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ENERGY PRODUCTIVITY IN AGRICULTURE IN EU COUNTRIES – DIRECTIONS AND DYNAMICS

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Abstract. The productivity of inputs, especially energy, is a subject of interest in many countries, including the countries of the European Union and the EU itself. To achieve a more sustainable economy, the EU launched the European Green Deal, a development strategy to transform the EU into a zero-emission economy. The study aims to assess changes in the productivity of energy inputs in agriculture in EU countries in connection with the changes in the volume of production and energy inputs. Based on Eurostat data, changes for the period 2010-2020 were determined. It was found that agricultural production in the EU-27 increased by 1.36%, while the amount of energy used in agriculture increased by as much as 12%. As a result, energy productivity decreased by as much as 10% from EUR 360,000 to EUR 325,000 per 1 TJ of energy input. A decrease in energy productivity was observed in 20 of the 27 countries surveyed. On average, production or energy use volume changes in particular countries were not large and did not exceed 5% in the analysed period. An increase in the efficiency of energy use in agriculture is possible through rational concentration of production, mechanization and introduction of innovations in production technologies. The phenomenon of emission leakage outside the EU and large imports of food should be avoided, as the efficiency of energy use in agriculture in the EU is higher than in less developed countries. Achieving a reduction in energy consumption in agriculture seems to be difficult to reconcile with maintaining production volumes.

Key words: energy productivity, agricultural productivity, energy inputs, Green Deal.

JEL code: Q11, Q49

Introduction

Energy is the currency of the economy of nature. Because the human economy is a subsystem of the biosphere, energy is similarly the fundamental currency of human economies (Daly & Farley, 2009). Energy is a scarce resource, especially in its direct form as solid, liquid, gaseous fuels or electricity. Currently, most energy comes from non-renewable fuels such as coal, oil and gas. The use of such resources must be subject to the principles of rational management, significantly when the available resources of such fuels are decreasing. An important aspect is the reduction of GHG emissions, including those from non-renewable fossil fuels.

Global climate change has been recognized as an essential threat to Europe and the world. To limit these changes, the EU launched the European Green Deal, a development strategy to transform the EU into a sustainable economy. Established in 2019, the European Green Deal outlines actions for a resource-efficient and zero-pollution EU by 2050. At the heart of the plan are UN climate protection goals to limit the temperature increase to 1.5°C, in line with the Paris Agreement (Dolge & Blumberga, 2021; European Commission, n.d.). Therefore, it is necessary to introduce technological improvements and innovations that maintain agricultural production at the current level and reduce the volume of inputs in that energy (Viksnina & Leibus, 2022).

Reducing the energy intensity of agricultural production is also supported by the fact that the increase in energy prices is not compensated by a proportional increase in the price of farm products, so it usually leads to a deterioration of profitability in agriculture (Ball et al., 2015).

The Green Deal will also affect agricultural production, considered an important source of air, water and soil pollution. This applies to reducing the use of fertilizers, pesticides, and energy in agriculture. In agriculture, energy use is not only supposed to be effective, but it is also necessary to reduce GHG emissions from fuels by using biofuels (Adamickova et al., 2020; Muska et al., 2021) and other renewable

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energy sources in accordance with the sustainable development paradigm (Naglis-Liepa et al., 2021; Naglis-Liepa & Pelse, 2014; Naglis-Liepa, Filipiak et al., 2022). It should be remembered that direct energy in agriculture is less than 30% of the total amount of energy that is embodied in fuels, fertilizers, pesticides, feed, seeds etc. (Giampietro, 2003; Vittuari et al., 2016).

Higher productivity of energy inputs in agriculture is observed in developed countries than in less developed ones. This is related to superior technology and better farm management (Mushtaq et al., 2009) but also results from a higher level of direct energy inputs correlated with an appropriate level of production mechanization (Karkacier et al., 2006). Progress in agricultural mechanization brings effects also reducing energy use per one unit of production, especially when technological progress in agriculture is observed (Bartova et al., 2018; Wicki, 2018).

In industrialized countries, most farmers rely on mechanization, and larger farms may be able to utilize their equipment more fully (Shahin et al., 2008), thereby increasing fuel efficiency per unit output. A study of Swiss dairy farms suggests that larger farms are more energy efficient than smaller farms (Pelletier et al., 2011).

Roughly 50% of the increase in energy inputs in agriculture was a consequence of a shift toward more energy-intensive technologies in place of comparatively expensive labour input. Relationships between energy inputs and production are complex and nonlinear. The diminishing returns law is often observed (Pelletier et al., 2011). However, some studies have confirmed that efficiency may change in accordance with the Environmental Kuznetz Curve; such relationships are more often observed in non-agricultural sectors (Zaman & Moemen, 2017).

It has also been shown that animal production is characterized by a much higher energy intensity than plant production, even intensive cash crops (Vittuari et al., 2016). Reducing energy consumption may therefore result from a change in the production structure with a reduction in animal production. Reducing direct energy consumption within crop production is more complicated, as it mainly concerns machinery fuel (Ziaei et al., 2015). In this context, it should be noted that a holistic approach is required, as, for example, increasing the volume of production of energy crops, which is profitable, leads to an increase in energy consumption (Prabhakar & Elder, 2009), and may also lead to additional emissions from LULUC.

Another important issue is the huge variation in energy input per unit of the same product produced in different places, even in one country. Complex and interdependent factors affect the amount of energy used per unit of food produced, including climate, soil conditions, farming practices, fertilizer systems, crop yields and other variables. Differences in inputs were even several times for different production systems in one country (Woods et al., 2010).

One of the major trade-offs in terms of energy use and 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 using more inputs per hectare (Phalan et al., 2011). Such an increase in production intensity is more beneficial than deforestation, which still occurs in less developed countries. Maintaining or increasing inputs per hectare is beneficial as long as it allows for higher input productivity (Tubiello et al., 2015). In Europe, there is an afforestation of agricultural land, and production is concentrated on better soils (Danilowska, 2019; Daugaviete et. al., 2020; Feldmanis, Pilvere, 2021). Therefore, it is possible to produce intensively and keep the output level without increasing the agricultural land area. In addition, increasing the scale of production is beneficial concerning the productivity of inputs. Higher input productivity is obtained in larger farms, including higher energy productivity. In addition, farms have a higher level of income and are more sustainable (Kusz et al., 2022; Wicki, 2019). In such large farms, obtaining part of the energy from renewable sources, e.g., biofuels and agricultural biogas, or

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even from photovoltaic installations, is more accessible (Adamickova et al., 2020; Wicki, 2017; Naglis-Liepa, Filipiak, et al., 2022; Pietrzykowski, Kusz, et al., 2022). Overall, actions to reduce energy consumption in agriculture usually lead to reduced agricultural production. Still, there is scope to reduce direct energy consumption by changing production techniques without harming crops. As a result, it is possible to save 10-14% of energy (Tsatsarelis, 1991).

Aim and method

The study aims to assess changes in the productivity of energy inputs in agriculture in EU countries in connection with the changes in the volume of production and energy inputs. There are three research tasks: 1) determining the level and structure of energy use in agriculture; 2) determining the level and dynamics of agricultural production in the EU countries; 3) determining the changes of productivity of energy in EU agriculture.

The data used for the analysis are from Eurostat databases: Economic accounts for agriculture - values at real prices (AACT_EAA04) and "Simplified energy balances" (NRG_BAL_S). We also used data on energy use in agriculture from FAOSTAT database Energy use. Data concern the period 2010-2021. The choice of the data period resulted from the fact that the EU Member States that joined the EU in 2007 already provided comparable data to Eurostat after 2007, and the method of measurement of energy input in agriculture did not change within the researched period. In the case of a lack of data on energy consumption in agriculture in Eurostat for a given year and country or data inconsistency, data from Eurostat were supplemented with information from FAOSTAT. Another reason for adopting 2010-2021 was that all EU countries' production value was expressed in fixed prices in Euros. Adopting a more extended period for analysis may lead to distortions resulting from changes in the value of national currencies.

Data in annual intervals were obtained for each country on: 1) total agricultural production value in basic prices expressed in constant 2015 euros; 2) energy input in agriculture in TJ.

The energy productivity (EP) per unit of energy inputs was adopted as the basic indicator:

$$EP = \frac{Production}{Energy} \qquad (1)$$

Where: *EP* is energy input productivity, *Production* is total value of agricultural production in constant 2015 euros and *Energy* is total direct energy input in agriculture in energy units (TJ).

It can be assumed that an increase in the production per unit of energy input shows desired changes toward low-input and low-emission agriculture. Improvement in agricultural practices, lowering intensity and changes in the agricultural production structure, according to EU policy toward agriculture, should result in higher production per unit of energy. Therefore, the indicator we use is a reversal of the relationship that is often considered in the context of energy use, i.e. energy intensity. However, using the energy productivity indicator is beneficial as it can be easily compared to such indices as land and labour productivity. An increase in energy productivity in agriculture, preferably resulting from an increase in production with a decrease in energy consumption, would be a desirable outcome of the changes.

Changes in EP over time were determined using the dynamics index and the annual growth rate index. First, the ratio of the dynamic was calculated by comparing the level of variables for 2018-2021 to that for 2010-2013 (formula 2). Four-year averages were used for comparison to avoid the accidental influence of the results in the base or final year on the result. It should be remembered that the analysis covered EU countries, and the phenomena affecting production level, e.g. drought, do not occur simultaneously in the entire EU. The second indicator is the average annual growth rate calculated based on the course of the exponential function for the time series. The function given below (formula 3) was used. Beta is the average annual growth rate.

$$Dynamics\ indicator = \frac{sum(x_{2018}:x_{2021})}{sum(x_{2010}:x_{2013})} \times 100 \quad (2)$$

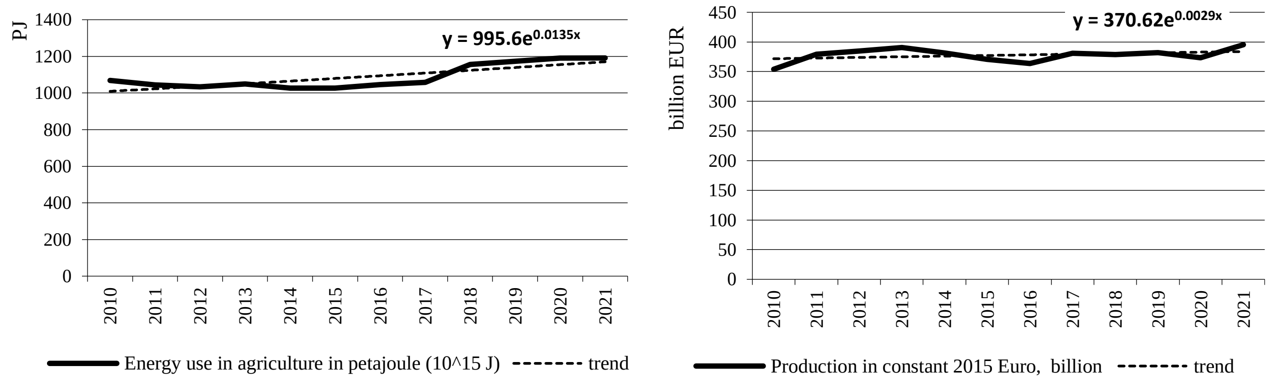
$$y = a \cdot e^{\beta xi} \quad (3)$$

Where: x_i– means annual data for individual country or whole EU-27.

Research results and discussion

Agricultural production and energy inputs in agriculture

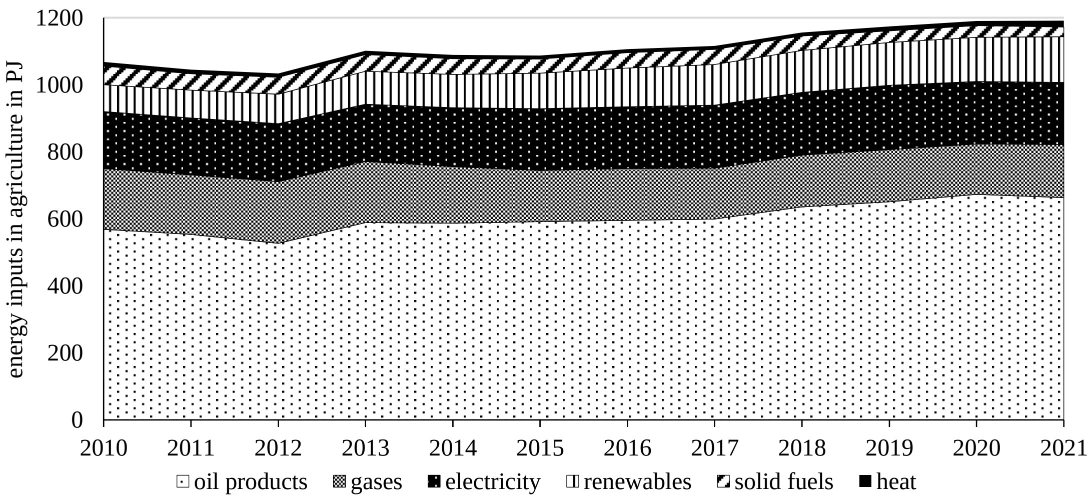
Direct energy use is an essential element of inputs in agriculture. Energy inputs are necessary not only for direct use in production processes, such as heating farm buildings or glasshouses, but are mostly used for indirect use. The energy, depending on the carrier, is used for heating, driving field machines or engines driving stationary machines. It is expected that with the increase in the scale of production, agricultural intensity and technological progress, energy inputs per unit of production will decrease (Wójcicki, 2006). Figure 1 presents energy inputs in agriculture in the EU-27 countries in 2010-2021. In 2010, in the EU-27, energy consumption in agriculture was around 1100 petajoules (PJ); by 2021, it had increased to about 1200 PJ per year. Energy consumption increased by 12.3% over the period, with an average annual increase of 1.35%. On the other hand, agricultural production in 2010-2021 (in constant 2015 prices) increased by only 1.36%. In 2010-2013, the total production value was EUR 377 billion, and in 2018-2021 it was, on average, EUR 382 billion. The average annual growth rate was 0.29%. As a result, the productivity of energy (EP) has been reduced by 10% (annual growth rate: -1.05%) (see also Table 1).



Source: author's calculations based on Eurostat data

Fig. 1. **Energy consumption in agriculture (in PJ) and value of agricultural production (2015 constant prices, EUR billion) in the EU-27 countries in 2010-2021**

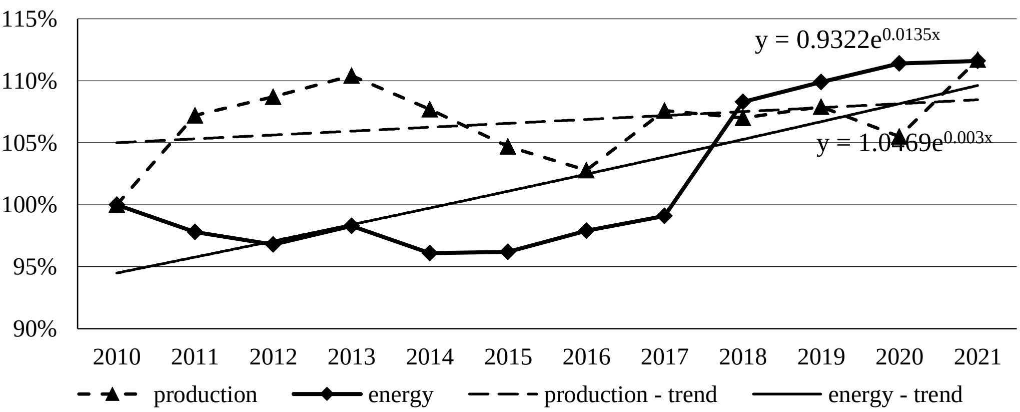
The structure of energy consumption is dominated by energy from oil products (Fig. 2). In 2010, it was about 53% of total consumption, and in 2021 already 56%. The second item in the energy consumption structure is electricity, with a share of about 15%, followed by gas. The energy from gaseous fuels was 17% in 2010 and 13% in 2021. The percentage of renewable energy in the total energy consumption in agriculture in the EU was not high. In 2010 it was 7.5%, and in 2021 it was 11.4%. It can be concluded that there were no significant changes in the structure of energy sources used in agriculture. The increase in mechanization in agriculture is associated with the growing demand for liquid fuels. A certain reduction in the energy demand can be expected with the rise in the scale of production on farms, which will enable the achievement of economies of scale in machinery use.



Source: author's calculations based on Eurostat data

Fig. 2. **Level and structure of energy inputs in agriculture in the EU-27 countries in 2010-2021 (in PJ)**

Figure 3 shows the dynamics of energy inputs in agriculture compared to production dynamics. In particular years, there were deviations from the trend. However, it can be noticed that energy inputs slowly but steadily increased, while production in agriculture, especially after 2013, did not increase. More important than the annual change assessment is the trend observation. It is clear that in the group of EU-27 countries in the last decade, the dynamics of energy consumption were higher than the dynamics of production. At the same time, this means that less and less product is produced per unit of energy.



Source: author's calculations based on Eurostat data

Fig. 3. **Dynamics of energy inputs in agriculture and agricultural production in the EU-27 countries in 2010-2021 (2010 =100%)**

Changes in energy productivity in agriculture in EU countries

Individual EU countries differ in the amount of agricultural production and energy consumption in agriculture, as well as due to the direction and dynamics of changes. Data for all countries individually are summarized in Table 1. An increase in energy productivity (EP) was observed for seven countries and a decrease for 20 (Table 1). In countries where EP increased, this resulted mainly from maintaining or slightly reducing energy inputs with a simultaneous increase in production. In two countries, Denmark and Slovakia, some decrease in production was observed, but the decline in energy consumption was more than proportional.

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Table 1

Level and dynamics of changes in energy inputs, production and energy productivity in agriculture in EU countries in 2010-2021

EP#	Energy inputs	Production	Country	The dynamics of change ((2018-2021)/(2010-2013))*100			Annual change rate		
				energy	production	EP	energy	production	EP
Increase	increase	increase	Spain	105	121	115	0,90%	2,45%	1,55%
			Poland	105	110	105	0,57%	1,42%	0,85%
	decrease	increase	Ireland	91	115	125	-1,12%	2,08%	3,19%
			Greece	93	116	124	-0,68%	1,79%	2,47%
			Sweden	95	108	114	-0,68%	1,04%	1,72%
		decrease	Denmark	84	96	114	-2,19%	-0,32%	1,87%
			Slovakia	93	97	104	-0,84%	-0,04%	0,81%
Decrease	increase	increase	Luxembourg	101	100	99	0,15%	0,10%	-0,05%
			Lithuania	105	102	96	0,74%	0,67%	-0,07%
			Slovenia	105	105	99	0,56%	0,31%	-0,26%
			Italy	105	100	95	0,60%	0,17%	-0,43%
			Czechia	112	106	94	1,50%	0,87%	-0,63%
			Portugal	122	113	93	2,47%	1,62%	-0,85%
			EU-27	**112**	**101**	**90**	**1,35%**	**0,29%**	**-1,05%**
			Cyprus	119	107	90	2,37%	0,96%	-1,40%
			Latvia	135	115	85	3,72%	2,09%	-1,63%
			Hungary	142	108	75	4,12%	1,17%	-2,95%
		decrease	Estonia	103	98	98	0,05%	0,12%	0,08%
			France	101	99	99	0,11%	-0,07%	-0,18%
			Austria	100	96	96	0,09%	-0,33%	-0,41%
			Netherlands	106	98	93	0,60%	-0,08%	-0,68%
			Belgium	110	95	87	1,27%	-0,36%	-1,63%
			Germany	109	89	82	0,88%	-1,25%	-2,14%
			Croatia	106	84	80	0,65%	-1,88%	-2,54%
			Romania	124	94	75	2,81%	-0,79%	-3,60%
			Malta$	139	79	54	4,05%	-2,81%	-6,85%
	decrease		Bulgaria	98	85	87	-0,23%	-1,79%	-1,56%
			Finland	98	86	87	-0,13%	-1,81%	-1,67%

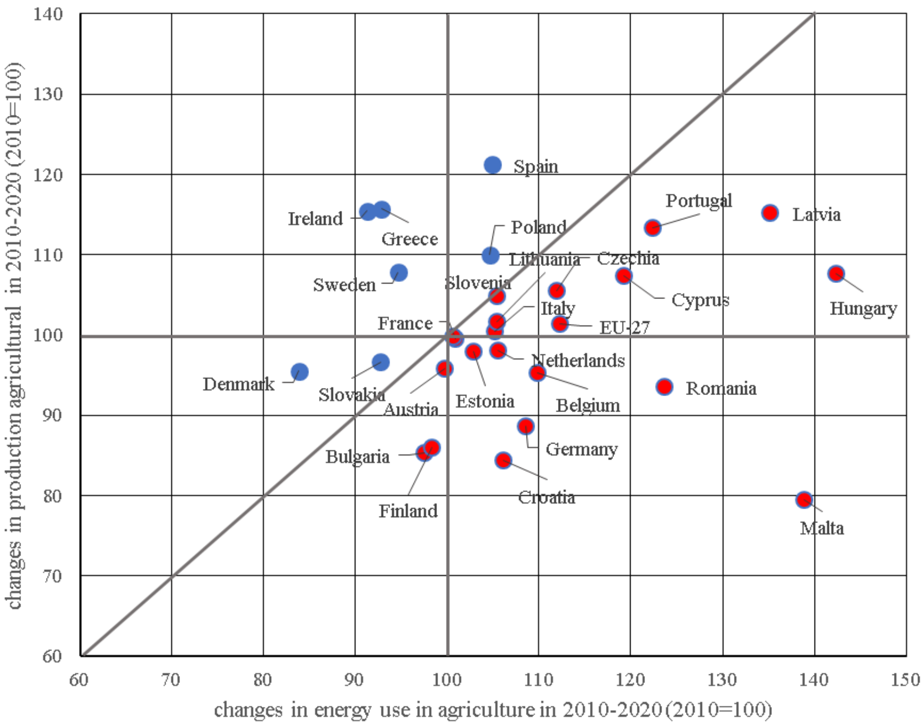
 # – productivity of energy inputs; $ – data for Malta are not entirely reliable; this does not affect the EU-27 results

Source: author's calculations based on Eurostat data

Two subgroups can be distinguished in the group of 20 countries where EP reduction was observed. In the first (9 countries), both energy inputs and production increased, but the dynamics of production growth were lower than energy inputs dynamics. On the contrary, in the second subgroup of countries, an increase in energy inputs and a decrease in production volumes were observed.

It is worth noting that the increase in EP can be obtained both in the strategy of increasing production and in the strategy of reducing it. Due to certain constant energy inputs for specific activities in agriculture, it seems reasonable to strive to increase output with specific energy inputs. Reducing production through its extensification may lead to a reduction in the consumption of such inputs as fertilisers, pesticides, fodder, etc., but reducing direct energy inputs per production unit is a challenge. In some countries, the strategy of greening agriculture may lead to an increase in the overall energy intensity of agricultural production.

Figure 4 shows the visualization of the relationship between the change in energy consumption in agriculture and the change in production volume.



Note: objects for which energy productivity decreased (below the diagonal) are marked in red, and objects for which energy productivity increased in blue.

Source: author's calculations based on Eurostat data

Fig. 4. **The relationship between the change in energy inputs in agriculture and the change in production in agriculture in EU countries in 2010-2021**

In the years 2010-2021, production increased in most EU-27 countries, but the dynamics were lower than the dynamics of energy inputs in agriculture. This means that achieving an increase in agricultural production in the conditions that exist for agriculture in EU countries requires a more than proportional increase in energy inputs, which is usually associated with an increase in the mechanization of work. On the other hand, reducing production does not lead to a proportional reduction in energy input. This is because lower production intensity allows for reducing the consumption of, e.g. fertilizers, which leads to lower yields, but energy expenditure for cultivation operations does not decrease proportionally, as they have fixed costs character. As a result, the productivity of energy inputs decreases. Other studies found that overall GHG emissions from agriculture in EU countries per unit of production decreased after 2010, but this reduction resulted mainly from better agricultural practices, lower inputs and a change in the production structure. Farm Gate Energy Use connected to direct energy inputs did not change significantly and did not contribute much to such reduction (Wicki & Wicka, 2022).

Taking into account changes in EP from agricultural production in the EU, in most countries, it is possible to maintain the volume of the agricultural output while maintaining the current consumption of direct energy in agriculture or with some reduction of energy consumption. The choice of development path depends on the policy in a given country. From the point of view of energy productivity in agriculture, it may be beneficial to increase the scale of production on farms, reduce the share of animal production and exclude the poorest soils from agricultural use (Danilowska, 2019; Daugaviete et al., 2020; Feldmanis & Pilvere, 2021). Striving to reduce production without structural changes leads to decreased output per unit of direct energy input. On the other hand, if a strategy to reduce greenhouse gas emissions is adopted, it is necessary to consider the effect of lowering all inputs. As E. Bennetzen (2016) points out, rational intensification of production is more effective than increasing the area of land used for agricultural production, especially when it is associated with deforestation.

Conclusions

1) In the countries of the European Union, the introduction of the Green Deal principles is associated with changes in each of the sectors of the economy, including agriculture. The use of non-renewable inputs in agriculture, including energy, is expected to decrease, according to sustainable development goals (SDG 7). This creates great challenges for this sector, especially if the current level of agricultural production and the modernization of agriculture is to be maintained. In particular, in some of the new Member States, agriculture is fragmented and structural changes are still needed. As a result, achieving environmental goals can be difficult.
2) The energy inputs structure was dominated by oil fuels, with a share of as much as 56%, followed by the consumption of electricity - 16.6%. The percentage of oil-based fuels, electricity and renewables increased in the input structure. The use of energy from oil increased by 17%, electricity by 10% and renewable energy by as much as 48%. Renewable energy in 2021 had a share of 11.4% of the total energy consumption in agriculture. Counting in the amount, the consumption of oil fuels increased the most, by as much as 96 PJ, i.e. by 8% of the total consumption. This resulted from the increase in the level of mechanization in agriculture.
3) Direct energy inputs in agriculture in the EU-27 countries increased in 2010-2021 by 12.3% to 1200 PJ per year, and the average annual growth rate was 1.35%. At the same time, agricultural production increased by only 1.36% to EUR 382 billion. This means that changes in energy consumption were not correlated with the size of production and, as a result, the relation production-energy deteriorated. On average, in the EU-27, direct energy productivity decreased from 360 to 325 thousand euro/TJ over the period under review, i.e. by around 10%. Energy productivity decreased at a rate of 1.05% per year. Therefore, it can be said that the intentions presented in the Green Deal policy, so far, are not reflected in the real economy. This may be due to the relatively short sustainable development policy implementation period.
4) Changes in the productivity of direct energy inputs were different in individual EU countries. In 7 countries, an increase and in 20 countries, decreases in energy productivity were observed. Most often, in as many as 18 countries, the dynamics of energy consumption were higher than the dynamics of production, and a decrease in agricultural production occurred in 14 countries. Nevertheless, changes in energy consumption and production volumes were not large, usually not exceeding 5 per cent compared to the base period. The trends found allow us to conclude that efforts to reduce the impact of agriculture on the environment should primarily consider the level of inputs or emissions per unit of production and not in relation to the acreage of production or considering the total amount of inputs used in given country.
5) An increase in the efficiency of energy use in agriculture is possible through the pursuit of rational concentration of production and its mechanization with the simultaneous introduction of innovations in production technologies. Another direction of action may be to change the production structure to one more dominated by plant production, which is less energy-intensive. However, the phenomenon of carbon leakage outside the EU and large imports of food of animal origin should be avoided, as the efficiency of energy use in agriculture is higher in highly developed countries.

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Limitations

The presented results are subject to certain limitations. The research period is relatively short; in a more extended period, one may observe different tendencies. Additionally, data presented in Eurostat are collected differently between countries and, in some cases, change rapidly from year to year. Therefore, it is difficult to demonstrate the changes for all EU countries more accurately in a comparable manner. Also, if one includes indirect energy use, i.e. in fertilisers, pesticides, and machinery, it may lead to a different picture of input efficiency changes in agriculture based on such a more comprehensive approach.

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