordingly, GHG emissions from agricultural production also increased, mainly emissions related to the size of crop and livestock production. On the other hand, emissions from land use and land use change (LULUC) decreased over 2000–2018, consistently with observed decreases in deforestation. The share of GHG emissions from agriculture in total emissions was around 18% in 2018 (FAO 2020). In 2018, total world emissions from agriculture and related land use reached 9.3 Gt of carbon dioxide equivalent (CO_2 eq). The three countries with the highest emissions from agriculture are Brazil, Indonesia and India, which account for 30% of global emissions.

According to the FAO (2020), Europe is responsible for 10% of global emissions from agricul ture. Between 1999 and 2019, farm gate emissions in Europe decreased by 13% to 854 Mt CO_2 eq. The change in emissions from agriculture in Europe could result in significant share from the trans formation of economies in the countries of the former Soviet bloc (Mohammed *et al.*, 2020: 285). With the development of agriculture and a greater level of mechanization, the emission from on-farms energy consumption may increase. Progress in agricultural mechanization brings, however, effects in reducing emissions from On-Farm Energy Use (OFEU) in countries where a high pace of technological progress in agriculture is observed (Bartova *et al.*, 2018; Kusz, 2018; Wicki, 2018).

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1. Factors determining the level of GHG emissions from agricultural production

GHG emissions from agriculture are most often stated per unit area, which tends to favour the low-cost system as being the most environmentally-friendly (Gregory *et al.*, 2002). However, for global environmental issues such as greenhouse gas emissions, this does not make much sense as these emissions do not only affect the local area but the global climate. Suppose, instead, the GHG emissions are expressed per product unit (i.e. emission intensity). In that case, the higher GHG emissions per area are not worse than the lower GHG emissions per area if the production is also proportionally higher. Unfortunately, many researchers (e.g. Syp, Osuch, 2019) focus on input-related emissions rather than assessing their productivity.

Many authors argue that intensification and greenhouse gas emissions are always related (van Beek *et al.*, 2010), but there are many exceptions. When agricultural emissions are analysed, the full portfolio of emission sources is seldom considered; land use change (LUC) is often overlooked (Bellarby *et al.*, 2013), although up to 90% of LUC emissions are due to agricultural activity; whether it is plant production or grazing (Houghton, 2012). One of the major trade-offs in terms of greenhouse gas emissions from agriculture is whether to increase production by increasing the area under cultivation, or to achieve higher yields in already cultivated areas (Phalan *et al.*, 2011). Bennetzen *et al.* (2016a) found that '*Since 1970, developed regions (EUR, NA and OCE) have reduced their agricultural area by 118 million ha (10%), while developing countries combined increased their agricultural area by 447 million ha (13%)*'.

While the inclusion of LUC in the analysis is very important, it is the case in most of the less developed areas, where deforestation and increasing areas of arable land are still taking place. In some European countries, emissions from LUC are negative because of the afforestation of agricultural land (Danilowska, 2019; Daugaviete et. al., 2020; Feldmanis, Pilvere, 2021). It is worth considering all emission sources if one wants to analyse how agricultural production contributes to greenhouse gas emissions. The FAO view (Tubiello *et al.*, 2021) allows this approach.

Assessing GHG emission change from agriculture, one should consider data availability and the area covered by the analysis. In this study, it was decided to use data compiled by FAO for EU countries. Farmgate emissions were assessed. Land-use change emission was omitted, as emissions from this respect mainly concern afforestation.

Many factors lead to the reduction of emissions from agriculture. Some researchers point to the development of organic farming, as less inputs per hectare are used (Muska *et al.*, 2021; Veveris, Puzulis, 2020), but emission per unit of production is not considered. Another suggested solution is the use of correct agricultural practices. Their dissemination may result from the implementation of the so-called sustainable agriculture (Brodzinska, Brodzinski, 2019; Naglis-Liepa *et al.*, 2021), which aims to use only the necessary inputs. Examples of good agricultural practices leading to emission reduction were: the correct use of manure instead of artificial fertilizers (Sanz-Cobena *et al.*, 2017; Pardo *et al.*, 2017), biogas production from manure and the use of digestate as fertilizer (Millers, Pilvere, 2021; Pardo *et al.*, 2017; Jarosz, 2016). However, the development of biogas production may lead to an increase in the demand for raw materials (Jarosz, 2016; Wicki, 2017) and an increase in emissions due to LUC (Oertel *et al.*, 2016).

An essential role in reducing emissions from agriculture is assigned to modern technologies (Vintere, 2020), including precision agriculture techniques. Positive effects are expected primarily due to the use of a precisely defined amount of fertilizers, pesticides, precise irrigation (Balafoutis *et al.*, 2017; Berbec, Kopinski, 2019; Pardo *et al.*, 2017) and tillage techniques (Sanz-Cobena *et al.*, 2017), but also the selection of plant varieties to local conditions and production intensity (Dudek, Wicki, 2019; Wicki, 2019). However, it is noted that in precision agriculture, the energy consumption is higher (Balafoutis *et al.*, 2017). Still, the overall balance is favourable due to the higher productivity of inputs on larger farms, where such technologies of precise agriculture are usually introduced (Wicki, 2021).

Some studies show that changing production techniques can reduce emissions from agriculture by little, by no more than 10%. A possible more significant reduction, even up to 40%, would have to result from a change in the production structure and its limitation and changes in the consumption structure (Herrero *et al.*, 2016). Furthermore, reducing emissions from agriculture may result from changes in the demand for food products. Therefore, it is postulated to educate consumers about emissions per product unit and encourage them to buy products with lower emissions, e.g., giving up meat, especially beef and dairy products (Sanz-Cobena *et al.*, 2017; Vintere, 2020). It is also emphasized that food production based on local resources should be promoted, as it does not require long-distance transport or long-term storage (Laborde *et al.*, 2021, Licite, Cunkskis, 2019).

Many of the modelled GHG mitigation measures negatively affect primary agricultural production. Nevertheless, it is assessed on a global scale that, in the long run, the negative effects of limiting global agricultural production are greater than the negative effects resulting from the effects of climate change (Meijl *et al.*, 2018). Other researchers, however, report the results of a neutral impact of policies on food production at the cost of US $ 20 per 1 t CO_2 eq. (Wollenberg *et al.,* 2016). All this is the basis for further investigations, mainly to show whether one can observe changes in emissions resulting from technical progress (understood as an increase in the productivity of inputs), which may lead, among others, to reduce GHG emissions per unit of production.

2. Aim and method

The study aims to assess changes in the level of greenhouse gas emissions from agriculture in the EU and the factors of these changes. There are three research tasks: 1) determining the level of GHG emissions from agriculture and its changes; 2) determining the intensity of emissions from agriculture in the EU countries; 3) determining the structure of changes in emission intensity. The postulate of research on specific regions results from different conditions for agriculture in regions (Meijl *et al.*, 2018).

The data used in the work come from the FAO databases: Crops and livestock products and Emissions Totals. Data concern the period 1999–2019. The selection of the data period resulted both from the fact that the new EU member states were already after the most significant changes resulting from the political transformation and the fact that the latest available data are from 2019.

Data were obtained for each country on: 1) total agricultural production volume (in 2014–2016 constant international dollars - Int. $); 2) GHG emissions from agriculture in CO_2 equivalent, taking into account the Global Warming Potential (GWP) of other gases. The follow GWP values of the IPCC Fifth Assessment report (Myhre, 2013: Tab. 8.7), were applied by FAO to convert CH_4 and N_2O amounts to equivalent CO_2 eq.: GWP - CH_4 = 28; GWP - N_2O = 265; 3) emissions from agricultural activities for the Farm Gate (FG) category and additionally for the On-Farm Energy Use (OFEU) category. On-Farm Energy Use has been included separately to assess how EI depends on such energy consumption. The share of OFEU emissions in the FG was determined for each country separately. Due to data gaps, emissions in the 'Land Use Change' (LUC) category was not included. Such data are available only for some countries and a few years (it should be remembered that in the FAO records, this category is not identical to the LULUC emission value calculated in accordance with the IPCC methodology).

The emissions intensity (EI) of CO_2 eq. per unit of production was adopted as the basic indicator:

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$$EI = \frac{E}{P} \quad (1)$$

where: *EI* is emission intensity, *E* is total emission of GHG in CO_2 eq., and *P* is value of agriculture production in constant 2014–2016 Int. $.

It can be assumed that a change in the amount of emission per product unit that does not result from a change in production is technological progress and therefore results from the improvement of agricultural practices. However, here we have a reversal of the relationship that we usually consider for factor productivity, so the beneficial change will be a reduction in emission (E) per unit of production (P). Alternatively, the inverse relationship (P / E) can be analysed, but these results are not comparable to those usually presented in the literature (Bennetzen *et al.*, 2015; Wollenberg *et al.*, 2016; Yan *et al.*, 2017). Lowering the EI means increasing the productivity of the inputs recognized in emission units.

It is possible to provide meaningful definitions of output growth and input growth between any two periods of time using index number theory. Changes in EI over time are found by comparing the rate of change in total output (E) with the rate of change in total input (P). Expressed as logarithms, changes in equation (1) over time can be written as:

$$\frac{d\ln(EI)}{dt} = \frac{d\ln(E)}{dt} - \frac{d\ln(P)}{dt} \quad (2)$$

which simply states that the rate of change in *EI* is the difference between the rate of change in aggregate emission and production.

Using the function *g*(.) to signify the annual rate of growth in a variable, the growth in emission is simply the growth rate of the production plus the growth in EI times respective sources shares in emission (*Sj*):

$$g(E) = g(P) + S_{fg}g(EI_{fg}) + S_{ofeu}g(EI_{ofeu}) \quad (3)$$

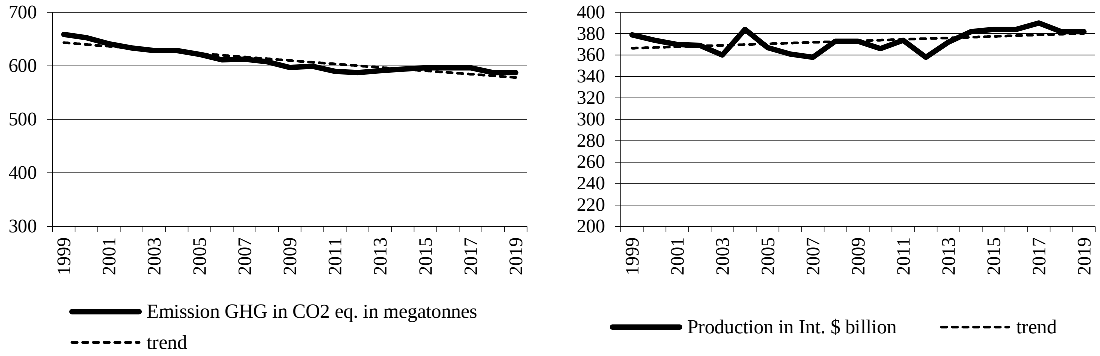
where: S_{fg} is share of emission in category FG, S_{ofeu} is share of emission in category OFEU.

Based on equation 3, it is possible to determine which part of the change in emissions results from the change in the production volume and which part from the change in the efficiency of the use of inputs causing the emission (increase in emission productivity).

Research results and discussion

1. Agricultural production and GHG emissions from agriculture in the EU

According to the FAO methodology, GHG emissions from agriculture (Farm Gate) in the EU countries decreased in 1999–2019. In 1999 it was about 659 Mt CO_2 eq. In 2019 it was 587 Mt CO_2 eq. Emissions fell by 10.8%. The average annual rate of emission reduction was 0.53%. In the same period, agricultural production (in constant prices) remained almost similar because it increased by 0.8% (Fig. 1). As a result, the greenhouse gas emission per unit of production (EI) has been reduced by 11.5% (CAGR: -0.72%). In 1999-2003 it was 1.74 kg CO_2 eq. per 1 Int. $, and in 2015–2019 only 1.54 kg CO_2 eq. per 1 Int. $.

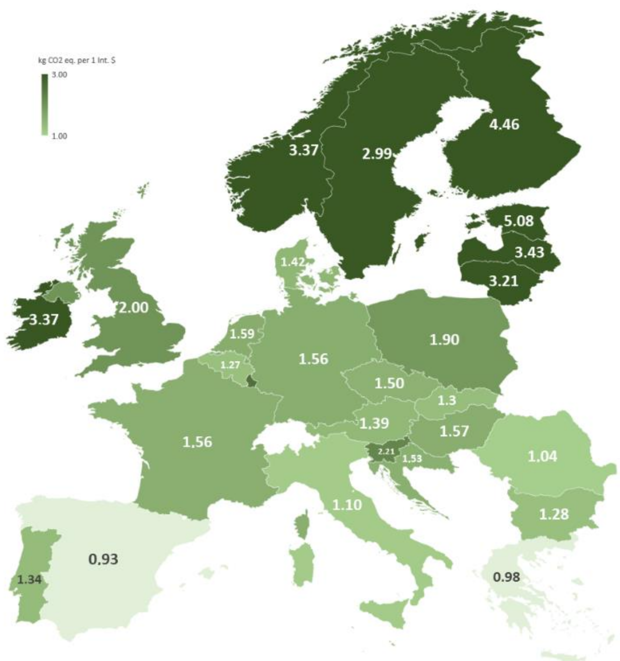


Source: author's calculations based on FAO data

Fig. 1. **Trend of CO_2 emissions eq. in agriculture and the trend of agricultural production in the EU in 1999–2019**

The observed changes are pretty high. It means that the current level of production can be sus tained with slightly less emissions. It is worth noting that emissions reduction may simultaneously result from structural changes in agriculture (especially in NMS), changes in the structure of inputs, and technological progress. As the scale of production in farms increases, the energy inputs per unit of product decrease, but from the other side, the increasing level of mechanization leads to an increase in energy demand.

Individual EU countries differ in the amount of agricultural production and GHG emission, and it is not justified to directly compare these amounts. Fig. 2 shows the CO_2 eq emissions per unit of the agricultural output in individual countries.



Source: author's calculations based on FAO data

Fig. 2. **Emission level in kg CO_2 eq. per 1 Int. $ of agricultural production in EU countries (avg for 2015–2019)**

The different level of EI in individual countries results both from the natural productivity of the agro-ecological system and the different structure of agricultural production and technical efficien cy of inputs. In the countries in the south, EI (per 1 Int. $) is the lowest and amounts to about 1 kg CO_2 eq. In the north, emissions exceed 3 kg CO_2 eq. per 1 Int. $. EI also results from differences in emission from the energy consumed by farms in individual countries. An important issue is the share of cattle and milk production, which is associated with high CH_4 emission, but it is not analysed here. The differences in the emission intensity of agricultural production between countries do not change significantly with time.

Changes in the intensity of emission of GHG from agriculture in EU countries in 1999-2019

When we want to reduce total emissions from agricultural production, it is essential to know the direction and dynamics of changes in the EI index. Table 1 presents the level of changes in emissions from agriculture in individual countries and the share of components in this result.

Various changes occurred in agriculture in the studied group of countries. In the countries of the post-Soviet bloc, agriculture was rebuilt after its collapse in the period of economic transformation. Mohammed *et al.* (2020) determined that after changes, in 1990–1995, emissions from agriculture in these countries decreased by as much as 30-40%. In the EU15 countries, further changes in agriculture concerned mainly the structure of farms, the increase in scale, and mechanization. Overall, in the EU, emissions from agriculture increased in only four countries during the period considered, and the value of production increased in 18 countries. Production increased by at least 15% in Bulgaria, Croatia, Estonia, Ireland, Latvia, Lithuania and Romania. Only Estonia, Latvia, Luxembourg, and Sweden have seen increased emissions. Across the EU, production increased by 4%, and GHG emissions decreased by 8%. In the whole EU intensity of emissions decreased by 11%. In individual countries, the changes in EI were very different. Emission intensity increased in five analysed countries: the Czech Republic, Italy, Malta, Slovenia and Sweden. The fastest (excluding Malta) EI grew in Sweden, as much as 0.39% annually in the analysed period. Slightly lower EI increases were observed in the Czech Republic (0.22% p.a.) and Italy (0.14% p.a.).

For each country, one can assess whether the change in the total EI level resulted from the in crease in the emission intensity resulting from changes of the production technique (FG) or energy consumption in farms (OFEU). In the four countries with EI increase, the emission intensity related to the agricultural practices increased (including fertilizers, manure management, enteric fer mentation, crop residues). Only in Sweden emission intensity from OFEU also increase. It follows that the modern mechanization of agriculture can lead to an increase in emissions from agriculture

The most significant reduction in EI from agriculture, with a dynamic of over 1.5% annually, was observed in Bulgaria, Croatia, Greece, Latvia, Lithuania (Table 1). The reduction of 1.0–1.5% per annum occurred in another nine countries: Belgium, Estonia, Ireland, Netherlands, Poland, Portugal, Romania, Spain and the UK. In the countries with the highest EI reduction, this was due to a significant increase in production with a slight decrease in GHG emissions. Only in Greece, the decline in EI result from a substantial reduction in agricultural production. This case shows that, without significant technical progress, reducing emissions requires a decrease in production. In other countries, a relatively constant level of production was observed with only a slight reduction in emissions. It means that in countries where the intensity of agriculture production is high, reducing GHG emissions from agriculture will be associated with lowering production volume, as progress in reducing EI is challenging to achieve.

Table 1

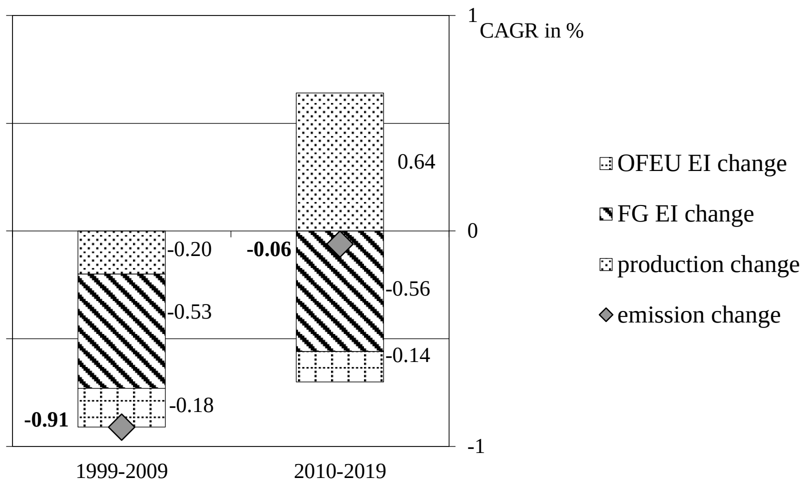
Changes in emission of CO_2 eq., production and emission intensity from agriculture production in EU countries in 1999-2019

Country	Dynamics of change [(2015-2019)/(1999-2003)]*100		Annual change (CAGR) in 1999–2019, %				
	FG emission	output	CO2 eq. emission	agricultural production	emission intensity (EI)		
					total	FG without OFEU	OFEU
Austria	90	103	-0.63	0.18	-0.80	-0.62	-0.18
Belgium	89	104	-0.75	0.27	-1.02	-0.54	-0.48
Bulgaria	91	115	-0.61	0.92	-1.53	-1.00	-0.53
Croatia	85	122	-1.22	1.09	-2.31	-1.83	-0.48
Czechia	94	93	-0.36	-0.59	**0.22**	**0.32**	-0.10
Denmark	90	102	-0.63	0.08	-0.72	-0.39	-0.33
Estonia	107	135	**0.46**	1.86	-1.35	-1.50	0.15
Finland	99	100	-0.10	-0.03	-0.07	0.14	-0.21
France	91	97	-0.58	-0.19	-0.39	-0.32	-0.07
Germany	91	105	-0.54	0.31	-0.85	-0.82	-0.03
Greece	66	82	-2.64	-1.39	-2.31	**0.38**	-2.69
Hungary	98	106	-0.15	0.10	-0.25	-0.22	-0.03
Ireland	96	116	-0.28	0.81	-1.09	-0.95	-0.13
Italy	89	88	-0.80	-0.94	**0.14**	**0.18**	-0.04
Latvia	109	160	**0.52**	2.72	-2.20	-2.08	-0.12
Lithuania	95	127	-0.34	1.47	-1.81	-1.79	-0.02
Luxembourg	108	118	**0.43**	0.91	-0.48	-0.36	-0.13
Malta	86	74	-0.96	-1.87	**0.92**	-0.15	1.06
Netherlands	91	112	-0.57	0.71	-1.28	-0.56	-0.72
Poland	94	111	-0.41	0.65	-1.05	-0.59	-0.47
Portugal	92	110	-0.58	0.46	-1.02	-0.58	-0.45
Romania	97	120	-0.33	0.94	-1.27	-1.46	0.19
Slovakia	83	87	-1.13	-1.01	-0.12	-0.06	-0.06
Slovenia	90	90	-0.70	-0.79	**0.09**	**0.18**	-0.09
Spain	96	114	-0.37	0.83	-1.20	-1.04	-0.16
Sweden	104	98	**0.23**	-0.15	**0.39**	**0.31**	**0.08**
United Kingdom	90	108	-0.67	0.44	-1.11	-1.06	-0.04
EU total	92	104	-0.53	0.19	-0.72	-0.53	-0.19

Source: author's calculations based on FAO data

In the structure of the total EI reduction, as much as 74% resulted from lower EI at the FG, while reduction of EI from OFEU had a share of 26%. A minimal decrease in EI from OFEU was observed in some countries. These were countries where agriculture was modernized and intensively mechanized (Estonia, Hungary, Latvia, Lithuania, Romania) and countries where labour is substituted by capital (France, Germany, Spain, UK). In particular countries, different factors can be indicated, e.g. concentration of land and production, changes in the intensity of production (both intensification and extensification), limiting the size of livestock production

The EI change was different in the followed decades. Between 1999 and 2009, GHG emissions from agriculture in the EU decreased by 0.91% annually. This change resulted in 22% from the re duction in production, 58% from the decrease in GHG emissions from agricultural production and 20% from the decrease in OFEU emissions. Together, the advances in technologies accounted for as much as 78% of the reduction in GHG emissions from agriculture (Fig. 3).



Source: author's calculations based on FAO data

Fig. 3. **Significance of factors of changes in GHG emissions from agriculture in the EU in the next decades in 1999-2019**

In 2010–2019, the progress in reducing EI was similar and amounted to -0.56% and -0.14% an nually (FG and OFEU, respectively). In this decade, GHG emissions from agriculture decreased by 0.06% annually, resulting from a production increase of 0.64% annually and a decrease in EI by 0.70% annually. The total change in EI resulted in as much as 75% from the EI reduction from agri cultural field practice (FG). The share of EI reduction from OFEU was 25% in 1999–2009 and 21% in 2010–2019.Therefore, one may conclude that GHG emission reduction from agriculture may be achieved mainly due to the improvement of agricultural practices towards low-emission ones and changes in the structure of the output.

Considering the changes in EI from agricultural production in the EU, in most countries, it is possible to maintain the volume of the agricultural output while stabilizing the current GHG emis sions from agriculture. Therefore, structural changes in NMS agriculture should not be an obstacle here. In a broader sense, the possible increase in agricultural production should occur in countries with lower EI of agricultural production.

Conclusions

1) Globally, agriculture is responsible for around 18% of GHG emissions. In Europe, it is 12% in total. Worldwide, there is an increase in emissions from agriculture, while in Europe, there is a slight decrease in emissions. Effective GHG mitigation policies should be economically effi cient, balancing human demand from different sectors at reasonable prices and sustainability of land resources use.
2) To reduce GHG emissions from agriculture, it is postulated, among others, to develop ecological or sustainable agriculture, introduce new production techniques, limit and change the structure of food consumption, mainly limiting the production of beef and dairy products. It usually leads to a reduction

in food production. Moreover, low-intensive agriculture, including organic agricul ture, is characterized by higher emissions per production unit. Therefore, we should verify each emission reduction policy regarding how much it will reduce emission per unit of production. In addition, emissions from transport from other countries and food storage in new supply chains should be considered to avoid emission leakage.

3) In 1999-2019, the intensity of GHG emissions from agricultural production in the EU decreased by 8%. It resulted from better farming practices and increased production at lower inputs. In the following decades, we observed less progress in reducing GHG emissions. However, still reduc tion in the emission intensity was achieved, mainly due to increasing production in NMS, to a lesser extent due to better production practices.

4) In NMS, a more significant reduction in the intensity of emissions from agriculture has been achieved. This is because they introduced more efficient techniques after the transformation pe riod, and the energy intensity per unit of production was reduced. In contrast, an increase in emission intensity has been observed in some countries with highly developed agriculture. It may be the effect of the gradual introduction of low-input farming systems. EU countries with more developed agriculture may still achieve emission reductions, but it can influence produc tion volumes, including the gradual abandonment of ruminants.

5) Given the impact of demand on the production structure and market prices, one can conclude that the key to reducing emissions from agriculture is now in the hands of consumers.

Limitations

The presented results are subject to certain limitations. The research period does not include the systemic transformation in many countries. The differences in production structures, especially the share of ruminant production, were not considered. Therefore, it is impossible to demonstrate the causes of the observed changes more accurately.

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