





Article

Changes in Energy Consumption in Agriculture in the EU Countries

Tomasz Rokicki ¹, Aleksandra Perkowska ^{1,*}, Bogdan Klepacki ¹, Piotr Bórawski ²,
Aneta Beldycka-Bórawska ² and Konrad Michalski ³

¹ Institute of Economics and Finance, Warsaw University of Life Sciences, 02-787 Warsaw, Poland; tomasz_rokicki@sggw.edu.pl (T.R.); bogdan_klepacki@sggw.edu.pl (B.K.)

² Department of Agrotechnology and Agribusiness, Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, 10-719 Olsztyn, Poland; pboraw@uwm.edu.pl (P.B.); aneta.beldycka-borawska@uwm.edu.pl (A.B.-B.)

³ Management Institute, Warsaw University of Life Sciences, 02-787 Warsaw, Poland; konrad_michalski@sggw.edu.pl

* Correspondence: aleksandra_perkowska@sggw.edu.pl; Tel.: +48-22-59-342-55

Abstract: The paper's main purpose was to identify and present the current situation and changes in energy consumption in agriculture in the European Union (EU) countries. The specific objectives were the determination of the degree of concentration of energy consumption in agriculture in the EU countries, showing the directions of their changes, types of energy used, and changes in this respect, establishing the correlation between energy consumption and changes in the economic and agricultural situation in the EU countries. All member states of the European Union were deliberately selected for research on 31 December 2018 (28 countries). The research period covered the years 2005–2018. The sources of materials were the literature on the subject, and data from Eurostat. Descriptive, tabular, and graphical methods were used to analyze and present materials, dynamics indicators with a stable base, Gini concentration coefficient, concentration analysis using the Lorenz curve, coefficient of variation, Kendall's tau correlation coefficient, and Spearman's rank correlation coefficient. A high concentration of energy consumption in agriculture was found in several EU countries, the largest in countries with the largest agricultural sector, i.e., France and Poland. There were practically no changes in the concentration level. Only in the case of renewable energy, a gradual decrease in concentration was visible. More and more countries developed technologies that allow the use of this type of energy. However, the EU countries differed in terms of the structure of the energy sources used. The majority of the basis was liquid fuels, while stable and gaseous fuels were abandoned in favor of electricity and renewable sources—according to which, in the EU countries, the research hypothesis was confirmed: a gradual diversification of energy sources used in agriculture, with a systematic increase in the importance of renewable energy sources. The second research hypothesis was also confirmed, according to which the increase in the consumption of renewable energy in agriculture is closely related to the economy's parameters. The use of renewable energy is necessary and results from concern for the natural environment. Therefore, economic factors may have a smaller impact.

Keywords: energy consumption; agriculture; renewable energy sources; development strategies; EU countries



Citation: Rokicki, T.; Perkowska, A.; Klepacki, B.; Bórawski, P.; Beldycka-Bórawska, A.; Michalski, K. Changes in Energy Consumption in Agriculture in the EU Countries. *Energies* **2021**, *14*, 1570. <https://doi.org/10.3390/en14061570>

Academic Editor: Piotr Gradziuk

Received: 4 January 2021

Accepted: 6 March 2021

Published: 12 March 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

In the European Union (EU), around 50% of agricultural production comes from plant production. Livestock production also generally needs land to feed the animals. About 47% of the land in the EU is used for agriculture. Therefore, it is a sector closely related to land use. Changes in the connection between land and agriculture proceed very slowly, and in the short term, this resource does not change significantly [1–5]. Agriculture in the European Union countries has been and will be diversified. They can be divided into segments.

Countries with a high level of socioeconomic development are most often distinguished, such as France, Germany, the Netherlands, Denmark, and Belgium. The second group includes the remaining EU-15 countries. The other two groups are the countries that joined the EU in 2004 and later [6–13]. In 2011–2013, labor productivity in agriculture in Eastern Europe accounted for only 19% of labor productivity in agriculture in Western Europe. This shows that there are still significant socioeconomic and technological gaps between Western and Eastern Europe, even though Eastern European countries joined the EU as early as 2004 [14–19]. In all Western European countries after 1950, the number of workers in the agricultural sector decreased. At the same time, productivity increased as the operation of machines replaced human labor. This resulted in high energy demand. Simultaneously, the importance of agriculture in generating GDP was gradually diminishing [20,21]. According to Giannakis and Bruggeman [22], the differences between individual countries result from the characteristics of human capital, environmental conditions, and technical efficiency of plant and animal production. By contrast, strong Szabo and Grznár [23] found links between the value of agricultural production and fixed and variable assets, the number of livestock, and the financial support provided. Pietrzak and Walczak [24,25] proved that the agrarian structure is one of the most important agricultural development determinants. Low concentration of land is a significant barrier to agriculture development due to high production costs and generating low income. According to Nowak and Róžańska-Boczula [26], such EU member states as the Netherlands, Denmark, Luxembourg, Belgium, Great Britain, and Slovakia have the most significant potential for agricultural production. The first four countries also showed the highest efficiency in the use of production factors, whereas low and average potential and efficiency characterized agriculture in most new member states. Similar dependencies were found by Popescu et al. [27–29], Bularca and Toma [30], Toma [31], and Svoboda et al. [32]. The EU countries also varied in terms of the production profile. There were specializations in agricultural production. Specialization can mean agricultural intensification and concentration. Specialization is related to mechanization, economies of size and scale, technological innovations, comparative advantages, and market forces. Agricultural specialization is also related to farms and agricultural land features, efficiency, and the geographical scale of specialization [33–37].

Energy is one of the basic inputs in agriculture [38]. At the farm level, energy is used directly as well as indirectly. Energy is used directly in plant production, livestock production, and the transport of agricultural products. Indirectly, energy is used outside the farm to produce and transport fertilizers, pesticides, and machines [39–42]. The increase in energy demand in agriculture results from the increase in mechanization. Energy supplies to modern and sustainable agricultural production systems and processing are one of the main factors in the growth of agricultural production [43–47]. In agriculture, various energy sources are used; often, these are hybrid systems that use both traditional and renewable energy sources [48,49].

Karkacier et al. [50] determined a strong relationship between energy use and agricultural productivity. Alipour et al. [51] used rice cultivation to show that water and electricity account for the largest share of total energy inputs in production systems. Chandio et al. [52] indicated that the increase positively influenced agricultural production in gas and electricity consumption. The presented research shows a strong relationship between energy consumption and the value of agricultural production. Energy efficiency in agriculture is one of the primary energy policy goals in countries with a significant agricultural sector [53–55].

The agricultural sector also supplies energy in the form of biomass. Biomass means the biodegradable fraction of products, waste and residues from agricultural production (including substances of plant and animal origin), forestry and related industries, including fisheries and aquaculture, as well as biogas and the biodegradable fraction of industrial and municipal waste [56,57]. Biomass can be used, among others, for the production of biodiesel and bioethanol [58]. In 2010, biomass was the source of 7.5% of the energy generated in the EU, and in 2020 this share amounted to 10%. In the world, energy production from biomass

has grown at a rate of 3.3% annually in recent years. The potential of agriculture in this respect is tremendous. It all depends on the progress made in introducing high-efficiency energy crops and on environmental issues [59–65].

The paper's main purpose was to identify and present the current situation and changes in energy consumption in agriculture in the European Union countries. The specific objectives were the determination of the degree of concentration of energy consumption in agriculture in the EU countries, showing the directions of their changes, types of energy used, and changes in this respect, establishing the correlation between energy consumption and changes in the economic and agricultural situation in the EU countries. Two hypotheses were put forward in the study. According to the first, in the EU, there was a gradual diversification of energy sources used in agriculture, with a systematic increase in the importance of renewable energy sources. The second hypothesis assumed that the increase in the consumption of renewable energy in agriculture is closely related to the economy's parameters.

2. Materials and Methods

All member states of the European Union were deliberately selected for research on 31 December 2018 (28 countries). The research period covered the years 2005–2018. The sources of materials were the literature on the subject and data from Eurostat. Descriptive, tabular, and graphical methods, dynamics indicators with a *constant basis*, Gini concentration coefficient, concentration analysis using the Lorenz curve, coefficient of variation, and Pearson's linear correlation coefficient were used for the analysis and presentation of materials.

The first stage of the research presents the energy consumption in agriculture in the EU countries. The primary sources of obtaining energy used for this purpose have been shown. The Gini concentration coefficient (Figure 1) was calculated [66]. It concerned total energy consumption in agriculture. This coefficient was also calculated for energy consumption in agriculture for individual types of energy. The results covered the two years of 2005 and 2018. They were used to determine the degree of concentration of energy consumption in agriculture. It is measured based on energy consumption in agriculture in the EU countries. If such energy consumption occurred in one country, the coefficient would be 1. If it is distributed among more countries, the coefficient becomes lower the closer it is to 0. This proves the even distribution of energy consumption in agriculture among EU countries. The Lorenz curve (Figure 2) is a graphical representation of the concentration of energy consumption in agriculture in EU countries [67].

<i>Gini coefficient</i>	
<i>concept</i>	measure of unevenness (concentration) of distribution of a random variable
<i>formula</i>	$G(y) = \frac{\sum_{i=1}^n (2i - n - 1) * y_i}{n^2 * \bar{y}}$ <p>where:</p> <p>n – number of observations,</p> <p>y_i - value of the "i-th" observation,</p> <p>\bar{y} - the average value of all observations, i.e.</p> $\bar{y} = \frac{1}{n} \sum_{i=1}^n y_i$

Figure 1. The Gini coefficient formula.

<i>Lorenz curve</i>	
<i>concept</i>	determines the degree of concentration of a one-dimensional random variable distribution
<i>coordinates</i>	$x_0 = z_0 = 0, \quad x_h = \frac{h}{n}, \quad z_h = \frac{\sum_{i=1}^h y_i}{\sum_{i=1}^n y_i}$ <p>With sorted observations y_i, which are non-negative value $0 \leq y_1 \leq y_2 \leq \dots \leq y_n$ is a polyline which apexes, for $h = 0, 1, \dots, n$</p>

Figure 2. The Lorenz curve formula.

In the second stage of the research, the structure of energy consumption in agriculture was presented. The share of energy sources used in agriculture was shown for sources such as oil and petroleum products, electricity, natural gas, renewables and biofuels, reliable fossil fuels. This division functioned in all EU. Only five countries were selected for analysis. France and Poland used the most energy in agriculture. The first of them belonged to the developed countries, and the second to the developing countries. Romania was in the middle of the EU countries' rate of energy consumption in agriculture. Simultaneously, in the analyzed period, the country recorded the highest increase in energy consumption in agriculture. Greece was also in the middle of the league. In turn, in this country, the largest decrease in energy consumption in agriculture was recorded among all EU countries. Latvia was at the end of the countries' ranking in terms of energy consumption in agriculture, but with relatively high growth dynamics. Apart from France, all analyzed countries were economically developing countries. The countries presented were, therefore, diverse in many aspects.

The third stage presents the share of renewable energy in the total energy consumption in agriculture. The focus was on countries with the highest share of this energy. The use of renewable energy in the economy is significant. There are similar trends in agriculture. At this stage, the differences between individual EU countries were indicated.

The dynamics indicators (Figure 3) for primary groups of energy sources in individual EU countries were calculated in the fourth stage [68]. As a result, knowledge was obtained about the directions and strength of energy consumption changes in agriculture from various sources.

<i>Dynamics indicators</i>	$i = \frac{y_n}{y_0} \quad \text{or} \quad i = \frac{y_n}{y_0} \cdot 100\%$ <p>y_n - the level of the phenomenon in a certain period</p> <p>y_0 - the level of the phenomenon during the reference period</p>
----------------------------	---

Figure 3. Dynamics indicators formula.

In the fifth stage, the coefficients of variation (Figure 4) for individual energy sources in agriculture for 2005–2018 were calculated. As a result, it was possible to determine whether the situation was stable or whether energy consumption was subject to substantial fluctuations [69].

<i>Coefficient of variation (Cv)</i>	
<i>concept</i>	eliminates the unit of measurement from the standard deviation of a series of number by dividing it by the mean of this series of numbers
<i>formula</i>	$C_v = \frac{S}{M}$ where : S - standard deviation from the sample M - arithmetic mean from the sample

Figure 4. The coefficients of variation formula.

In the sixth stage of the research, the relationship between the amount of energy consumption in agriculture in the EU countries and the economy's basic parameters and agriculture was examined. The parameters were selected on purpose based on the literature review. The indicators assessing the economic situation included the value of GDP, final consumption expenditure of households, export, and import of goods and services. The level of economic development is assessed by the parameters of the economy per capita. The following basic parameters were used to assess agricultural production: gross value added of agriculture, forestry, and fishing; area of crops and of grain sowing; and cows' milk production.

At this stage of the research, non-parametric tests were used to establish the correlation between the variables. The first is Kendall's tau correlation coefficient. It is based on the difference between the probability that two variables fall in the same order (for the observed data) and the probability that they are different. This coefficient takes values in the range $<-1, 1>$. Value 1 means full match, value 0 no match of orderings, and value -1 the complete opposite. The Kendall coefficient indicates not only the strength but also the direction of the relationship. It is a good tool for describing the similarity of the data set orderings. Kendall's tau correlation coefficient is calculated using the formula [70]

$$\tau = P[(x_1 - x_2)(y_1 - y_2) > 0] - P[(x_1 - x_2)(y_1 - y_2) < 0]$$

The given formula estimates Kendall's tau from a statistical sample. All possible pairs of the sample observations are combined, and then the pairs are divided into three possible categories:

P—concordant pairs, when the compared variables within two observations change in the same direction, i.e., either in the first observation both are greater than in the second, or both are less than in the second;

Q—incompatible pairs, when the variables change in the opposite direction, i.e., one of them is more significant for this observation in the pair, for which the other is less than;

T—related pairs when one of the variables has equal values in both observations.

The Kendall tau estimator is then calculated from the formula

$$\tau = \frac{P - Q}{P + Q - T}$$

$$\text{Additionally, } P + Q + T = \binom{N}{2} = \frac{N(N-1)}{2}$$

where

N—sample size

The formula can be represented as

$$\tau = 2 \frac{P - Q}{N(N - 1)}$$

The second non-parametric test is Spearman's rank correlation coefficient. It is used to describe the strength of the correlation of two features. It is used to study the relationship between quantitative traits for a small number of observations. Spearman's rank correlation coefficient is calculated according to the formula [71]

$$r_s = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2 - 1)}$$

where d_i —differences between the ranks of the corresponding feature x_i and feature y_i ($i = 1, 2, \dots, n$)

The correlation coefficient takes values in the range $-1 \leq r_s \leq +1$. A positive sign of the correlation coefficient indicates a positive correlation, while a negative sign indicates a negative correlation. The closer the modulus (absolute value) of the correlation coefficient is to 1, the stronger the correlation between the examined variables.

3. Results

In 2005–2018, energy consumption in agriculture in the EU countries decreased by 5.9%. Several sources of energy could be distinguished (Figure 5). The energy consumption from renewable energy sources increased the fastest, as there was an increase in 2005–2018 by 85%. Electricity consumption increased by 25%. There was a decrease in consumption in the remaining cases, i.e., heat by 33%, gas products by 23%, crude oil by 15%, and fossil fuels by 9%. This situation is good for the natural environment.

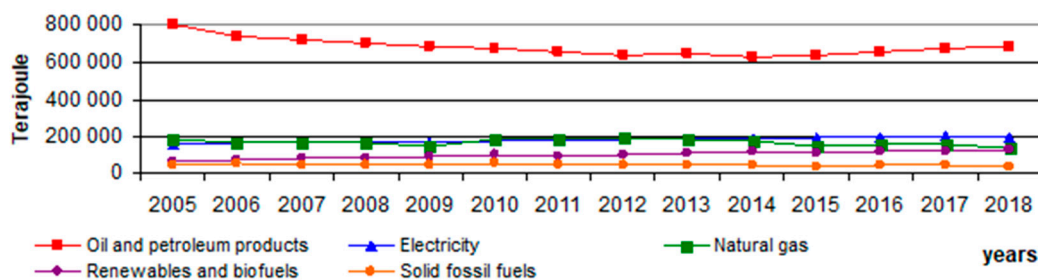


Figure 5. Sources of energy used in agriculture in 2005–2018.

The Gini coefficient was used to determine the concentration of energy consumption in agriculture from its various EU countries' sources. This coefficient is a correct and commonly used measure of inequality. The number of observations was 28 (all EU countries). The results are presented for total energy consumption and five types of energy, i.e., energy from crude oil, electricity, natural gas, renewable sources, and solid fuels. The Gini coefficient for total energy consumption in agriculture in 2005, calculated from the sample, was 0.61, and the estimated coefficient for the population was 0.63. This meant quite a high concentration of energy consumption in agriculture in several EU countries. When the research was repeated in 2018, the results were virtually identical. Therefore, there have been no significant changes in the distribution of energy consumption in agriculture in the EU countries. The Gini coefficients for energy consumption in agriculture were also calculated for individual types of energy. Additionally, the differentiation was presented using the Lorenz concentration curve (Figure 6). In 2018, the concentration of energy consumption was the highest in solid fuels (the coefficient from the sample was 0.95 and the estimated 0.99), and the lowest for electricity (from the sample 0.62, estimated 0.64). In 2018, Poland was responsible for 96% of the solid fuels consumed in agriculture. It was mainly hard coal. In natural gas, the Netherlands accounted for 61% of the consumption of this raw material in agriculture in the EU. The most energy from renewable sources was consumed in Germany (26%) and Poland (17%). It was mainly biodiesel. Overall, there were differences between energy types in the level of consumption concentration. Concentration coefficients were also calculated for the earlier periods, with a frequency

every three years. Only between 2014 and 2018, there was a four-year gap. As a result, the results concern the years 2005–2018. Such a summary allows determining the direction and pace of the changes in the concentration of energy consumption in agriculture. Generally, it can be noticed that the concentration of energy consumption in agriculture is maintained in several countries (Table 1). The reasonably stable situation also results from the permanent land stock, which is the primary production factor in agriculture. This limits the possibility of a drastic increase in agricultural production. Another reason may be relatively stable energy consumption and countries using technologies that ensure similar energy efficiency (such as tractors and machines, technologies for fattening animals, milk production, etc.). Only in the case of renewable energy sources, a gradual decrease in the concentration of its consumption in agriculture can be observed. More and more countries are developing technologies that allow the use of this type of energy. Agriculture is a sector that produces more renewable energy than it consumes.

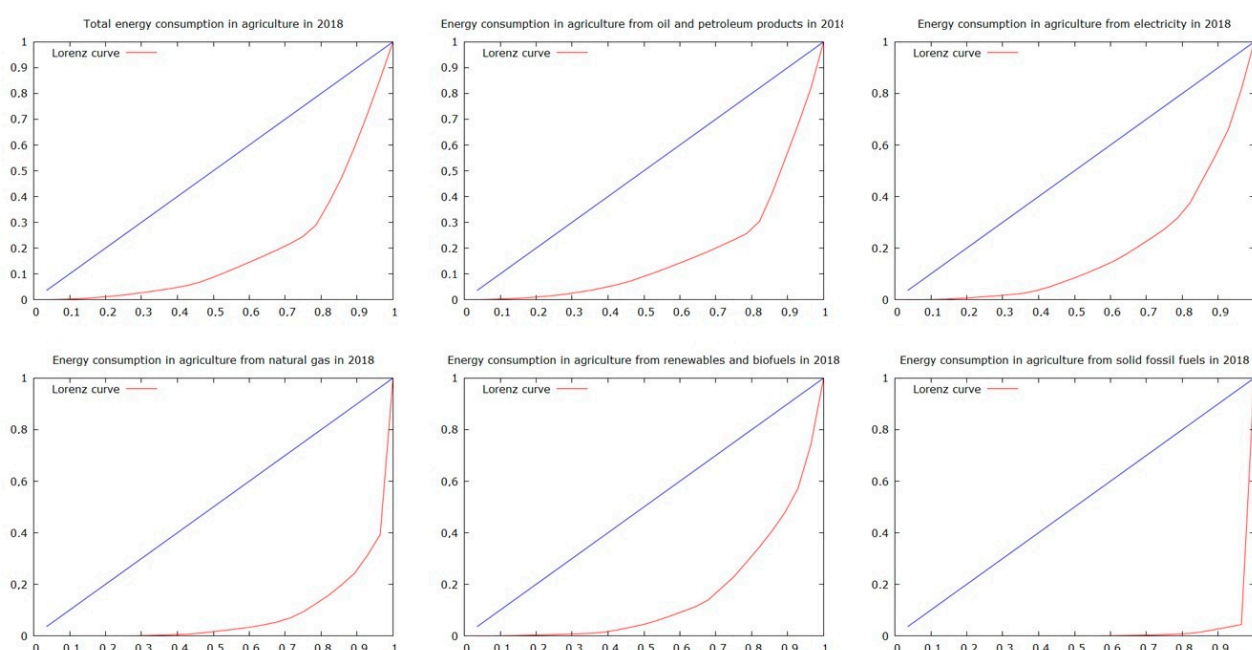


Figure 6. Lorenz concentration curves for the types of energy used in agriculture in the EU countries in 2018.

Table 1. Estimated Gini coefficients for the types of energy used in agriculture in the EU countries in 2005–2018.

Type of Energy Source	Estimated Gini Coefficients in Years				
	2005	2008	2011	2014	2018
Total	0.63	0.62	0.63	0.64	0.64
Oil and petroleum products	0.65	0.65	0.65	0.66	0.66
Electricity	0.66	0.64	0.64	0.64	0.64
Natural gas	0.88	0.86	0.84	0.85	0.87
Renewables and biofuels	0.79	0.76	0.73	0.71	0.71
Solid fossil fuels	0.97	0.98	0.99	0.99	0.99

Each country has a separate history and conditions, also in terms of the energy resources used. Five different countries, i.e., France, Poland, Romania, Greece, and Latvia, were selected for a more detailed analysis. France has the highest energy consumption in agriculture of any EU country. It was also an economically developed country, including in terms of agriculture. In 2005–2018, energy consumption in agriculture in this country decreased by 2.8%. Poland came second in terms of energy consumption. It was a developing country that joined the EU in 2004 and had fairly fragmented agriculture. The total energy

consumption in agriculture decreased by 11.7% in the analyzed period, which could be due to agriculture's ongoing transformation. Romania was also one of the countries admitted to the EU in 2004, catching up with Western European countries. In this country, energy consumption in agriculture increased by 163%, by far the highest among all EU countries. Despite this, Romania was in the middle of the EU countries' rate in energy consumption in agriculture. The largest decrease in energy consumption was recorded in Greece, by as much as 77%. As a result, it was ranked 17th in the EU. It was an economically developed country but suffering the effects of the economic crisis and having financial problems. The agricultural sector has also felt the effects of the economic downturn. Latvia was one of the newly admitted countries to the EU, with a small agricultural sector, but with a high energy consumption dynamics, because an increase of 43% was achieved. Despite this, the country ranked 21st in the EU.

In France, almost $\frac{3}{4}$ of the energy used in agriculture came from oil and a dozen or so from electricity (Figure 7). The share of other sources was small. The share of crude oil decreased quite slowly, while electricity and renewable energy sources increased. The situation was, therefore, relatively stable. In Poland's case, crude oil also dominated, but its share systematically decreased from 65% in 2005 to 59% in 2018 (Figure 8). Solid fuels, mainly coal, were also of great importance. A dozen or so percent of energy from renewable sources was also used, mainly it was biodiesel. This share remained at a double-digit level throughout the period considered. The other sources were of little importance.

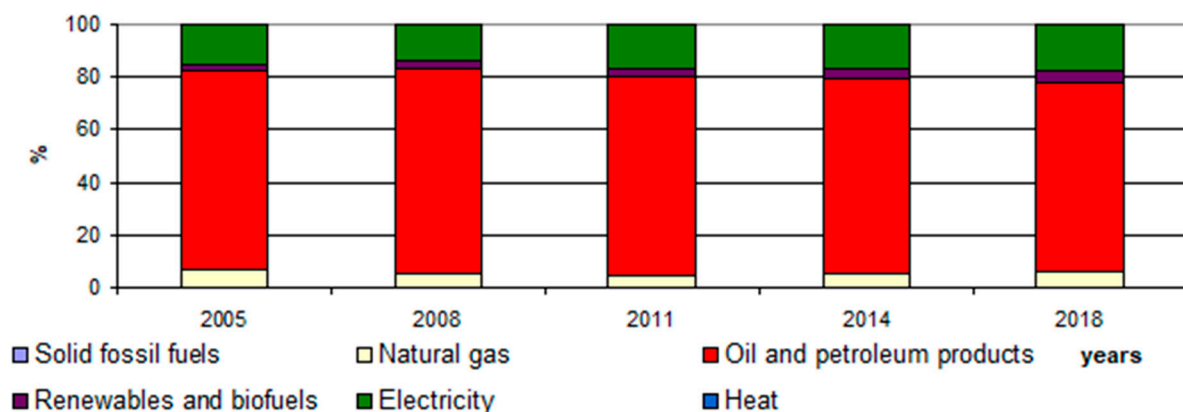


Figure 7. Structure of energy used in agriculture in France in 2005–2018.

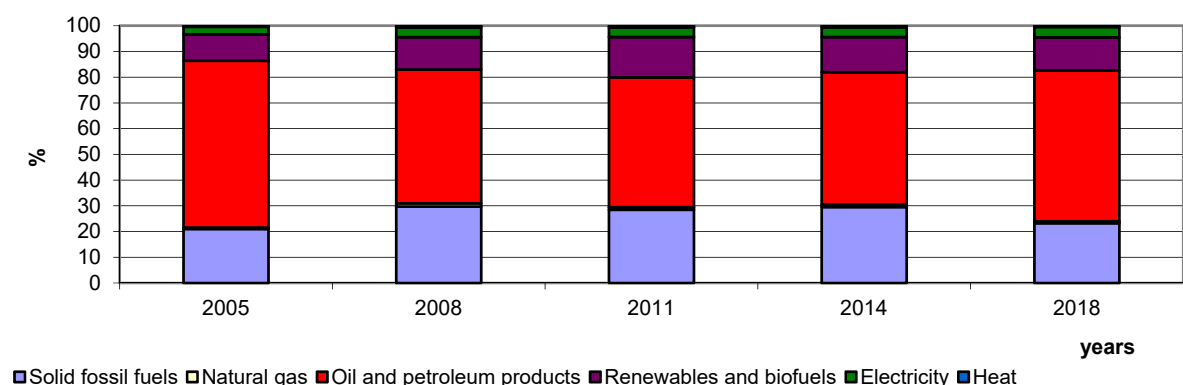


Figure 8. Structure of energy used in agriculture in Poland in 2005–2018.

In Romania, the share of crude oil in the energy used in agriculture was at a similar level as in Poland (Figure 9). In this country, however, the importance of this source grew, as its share increased from 55% in 2005 to 64% in 2018. Almost 20% were used for gas products (also increased in importance), and a dozen for electricity. Noteworthy is the very small share of energy consumed from renewable sources (1–2%). Peat was used

for energy purposes at a similar level. It was one of the few countries that used such an energy source. In Greece, there were very large changes in the structure of energy used in agriculture (Figure 10). The reason was a large reduction in energy consumption. Crude oil decreased in importance (a decrease from 76 to 14% in 2005–2018), while electricity gained in importance (an increase from 22 to 74%). A positive aspect was the increase in renewable energy consumption from 1% to 12%. In Latvia, there was the largest consumption of crude oil in agriculture (Figure 11). Its consumption in the analyzed period was around 60–70%. In the case of electricity, it was around 10%. The importance of gaseous products has decreased, while of thermal energy and energy obtained from renewable sources has increased.

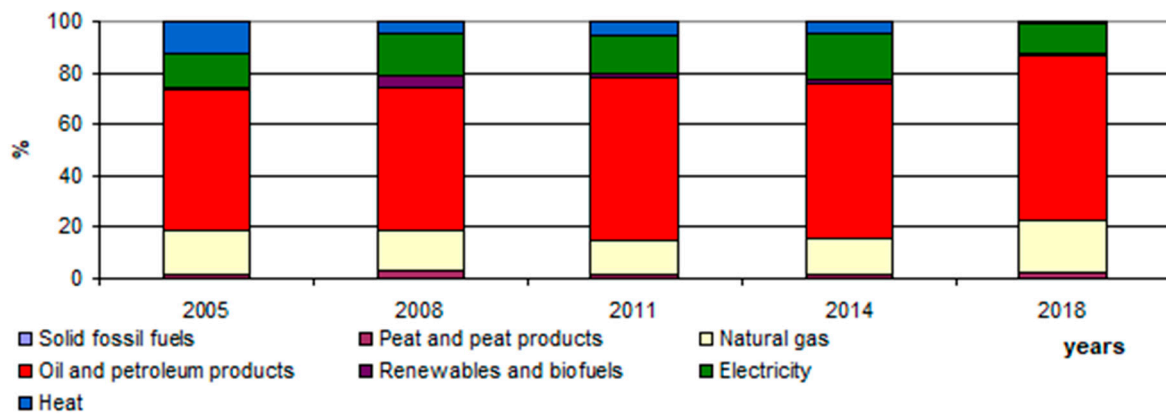


Figure 9. Structure of energy used in agriculture in Romania in 2005–2018.

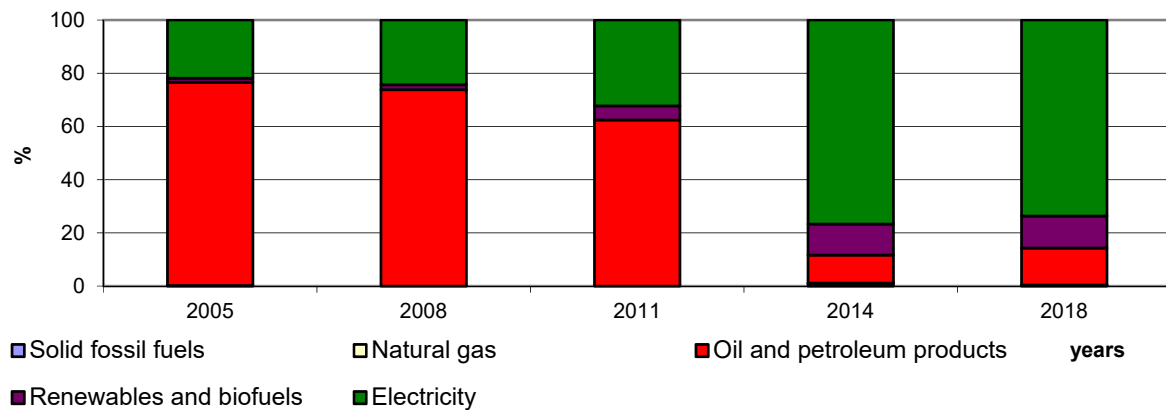


Figure 10. Structure of energy used in agriculture in Greece in 2005–2018.

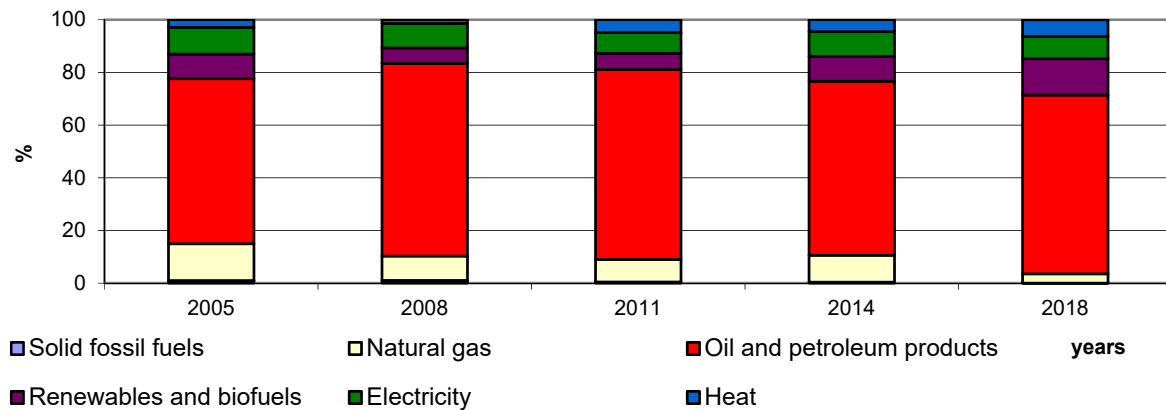


Figure 11. Structure of energy used in agriculture in Latvia in 2005–2018.

In the EU countries, crude oil was the most important, as it satisfied more than half of the needs of the agricultural sector. In 2005, it was 63% and in 2018, 57%. It was followed by electricity (16% in 2018), natural gas (12%), and renewable energy sources (10%). The share of energy from heat and peat combustion was very low. Apart from Greece, all countries presented had a structure similar to the EU average. Liquid fuels dominated, which is obvious, because they were the power source for tractors and agricultural machinery. The share of other sources was smaller and each country had a structure that often corresponded to energy resources found in the country or those that can be easily supplied.

The share of energy from renewable energy sources in total energy consumption in agriculture varied across countries. In 2018, in the top five countries, it was above 20% (Figure 12. Sweden was the clear leader with 35%, followed by Austria (33%), Finland (25%), Germany, and Slovakia (23% each). These were economically developed countries that allocated large resources to the implementation of new technologies ensuring the use of renewable energy. Only Slovakia was a developing country that significantly increased renewable energy use, as in 2005 it was only 1%. As many as 12 countries have achieved or exceeded the 10% share of renewable energy, which is the EU average. There were also economically highly developed countries that had a very small share of renewable energy in energy consumption in agriculture. Examples are Italy (2% in 2018), Spain (3%), and France (5%). Nevertheless, the importance of this energy source was systematically growing.

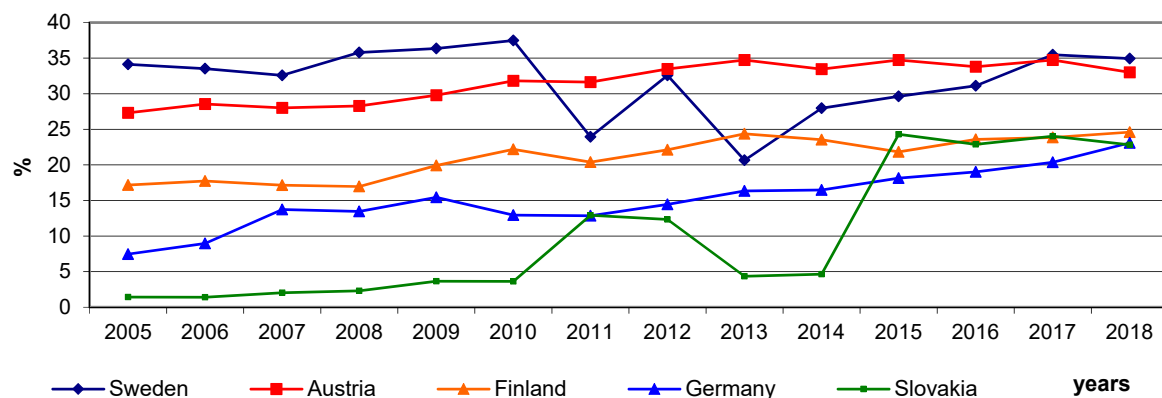


Figure 12. Top 5 EU countries in share of renewable energy in the total energy use in agriculture in the in 2005–2018.

In the next stage, the dynamics indicators for the basic groups of energy sources were calculated. The 2005 level was adopted as the basis (Table 2). Over 14 years, the increase in energy consumption in agriculture was recorded in 11 EU countries, by far the largest in Romania, and significant in Latvia, Germany, and the United Kingdom. In turn, substantial declines occurred in Greece, but also significant in Bulgaria, Sweden, Ireland, and Portugal. The reason for the drops may be the limitation of agricultural production or the use of more effective technology. In turn, when energy consumption increases, the reasons are the opposite. Each country should be analyzed separately due to the natural, economic, and social conditions. In the case of Greece, a substantial reduction in oil consumption can be observed, which may be related to the cessation or reduction of many agricultural production. Increase in this country was recorded in the case of the consumption of renewable energy sources. In Romania, all energy sources' consumption, except for fossil fuels, increased (decrease by 50%). In Latvia, fossil and gas fuels have been abandoned. The consumption of energy from renewable sources in the Netherlands and Belgium proliferated, as it increased by several dozen times. These countries, however, started out from low consumption of this type of energy. In general, countries are moving away from fossil fuels, and mostly from gas and heat. As a rule, oil consumption was reduced. Electricity consumption increased in most countries. In the case of renewable energy, its consumption has been systematically growing in all EU countries. Only Sweden (with a very high share of renewable energy) and Bulgaria recorded declines. Some countries did

not use renewable energy in 2005. Therefore, it was not possible to calculate the dynamics index for such countries.

Table 2. Dynamics indicators for energy used in agriculture in EU countries in 2005–2018 (year 2005 = 100).

Countries	Dynamics Indicators for Types of Energy Used in Agriculture in 2005–2018						
	Total	Solid Fossil Fuels	Natural Gas	Oil and Petroleum Products	Renewables and Biofuels	Electricity	Heat
Romania	263.40	49.82	310.99	309.87	198.55	227.27	17.81
Latvia	142.99	0.18	36.10	154.89	211.59	119.67	308.26
Germany	134.80	-	-	93.83	417.30	-	-
United Kingdom	134.02	-	45.92	222.34	195.02	80.95	-
Estonia	118.96	81.01	66.65	137.33	103.81	76.19	70.83
Hungary	114.34	21.00	48.82	169.60	225.12	104.86	150.00
Czechia	113.28	31.94	77.47	98.75	745.13	94.59	55.19
Cyprus	111.99	-	-	86.26	-	147.13	-
Luxembourg	105.71	-	724.74	96.46	160.71	102.11	-
Lithuania	103.22	199.15	73.49	111.29	237.97	110.90	41.34
Austria	100.48	19.45	118.48	80.52	121.42	125.12	159.74
Croatia	99.48	-	102.55	94.28	-	94.48	-
Slovenia	97.30	-	-	93.75	-	-	-
Belgium	97.17	52.00	1 533.80	41.68	2 807.09	457.57	-
France	97.13	-	80.41	91.87	198.37	114.04	-
Finland	96.13	64.38	7.33	74.88	137.67	120.26	123.86
Malta	94.48	-	-	74.33	-	-	-
EU	94.13	90.60	77.36	96.38	185.30	124.82	66.81
Netherlands	94.00	-	74.67	94.45	4 093.37	172.32	39.90
Italy	93.00	-	81.03	90.24	202.12	103.69	879.48
Poland	88.29	97.71	116.89	79.82	110.60	123.50	97.21
Denmark	87.06	21.94	68.03	93.63	108.34	91.36	79.55
Slovakia	80.24	15.49	48.01	73.72	1 280.81	61.22	20.67
Spain	78.84	-	39.84	79.44	389.18	94.71	-
Portugal	73.24	-	101.96	65.91	-	107.53	0.00
Ireland	66.57	-	-	62.59	-	86.74	-
Sweden	62.25	-	26.89	58.02	63.75	78.08	100.00
Bulgaria	60.95	191.79	53.87	50.25	92.53	137.82	2 816.45
Greece	22.92	24.01	-	4.16	186.10	77.22	-

The coefficients of variation for individual energy sources in agriculture were calculated for the years 2005–2018 (Table 3). In the case of total energy, there were no large fluctuations in energy consumption in individual years. The exception was Greece. Energy consumption from crude oil was also relatively stable, apart from Greece, where this demand has decreased very drastically, and Great Britain, where there has been a large increase in oil consumption. There was also little variability in the case of electricity. More significant variability occurred with heat, solid, and gaseous fuels. There was quite a lot of variability in most countries in renewable energy due to the rapidly growing consumption of this energy in almost all EU countries.

To establish the relationship between the amount of energy consumption in agriculture in the EU countries and the basic parameters of the economy and agriculture, Kendall's tau correlation coefficient and Spearman's rank correlation coefficient were calculated (Tables 4 and 5). $p = 0.05$ was adopted as the border value of the significance level. Significant results are marked in bold in the table. Correlation coefficients were calculated for all EU countries for the entire 2005–2018 period. The study tried to check the correlation, which does not indicate that a given factor affects another, but a strong or weak relationship between them. In the case of energy, the total consumption in agriculture and the most critical groups, i.e., crude oil and renewable energy, were used for calculations.

Table 3. Coefficients of variation of energy used in agriculture in EU countries in 2005–2018.

Countries	Coefficients of Variation in the Volume of Energy Used in Agriculture by Types						
	Total	Solid Fossil Fuels	Natural Gas	Oil and Petroleum Products	Renewables and Biofuels	Electricity	Heat
France	0.02	-	0.12	0.03	0.21	0.08	-
Austria	0.02	0.72	0.20	0.06	0.10	0.07	0.20
EU	0.02	0.08	0.09	0.09	0.19	0.07	0.13
Finland	0.03	0.27	0.85	0.07	0.13	0.07	0.08
Croatia	0.03	-	0.12	0.06	-	0.05	-
Slovenia	0.04	-	-	0.05	-	-	-
Lithuania	0.04	0.56	0.22	0.07	0.22	0.07	0.33
Netherlands	0.04	-	0.09	0.04	0.68	0.17	0.34
Italy	0.05	-	0.09	0.06	0.42	0.03	0.72
Denmark	0.06	0.41	0.14	0.07	0.03	0.04	0.11
Slovakia	0.07	0.57	0.20	0.08	0.90	0.15	0.69
Cyprus	0.07	-	-	0.12	-	0.11	-
Poland	0.07	0.08	0.16	0.15	0.07	0.06	0.09
Czechia	0.08	0.34	0.11	0.01	0.66	0.10	0.27
Belgium	0.08	0.56	0.31	0.29	0.49	0.34	-
Luxembourg	0.08	-	1.55	0.10	0.23	0.13	-
Spain	0.10	-	0.67	0.12	0.37	0.14	-
Latvia	0.12	0.75	0.29	0.12	0.38	0.12	0.49
Hungary	0.13	0.99	0.25	0.21	0.34	0.10	0.36
Estonia	0.13	1.79	0.20	0.19	0.40	0.09	0.21
Portugal	0.14	-	0.18	0.17	-	0.09	0.80
Germany	0.15	-	-	0.02	0.36	-	-
Ireland	0.16	-	-	0.19	-	0.04	-
Sweden	0.18	-	0.45	0.14	0.27	0.24	0.00
United Kingdom	0.19	-	0.30	0.51	0.59	0.14	-
Bulgaria	0.20	0.26	0.29	0.30	0.69	0.12	0.77
Romania	0.25	2.20	0.39	0.30	1.01	0.25	0.36
Malta	0.26	-	-	0.36	-	-	-
Greece	0.60	1.38	-	0.98	0.23	0.10	-

Table 4. Kendall's tau correlation coefficients between the volume of use of energy in agriculture in the EU countries and the parameters of the economy and agriculture.

Tested Parameters	Kendall's Tau Correlation Coefficient					
	Total Energy		Oil and Petroleum Products		Renewables and Biofuels	
	τ	p -Value	τ	p -Value	τ	p -Value
Correlation coefficients between energy consumption and						
Value of GDP	0.978	0.001	-0.341	0.080	0.868	0.001
Final consumption expenditure of households	0.978	0.001	-0.341	0.080	0.868	0.001
Export of goods and services	0.978	0.001	-0.341	0.080	0.868	0.001
Import of good and services	0.978	0.001	-0.341	0.080	0.824	0.001
GDP per capita	0.999	0.001	-0.319	0.100	0.846	0.001
Final consumption expenditure of households per capita	0.999	0.001	-0.319	0.100	0.846	0.001
Gross value added of agriculture, forestry, and fishing	0.934	0.001	-0.341	0.080	0.780	0.001
Area of agricultural crops	-0.495	0.012	0.692	0.001	-0.604	0.002
Area of grain sowing	-0.538	0.006	0.077	0.743	-0.516	0.009
Cows' milk production	0.495	0.016	-0.165	0.381	0.560	0.006

Table 5. Spearman’s rank correlation coefficients between the volume of use of energy in agriculture in the EU countries and the parameters of the economy and agriculture.

Tested Parameters	Spearman’s Rank Correlation Coefficient					
	Total Energy		Oil and Petroleum Products		Renewables and Biofuels	
	τ	<i>p</i> -Value	τ	<i>p</i> -Value	τ	<i>p</i> -Value
Correlation coefficients between energy consumption and						
Value of GDP	0.996	0.010	−0.442	0.100	0.947	0.010
Final consumption expenditure of households	0.996	0.010	−0.442	0.100	0.947	0.010
Export of goods and services	0.996	0.010	−0.442	0.100	0.952	0.010
Import of good and services	0.996	0.010	−0.437	0.100	0.930	0.010
GDP per capita	0.999	0.010	−0.429	0.100	0.934	0.010
Final consumption expenditure of households per capita	0.999	0.010	−0.429	0.100	0.934	0.010
Gross value added of agriculture, forestry, and fishing	0.982	0.010	−0.442	0.100	0.903	0.010
Area of agricultural crops	− 0.723	0.010	0.824	0.010	− 0.780	0.010
Area of grain sowing	− 0.692	0.010	0.169	0.100	− 0.697	0.010
Cows’ milk production	0.618	0.050	−0.178	0.100	0.675	0.010

In Kendall’s tau correlation, significant positive relations were found for all parameters with the total energy supply in agriculture. The strength of the relationship was very significant for the economic parameters. These relationships were solid for both the global performance and per capita performance parameters. The parameters related to agriculture were less related to the energy supply in the agricultural sector. A solid relationship was in the case of gross value added of agriculture, forestry, and fishing. Hostile average relations were in the case of total agricultural area and agricultural area of the grain. In general, these areas slightly decreased, and there was a systematic increase in energy consumption in agriculture. Average positive relations were between cows’ milk production and total energy consumption in agriculture. Both parameters tended to increase. Similar relationships were found between renewables and biofuels consumption in agriculture and the studied parameters. Interestingly, in renewable energy, the strength of dependence was lower for the relationship with all the analyzed parameters of the economy and agriculture than in total and crude energy. This may indicate certain independence in the development of these energy sources. It is merely a necessity and additionally contributes to the protection of the natural environment. In this case, social factors are more critical than in the case of other energy sources. Oil and petroleum product consumption relationships were inconsistent with all parameters, except for the total agricultural area. A strong positive correlation was obtained for this parameter. Diesel fuel was mainly used to power tractors and agricultural machines that are used to cultivate the land. So, such dependencies are not strange. The presented correlation results indicate solid relationships between the volume of energy consumption in agriculture and the economic potential and economic development level. The general situation in the economy was more decisive. When favorable, it also fueled agriculture and favored more work. In turn, the economic crisis also affected agriculture and led to a reduction in production. In land-related parameters, these relationships were negative because land resources do not increase but even decrease. In turn, energy consumption in agriculture grew, including as a result of replacing human labor with devices and greater mechanization of labor and the use of crops and agricultural production requiring greater energy consumption per production unit. Milk production increased in animal production, which was positively correlated with energy consumption in agriculture. It must also be said that differences were depending on the type of energy. The lower strength of the relationship was found in the case of renewables and biofuels. The results were generally not significant for oil and petroleum products consumption.

The analysis carried out with the use of Spearman's rank correlation coefficients gave very similar results. The strength of the relationship was slightly different. Both tests confirm the close relationship between total energy consumption in agriculture and economic parameters and smaller ones with agricultural parameters. In the case of renewable energy, the strength of the relationship was also smaller. On the other hand, the consumption of diesel oil was not related to the economic situation or directly to agricultural production parameters. The only exception was the agricultural land area, which strongly influenced diesel fuel consumption for tractors and agricultural machinery.

4. Discussion

Many authors confirm a strong relationship between energy consumption and agricultural productivity [72,73]. The main factor of the increase in productivity was technological progress, taking place precisely due to mechanization and the use of machines requiring energy supply [74–77]. Agriculture's energy use and trends have varied around the world. In the EU, US, and Japan, most energy consumption indicators were decreasing. Only the Netherlands and Spain saw an increase. In developing countries, energy consumption in agriculture has increased [78,79]. There were differences between individual EU countries. Most EU countries could better rationalize their use of inputs (resources), achieving greater production efficiency. Western European countries were more productive than those in Eastern Europe [80,81]. Countries should also find an appropriate compromise between meeting the demand for products through domestic production and import. One cannot forget about environmental protection in these activities [82]. For example, supporting organic farms contributes to the reduced energy consumption in agriculture in the EU [83–86]. On the other hand, saving energy does not only mean saving fuel and electricity. Essential areas of energy saving include reducing the demand for power (machines and devices), reducing the energy consumption of production as a whole, and using alternative energy sources for production. The technical and technological modernization of agriculture directly impacts the energy consumption of production [87–91]. One of the saving methods is the introduction of precision farming [92,93].

Changes in energy consumption from individual sources have been and will be varied. Farajian [94], in his research, predicted that there would be an increase in electricity consumption in agriculture and a decline in diesel fuel consumption. Electricity is consumed in four categories: farm buildings, agricultural land, cultivation procedures, and farms. Electricity is supplied to all machines located in outbuildings, such as milking machines and grain mills. Electrical equipment is also used to harvest and plant irrigation and dry with fans [95–97].

The relationship between economic activity and energy use is fairly well researched. The first results of research on this subject were published in the 1950s [98,99]. The topic was developed in the following decades, with particular emphasis on the US economy, including by Schurr et al. [100], Warren [101] de Janosi and Grayson [102], Solow [103], and Rasche and Tatom [104]. Studies on other countries on the relationship between economic performance and energy consumption were initiated by Kraft and Kraft [105]. The studies covered different periods and different methods were used. One should mention the research by Humphrey and Stanislaw [106] for Great Britain, Zilberfarb and Adams [107] for developing countries, Yu and Choi [108] for international comparison, Adams and Miovic [109] for Western Europe, Abakah [110] for Ghana, Shafik and Bandyopadhyay [111] for the Country Panel, Hawdon and Pearson [112] for the UK, Masih and Masih [113] for the Country Panel, Cheng and Lai [114] for Taiwan, and Naqvi [115] for Pakistan. In the following years, many researchers dealt with the relationship between economic growth and energy consumption. Increasingly longer periods are used from a large number of countries, using increasingly reliable econometric methods. Despite numerous studies, there is still no clear answer to the relationship between economic growth and energy consumption. Some researchers support the hypothesis that energy consumption leads to economic growth, e.g., Apergis and Payne [116], Ozturk et al. [117], Ouedraogo [118], Aslan

et al. [119]. Some researchers claim that economic growth affects energy consumption, e.g., Huang and Hwang [120], Narayan et al. [121], Kasman and Duman [122]. Some researchers support the feedback hypothesis that there is a two-way causal relationship between energy use and economic growth, e.g., Constantini and Martini [123], Belke et al. [124], Coers and Sanders [125]. There is also a group of researchers who support the neutrality hypothesis that economic growth and energy consumption are independent, e.g., Wolde-Rufael [126], Kahsai et al. [127], Laughter and Pope [128]. The results and relationships depended on the countries (groups of countries), periods, and methods used.

Different results have been obtained for the relationship between the volume of agricultural production and energy consumption. For example, Dogan et al. [129] studied the electricity consumption in agriculture in Turkey in 1995–2013. They found that the use of electricity in agriculture affected agricultural production in non-coastal regions, while a two-way causal link existed between these variables for coastal regions. Raeni et al. [130] found, based on Iranian agriculture that a 1% increase in agricultural energy consumption leads to a 1.29% increase in agricultural production in the long run. Similar results were achieved by, among others, Altinay and Karagol [131], Lee and Chang [132], Adebola [133] and Apergis and Payne [134]. Apergis and Payne [135] found a two-way causality between renewable and nonrenewable energy consumption and economic growth in the short and long term. They also found short-term substitutability between the two energy sources. In general, the current trend is to decouple energy consumption from economic growth. According to this assumption, energy consumption should fall and economic growth should follow [136]. The ways to achieve this goal are to reduce the area of crops with the simultaneous advancement of agricultural technology, improving the productivity per unit area. There were, however, significant differences in agricultural technology between countries [137,138]. Developed countries and regions may be more suited to introducing new agricultural technologies to improve productivity than developing countries [139]. In developing countries, compensation for agricultural productivity may come from educating farmers in agricultural knowledge and experience [140,141]. In Western European countries, a situation is observed where agricultural production remains at a similar level, but the consumption of energy allocated for this purpose is falling [142]. There is a significant difference between the old (EU-15) and new EU member states (admitted after 2004) in agricultural productivity. Consequently, there are also differences in the efficiency of energy use [143,144]. It is precisely the increase in energy efficiency in agriculture that should reduce the differences between developed and developing countries [145].

Many studies have confirmed the relationship between energy consumption in agriculture and economic growth [146,147]. These dependencies were analyzed, even taking into account the environmental Kuznets curve. The attention was paid to CO₂ emissions from agriculture-related to energy consumption in agriculture and economic growth. The relationships were one-way [148]. It is precisely the reduction of pollutant emissions into the environment that is the primary goal of agriculture. The emission of pollutants is inextricably linked with energy consumption. Therefore, the aim is to apply energy-efficient technologies and implement innovations in agriculture [149–153].

5. Conclusions

Energy is an indispensable production resource in agriculture. First of all, it is used to power machines and devices operating in this sector. In the EU countries, the total energy consumption has decreased. However, according to its circumstances, there are changes in their origin sources, and each country has its structure in this regard. It was found that the concentration level of energy consumption in agriculture did not change and was relatively high. This situation is influenced by the relative stability of production, which is conditioned, among other things, by the land-owned resources. Another reason may be relatively stable energy consumption and countries with technologies that ensure similar energy efficiency. Only in the case of renewable energy sources, a gradual decrease in the concentration of its consumption in agriculture can be observed. More and more countries

are developing technologies that allow the use of this type of energy. Agriculture was a sector that produced more renewable energy than it consumed.

In the EU countries, crude oil was of the most significant importance, as about 60% of the energy used in agriculture came from this source. Electricity and natural gas accounted for a dozen or so percent, and renewable energy accounted for 10%. In most countries, the structure was similar, i.e., with the dominant importance of crude oil. In the case of other energy sources, the proportions were varied. Overall, renewable energies grew in importance in all countries. In the top five countries in 2018, such sources accounted for over 20% of the energy used in agriculture. As a rule, economically developed countries developed this type of technology, but there were also examples of developing countries, such as Slovakia, which dynamically increased the production and energy use from renewable sources. There were also examples of economically developed countries that used very little renewable energy in agriculture, such as Italy and Spain. Overall, the EU is shifting away from fossil and gaseous fuels, the importance of liquid fuels and the growing importance of electricity and renewable energy. The rapid changes created high volatility for fuels that were gaining in importance and those that were losing. Energy sources with stabilized consumption, such as electricity and crude oil, were characterized by low consumption volume variability. There was also a significant stabilization concerning the total energy used in agriculture. The first hypothesis was confirmed. There are processes of diversification of energy sources used in agriculture, but these changes are prolonged. The importance of renewable energy sources is also systematically growing.

A significant influence of the economic situation on energy consumption in agriculture was found. The better it was, the more energy was used in agriculture. The union strength was lower in the case of renewables. Thus, the second hypothesis was confirmed, according to which the increase in the consumption of renewable energy in agriculture is closely related to the economy's parameters. It should be added that this relationship was not very strong. Such energy is a necessity and results from concern for the natural environment. Therefore, economic factors may have a smaller impact.

A close correlation was also established between agricultural parameters concerning land resources and production volume and energy consumption. Thus, the already known regularities were confirmed. In agriculture, energy consumption will increase as a result of increasingly replacing human work with devices. It seems that the increase in mechanization will be faster than the development of energy-consuming technologies. The only chance to achieve progress in mechanization in agriculture without increasing the harmful impact on the environment is by introducing renewable energy sources. The conducted research confirms this trend. These energy sources are also increasingly commonly introduced by all countries, regardless of the level of economic development. In the following years, increasing consumption of energy from renewable sources should be observed. Modern agriculture in the European Union should follow this direction.

Author Contributions: Conceptualization, T.R., A.P., B.K.; data curation, T.R., A.P., P.B., A.B.-B.; formal analysis, T.R., B.K., P.B., A.P.; methodology, T.R., B.K., P.B., A.P.; resources, T.R., A.P., B.K., K.M., A.B.-B.; visualization, T.R., P.B., K.M., A.P.; writing—original draft, T.R., A.P., B.K.; writing—review and editing, T.R., A.P., P.B., A.B.-B., K.M.; supervision, T.R., B.K.; funding acquisition, T.R., B.K., P.B., A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Giannakis, E.; Bruggeman, A. The highly variable economic performance of European agriculture. *Land Use Policy* **2015**, *45*, 26–35. [[CrossRef](#)]
2. Schulp, C.J.; Levers, C.; Kuemmerle, T.; Tieskens, K.F.; Verburg, P.H. Mapping and modelling past and future land use change in Europe's cultural landscapes. *Land Use Policy* **2019**, *80*, 332–344. [[CrossRef](#)]

3. Kristensen, S.B.P.; Busck, A.G.; van der Sluis, T.; Gaube, V. Patterns and drivers of farm-level land use change in selected European rural landscapes. *Land Use Policy* **2016**, *57*, 786–799. [CrossRef]
4. Leśniewska-Napierała, K.; Nalej, M.; Napierała, T. The Impact of EU Grants Absorption on Land Cover Changes—The Case of Poland. *Remote Sens.* **2019**, *11*, 2359. [CrossRef]
5. Veronica, P.; Raluca, T.A. Convergence of Romanian and European Union Agriculture—Evolution and Prospective Assessment. *Ovidius Univ. Ann. Econ. Sci. Ser.* **2018**, *18*, 239–247.
6. Reiff, M.; Surmanová, K.; Balcerzak, A.P.; Pietrzak, M.B. Multiple criteria analysis of European Union agriculture. *J. Int. Stud.* **2016**, *9*, 62–74. [CrossRef] [PubMed]
7. Nowak, A.; Kaminska, A. Agricultural competitiveness: The case of the European Union countries. *Agric. Econ.* **2016**, *62*, 507–516.
8. Dos Santos, M.L. Segmenting Farms in the European Union. *Agric. Econ.* **2013**, *59*, 49–57.
9. Carraresi, L.; Banterle, A. Agri-food Competitive Performance in EU Countries: A Fifteen-Year Retrospective. *Int. Food Agribus. Manag. Rev.* **2015**, *18*, 37–62.
10. Spicka, J. The economic disparity in European agriculture in the context of the recent EU enlargements. *J. Econ. Sustain. Dev.* **2013**, *4*, 125–133.
11. Reiff, M.; Ivanicova, Z.; Surmanova, K. Cluster analysis of selected world development indicators in the fields of agriculture and the food industry in European Union countries. *Agric. Econ.* **2018**, *64*, 197–205. [CrossRef]
12. Reiff, M.; Surmanova, K.; Balcerzak, A.P.; Pietrzak, M.B. *Quantitative Analysis of European Union Agriculture Performance*; Institute of Economic Research Working Papers No. 32/2016; 2016. Available online: http://www.badania-gospodarcze.pl/images/Working_Papers/2016_No_32.pdf (accessed on 10 January 2021).
13. Coca, O.; Ștefan, G.; Cretu, A.; Creangă, D.E. Research on the Development of Agriculture in the European Union. A Structural Analysis by Geographical Groups of Countries. *Rom. Agric. Res.* **2020**, *37*, 229–242.
14. Vanschoenwinkel, J.; Mendelsohn, R.; Van Passel, S. Do Western and Eastern Europe have the same agricultural climate response? Taking adaptive capacity into account. *Glob. Environ. Chang.* **2016**, *41*, 74–87. [CrossRef]
15. Swinnen, J.F.; Swinnen, J.; Vranken, L. *Land & EU Accession: Review of the Transitional Restrictions on New Member States on the Acquisition of Agricultural Real Estate*; CEPS: Brussels, Belgium, 2009.
16. Hartvigsen, M. Land reform and land fragmentation in Central and Eastern Europe. *Land Use Policy* **2014**, *36*, 330–341. [CrossRef]
17. Andrejovská, A.; Buleca, J.; Hudáková, M. Categorization of the EU Countries in the Context of Agricultural Production. *AGRIS On-Line Pap. Econ. Inform.* **2016**, *8*, 3–14. [CrossRef]
18. Rokicki, T.; Perkowska, A.; Ratajczak, M. Differentiation in Healthcare Financing in EU Countries. *Sustainability* **2021**, *13*, 251. [CrossRef]
19. Rokicki, T.; Perkowska, A. Changes in Energy Supplies in the Countries of the Visegrad Group. *Sustainability* **2020**, *12*, 7916. [CrossRef]
20. Ciutacu, C.; Chivu, L.; Andrei, J.V. Similarities and dissimilarities between the EU agricultural and rural development model and Romanian agriculture. Challenges and perspectives. *Land Use Policy* **2015**, *44*, 169–176. [CrossRef]
21. Popescu, G.H.; Nicoale, I.; Nica, E.; Vasile, A.J.; Andreea, I.R. The influence of land-use change paradigm on Romania’s agro-food trade competitiveness—An overview. *Land Use Policy* **2017**, *61*, 293–301. [CrossRef]
22. Giannakis, E.; Bruggeman, A. Regional disparities in economic resilience in the European Union across the urban-rural divide. *Reg. Stud.* **2020**, *54*, 1200–1213. [CrossRef]
23. Szabo, L.; Grznár, M. Agriculture in the EU and Position of the Slovak Republic. *Agric. Econ.* **2015**, *61*, 493–501. [CrossRef]
24. Pietrzak, M.B.; Walczak, D. The Analysis of the Agrarian Structure in Poland with the Special Consideration of the Years 1921 and 2002. *Bulg. J. Agric. Sci.* **2014**, *20*, 1018–1039.
25. Walczak, D.; Pietrzak, M.B. Analysis of Agrarian Structure in Poland in 1921 and 2002 based on the Example of Selected Districts. In *Business Challenges in the Changing Economic Landscape*; Bilgin, M.H., Danis, H., Demir, E., Can, U., Eds.; Springer: Berlin/Heidelberg, Germany, 2016; Volume 1, pp. 461–472.
26. Nowak, A.; Różańska-Boczula, M. Differentiation in the production potential and efficiency of farms in the member states of the European Union. *Agric. Econ.* **2019**, *65*, 395–403. [CrossRef]
27. Popescu, A.; Dinu, T.A.; Stoian, E. Efficiency of the agricultural land use in the European Union. Scientific Papers Series-Management. *Econ. Eng. Agric. Rural Dev.* **2019**, *19*, 475–486.
28. Popescu, A. Considerations on utilized agricultural land and farm structure in the European Union. Scientific Papers Series Management. *Econ. Eng. Agric. Rural Dev.* **2013**, *13*, 221–226.
29. Popescu, A.; Alecu, I.N.; Dinu, T.A.; Stoian, E.; Condei, R.; Ciocan, H. Farm Structure and Land Concentration in Romania and the European Union’s Agriculture. *Agric. Agric. Sci. Procedia* **2016**, *10*, 566–577. [CrossRef]
30. Bularca, E.; Toma, E. Agricultural labour productivity and its impact in farming system. *Sci. Pap. Ser. Manag. Econ. Eng. Agric. Rural Dev.* **2019**, *19*, 91–96.
31. Dorward, A. Agricultural labour productivity, food prices and sustainable development impacts and indicators. *Food Policy* **2013**, *39*, 40–50. [CrossRef]
32. Svoboda, J.; Lososová, J.; Zdeněk, R. Analysis of costs and their effectiveness in the EU agrarian sector. *Custos Agronegocio Line* **2020**, *16*, 151–173.

33. Abson, D.J. The economic drivers and consequences of agricultural specialization. In *Agroecosystem Diversity*; Academic Press: Cambridge, MA, USA, 2019; pp. 301–315. Available online: <https://www.sciencedirect.com/science/article/pii/B9780128110508000194> (accessed on 10 January 2021).
34. Brunori, G.; D'Amico, S.; Rossi, A. Practices of Sustainable Intensification Farming Models: An Analysis of the Factors Conditioning Their Functioning, Expansion, and Transformative Potential. In *Agroecosystem*; Academic Press: Cambridge, MA, USA, 2019; pp. 317–333.
35. Pavlov, A.Y. Managing sustainable development of rural areas using algorithms of agricultural specialization. *Mediterr. J. Soc. Sci.* **2015**, *6*, 147. [[CrossRef](#)]
36. Pierangeli, F.; Henke, R.; Coronas, M.G. Multifunctional agriculture: An analysis of country specialization and regional differentiation. In Proceedings of the European Association of Agricultural Economists (EAAE), Ghent, Belgium, 26–29 August 2008. No. 725-2016-49366.
37. Vlasenko, T.; Vlasovets, V.; Timofeev, S.; Kravets, A. Specialization issues of production of agrarian enterprises. In *SHS Web of Conferences*; EDP Sciences: Paris, France, 2019; Volume 67, p. 06056.
38. Mushtaq, K.; Abbas, F.; Ghafoor, A. Energy use for economic growth: Cointegration and causality analysis from the agriculture sector of Pakistan. *Pak. Dev. Rev.* **2007**, *46*, 1065–1073. [[CrossRef](#)]
39. Sebri, M.; Abid, M. Energy use for economic growth: A trivariate analysis from Tunisian agriculture sector. *Energy Policy* **2012**, *48*, 711–716. [[CrossRef](#)]
40. Agheli, L. Estimating the demand for diesel in agriculture sector of Iran. *Int. J. Energy Econ. Policy* **2015**, *5*, 660–667.
41. Ceylan, Z. Assessment of agricultural energy consumption of Turkey by MLR and Bayesian optimized SVR and GPR models. *J. Forecast.* **2020**, *39*, 944–956. [[CrossRef](#)]
42. Zaman, K.; Khan, M.M.; Ahmad, M.; Rustam, R. The relationship between agricultural technology and energy demand in Pakistan. *Energy Policy* **2012**, *44*, 268–279. [[CrossRef](#)]
43. Perea, R.G.; Poyato, E.C.; Montesinos, P.; Díaz, J.R. Prediction of irrigation event occurrence at farm level using optimal decision trees. *Comput. Electron. Agric.* **2019**, *157*, 173–180. [[CrossRef](#)]
44. Qiao, F. Increasing wage, mechanization, and agriculture production in China. *China Econ. Rev.* **2017**, *46*, 249–260. [[CrossRef](#)]
45. Tanikawa, T. Mechanization of Agriculture Considering Its Business Model. In *Smart Plant Factory*; Springer: Singapore, 2018; pp. 241–244.
46. Kalita, A. Changes in labor pattern and agricultural mechanization. *J. Manag. Res. Anal.* **2019**, *6*, 9–13. [[CrossRef](#)]
47. Mihov, M.; Kr, G.; Ivanova, N. Current Problems of Agricultural Production Mechanization. *Mech. Agric. Conserv. Resour.* **2017**, *63*, 111–114.
48. Zheng, S.; Lam, C.M.; Hsu, S.C.; Ren, J. Evaluating efficiency of energy conservation measures in energy service companies in China. *Energy Policy* **2018**, *122*, 580–591. [[CrossRef](#)]
49. Raza, M.Y.; Wasim, M.; Sarwar, M.S. Development of Renewable Energy Technologies in rural areas of Pakistan. *Energy Sources Part A Recovery Util. Environ. Eff.* **2020**, *42*, 740–760. [[CrossRef](#)]
50. Karkacier, O.; Goktolga, Z.G.; Cicek, A. A regression analysis of the effect of energy use in agriculture. *Energy Policy* **2006**, *34*, 3796–3800. [[CrossRef](#)]
51. Alipour, A.; Veisi, H.; Darijani, F.; Mirbagheri, B.; Behbahani, A.G. Study and determination of energy consumption to produce conventional rice of the Guilan province. *Res. Agric. Eng.* **2012**, *58*, 99–106. [[CrossRef](#)]
52. Chandio, A.A.; Jiang, Y.; Rehman, A. Energy consumption and agricultural economic growth in Pakistan: Is there a nexus? *Int. J. Energy Sect. Manag.* **2019**, *13*, 597–609. [[CrossRef](#)]
53. Inumula, K.M.; Singh, S.; Solanki, S. Energy Consumption and Agricultural Economic Growth Nexus: Evidence from India. *Int. J. Energy Econ. Policy* **2020**, *10*, 545. [[CrossRef](#)]
54. Pamučar, D.; Behzad, M.; Božanić, D.; Behzad, M. Decision making to support sustainable energy policies corresponding to agriculture sector: Case study in Iran's Caspian Sea coastline. *J. Clean. Prod.* **2020**, 125302. [[CrossRef](#)]
55. Chang, J.; Leung, D.Y.; Wu, C.Z.; Yuan, Z.H. A review on the energy production, consumption, and prospect of renewable energy in China. *Renew. Sustain. Energy Rev.* **2003**, *7*, 453–468. [[CrossRef](#)]
56. Haberl, H.; Beringer, T.; Bhattacharya, S.C.; Erb, K.H.; Hoogwijk, M. The global technical potential of bio-energy in 2050 considering sustainability constraints. *Curr. Opin. Environ. Sustain.* **2010**, *2*, 394–403. [[CrossRef](#)]
57. Gabrielle, B.; Bamière, L.; Caldes, N.; De Cara, S.; Decocq, G.; Ferchaud, F.; Richard, G. Paving the way for sustainable bioenergy in Europe: Technological options and research avenues for large-scale biomass feedstock supply. *Renew. Sustain. Energy Rev.* **2014**, *33*, 11–25. [[CrossRef](#)]
58. Ballarin, A.; Vecchiato, D.; Tempesta, T.; Marangon, F.; Troiano, S. Biomass energy production in agriculture: A weighted goal programming analysis. *Energy Policy* **2011**, *39*, 1123–1131. [[CrossRef](#)]
59. Popp, J.; Lakner, Z.; Harangi-Rakos, M.; Fari, M. The effect of bioenergy expansion: Food, energy, and environment. *Renew. Sustain. Energy Rev.* **2014**, *32*, 559–578. [[CrossRef](#)]
60. Araújo, K.; Mahajan, D.; Kerr, R.; Silva, M.D. Global biofuels at the crossroads: An overview of technical, policy, and investment complexities in the sustainability of biofuel development. *Agriculture* **2017**, *7*, 32. [[CrossRef](#)]
61. Bilgen, S.; Keleş, S.; Sarıkaya, İ.; Kaygusuz, K. A perspective for potential and technology of bioenergy in Turkey: Present case and future view. *Renew. Sustain. Energy Rev.* **2015**, *48*, 228–239. [[CrossRef](#)]

62. Ozturk, M.; Saba, N.; Altay, V.; Iqbal, R.; Hakeem, K.R.; Jawaid, M.; Ibrahim, F.H. Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia. *Renew. Sustain. Energy Rev.* **2017**, *79*, 1285–1302. [[CrossRef](#)]
63. Öztürk, M.; Gücel, S.; Armagan, B.; Kucuk, M. An overview of the biomass potential in Turkey and possibilities for the utilization of degraded areas. In Proceedings of the 1st Intern. Nuclear and Renewable Energy Conference (INREC 10), Amman, Jordan, 21 March 2010; pp. 21–24.
64. Godard, C.; Boissy, J.; Gabrielle, B. Life-cycle assessment of local feedstock supply scenarios to compare candidate biomass sources. *Gcb Bioenergy* **2013**, *5*, 16–29. [[CrossRef](#)]
65. Collotta, M.; Champagne, P.; Tomasoni, G.; Alberti, M.; Busi, L.; Mabee, W. Critical indicators of sustainability for biofuels: An analysis through a life cycle sustainability assessment perspective. *Renew. Sustain. Energy Rev.* **2019**, *115*, 109358. [[CrossRef](#)]
66. Dixon, P.M.; Weiner, J.; Mitchell-Olds, T.; Woodley, R. Erratum to ‘Bootstrapping the Gini Coefficient of Inequality. *Ecology* **1988**, *69*, 1307. [[CrossRef](#)]
67. Dagum, C. The Generation and Distribution of Income, the Lorenz Curve and the Gini Ratio. *Econ. Appliquée* **1980**, *33*, 327–367.
68. Starzyńska, W. *Statystyka Praktyczna Wydawnictwo Naukowe*; PWN: Warszawa, Poland, 2002.
69. Abdi, H. Coefficient of variation. *Encycl. Res. Des.* **2010**, *1*, 169–171.
70. Kendall, M.G. *Rank Correlation Methods*; Griffin: London, UK, 1955; p. 19.
71. Spearman, C. The proof and measurement of association between two things. *Am. J. Psychol.* **1904**, *15*, 72–101. [[CrossRef](#)]
72. Pelletier, N.; Audsley, E.; Brodt, S.; Garnett, T.; Henriksson, P.; Kendall, A.; Kramer, K.J.; Murphy, D.; Nemecek, T.; Troell, M. Energy intensity of agriculture and food systems. *Annu. Rev. Environ. Resour.* **2011**, *36*, 223–246. [[CrossRef](#)]
73. Yang, Z.; Wang, D.; Du, T.; Zhang, A.; Zhou, Y. Total-factor energy efficiency in China’s agricultural sector: Trends, disparities and potentials. *Energies* **2018**, *11*, 853. [[CrossRef](#)]
74. Fuglie, K.O.; McDonald, J.M.; Ball, V.E. *Productivity Growth in US Agriculture*; Economic Brief Number 9; Economic Research Service: Washington, DC, USA, 2007; p. 9.
75. Po-Chi, C.H.E.N.; Ming-Miin, Y.U.; Chang, C.C.; Shih-Hsun, H.S.U. Total factor productivity growth in China’s agricultural sector. *China Econ. Rev.* **2008**, *19*, 580–593.
76. Gong, B. Agricultural reforms and production in China: Changes in provincial production function and productivity in 1978–2015. *J. Dev. Econ.* **2018**, *132*, 18–31. [[CrossRef](#)]
77. Yang, F.; Yang, M.; Nie, H. Productivity trends of Chinese regions: A perspective from energy saving and environmental regulations. *Appl. Energy* **2013**, *110*, 82–89. [[CrossRef](#)]
78. Ghisellini, P.; Setti, M.; Ulgiati, S. Energy and land use in worldwide agriculture: An application of life cycle energy and cluster analysis. *Environ. Dev. Sustain.* **2016**, *18*, 799–837. [[CrossRef](#)]
79. Pellegrini, P.; Fernández, R.J. Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 2335–2340. [[CrossRef](#)] [[PubMed](#)]
80. Toma, P.; Miglietta, P.P.; Zurlini, G.; Valente, D.; Petrosillo, I. A non-parametric bootstrap-data envelopment analysis approach for environmental policy planning and management of agricultural efficiency in EU countries. *Ecol. Indic.* **2017**, *83*, 132–143. [[CrossRef](#)]
81. Rokicki, T.; Perkowska, A. Diversity and Changes in the Energy Balance in EU Countries. *Energies* **2021**, *14*, 1098. [[CrossRef](#)]
82. Miglietta, P.P.; Giove, S.; Toma, P. An optimization framework for supporting decision making in biodiesel feedstock imports: Water footprint vs. import costs. *Ecol. Indic.* **2018**, *85*, 1231–1238. [[CrossRef](#)]
83. Gomiero, T.; Paoletti, M.G.; Pimentel, D. Energy and environmental issues in organic and conventional agriculture. *Crit. Rev. Plant Sci.* **2008**, *27*, 239–254. [[CrossRef](#)]
84. Pimentel, D.; Hepperly, P.; Hanson, J.; Douds, D.; Seidel, R. Environmental, energetic, and economic comparisons of organic and conventional farming systems. *BioScience* **2005**, *55*, 573–582. [[CrossRef](#)]
85. Pergola, M.; D’Amico, M.; Celano, G.; Palese, A.; Scuderi, A.; Di Vita, G.; Pappalardo, G.; Inglese, P. Sustainability evaluation of Sicily’s lemon and orange production: An energy, economic and environmental analysis. *J. Environ. Manag.* **2013**, *128*, 674–682. [[CrossRef](#)]
86. Fess, T.L.; Benedito, V.A. Organic versus conventional cropping sustainability: A comparative system analysis. *Sustainability* **2018**, *10*, 272. [[CrossRef](#)]
87. Polukhin, A.A.; Lankin, A.S.; Novoselov, E.A.; Silko, E.A. Economic assessment of energy consumption in agriculture of the Russian Federation. *Econ. Work Manag. Agric.* **2019**, *1*, 58–63.
88. Quan-le, L.I.U. The Saving Energy of Agriculture Machine Is the Only Way of Agriculture Modernization. *Chin. Agric. Mech.* **2006**, *6*.
89. Xiangxin, L.; Yali, Z.; Chao, Z.; Xianghui, Y.; Yan, Z. The Analysis of Energy Consumption of Agricultural Machinery in Our Country and the Technology of Energy Consumption. *J. Agric. Mech. Res.* **2012**, *4*.
90. Wang, X.Y.; Wang, S.; Zhang, Z.Y. Construction of energy conservation and emission reduction technology system of agricultural mechanization. *Chin. Agric. Mech.* **2010**, *4*, 6–10. [[CrossRef](#)]
91. Kondratieva, N.P.; Vladykin, I.R.; Litvinova, V.M.; Krasnolutskaia, M.G.; Bolshin, R.G. Energy-saving technologies and electric equipment applied in agriculture. *Res. Agric. Electr. Eng.* **2016**, *2*, 62–68.
92. Jawad, H.M.; Nordin, R.; Gharghan, S.K.; Jawad, A.M.; Ismail, M. Energy-efficient wireless sensor networks for precision agriculture: A review. *Sensors* **2017**, *17*, 1781. [[CrossRef](#)]

93. Zambon, I.; Cecchini, M.; Egidi, G.; Saporito, M.G.; Colantoni, A. Revolution 4.0: Industry vs. agriculture in a future development for SMEs. *Processes* **2019**, *7*, 36. [[CrossRef](#)]
94. Farajian, L.; Moghaddasi, R.; Hosseini, S. Agricultural energy demand modeling in Iran: Approaching to a more sustainable situation. *Energy Rep.* **2018**, *4*, 260–265. [[CrossRef](#)]
95. Golmohamadi, H. Agricultural Demand Response Aggregators in Electricity Markets: Structure, Challenges and Practical Solutions—a Tutorial for Energy Experts. *Technol. Econ. Smart Grids Sustain. Energy* **2020**, *5*, 1–17. [[CrossRef](#)]
96. Marks, G.; Wilcox, E.; Olsen, D.; Goli, S. *Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study (No. LBNL-6108E)*; Lawrence Berkeley National Lab. (LBNL): Berkeley, CA, USA, 2013.
97. Liu, J.; Chai, Y.; Xiang, Y.; Zhang, X.; Gou, S.; Liu, Y. Clean energy consumption of power systems towards smart agriculture: Roadmap, bottlenecks and technologies. *CSEE J. Power Energy Syst.* **2018**, *4*, 273–282. [[CrossRef](#)]
98. Mason, E.S. *Reports on the Productive Uses of Nuclear Energy: Energy Requirements and Economic Growth*; National Planning Association: Washington, DC, USA, 1955; pp. 1–51.
99. Frank, A.G. Industrial capital stocks and energy consumption. *Econ. J.* **1959**, *69*, 170–174. [[CrossRef](#)]
100. Schurr, S.H.; Netschert, B.C.; Eliasberg, V.F.; Lerner, J.; Landsberg, H.H. *Energy in the American Economy, 1850–1975: An Economic Study of Its History and Prospects*; No. HD9545 R45; Johns Hopkins Press: Baltimore, MD, USA, 1955.
101. Warren, J.C. Energy and economic advances. In *The Philippine Economic Journal Manila*; Philippine Economic Society: Quezon, Philippine, 1964.
102. de Janosi, P.E.; Grayson, L.E. Patterns of energy consumption and economic growth and structure. *J. Dev. Stud.* **1972**, *8*, 241–249. [[CrossRef](#)]
103. Solow, R.M. The economics of resources or the resources of economics. In *Classic Papers in Natural Resource Economics*; Palgrave Macmillan: London, UK, 1974; pp. 257–276.
104. Rasche, R.H.; Tatom, J.A. Energy resources and potential GNP. *Fed. Reserve Bank St. Louis Rev.* **1977**, 5910–5924. [[CrossRef](#)]
105. Kraft, J.; Kraft, A. On the relationship between energy and GNP. *J. Energy Dev.* **1978**, *3*, 401–403.
106. Humphrey, W.S.; Stanislaw, J. Economic growth and energy consumption in the UK, 1700–1975. *Energy Policy* **1979**, *7*, 29–42. [[CrossRef](#)]
107. Zilberfarb, B.Z.; Adams, F.G. The energy-gdp relationship in developing countries: Empirical evidence and stability tests. *Energy Econ.* **1981**, *3*, 244–248. [[CrossRef](#)]
108. Yu, E.S.; Choi, J.Y. The causal relationship between energy and GNP: An international comparison. *J. Energy Dev.* **1985**, *10*, 249–272.
109. Adams, F.G.; Miovic, P. On relative fuel efficiency and the output elasticity of energy consumption in western Europe. *J. Ind. Econ.* **1968**, *17*, 41–56. [[CrossRef](#)]
110. Abakah, E.M. Real incomes and the consumption of woodfuels in Ghana: An analysis of recent trends. *Energy Econ.* **1990**, *12*, 227–231. [[CrossRef](#)]
111. Shafik, N.; Bandyopadhyay, S. *Economic Growth and Environmental Quality: Time-Series and Cross-Country Evidence*; World Bank Publications: Washington, DC, USA, 1992; Volume 904.
112. Hawdon, D.; Pearson, P. Input-output simulations of energy, environment, economy interactions in the UK. *Energy Econ.* **1995**, *17*, 73–86. [[CrossRef](#)]
113. Masih, A.M.; Masih, R. Energy consumption, real income and temporal causality: Results from a multi-country study based on cointegration and error-correction modelling techniques. *Energy Econ.* **1996**, *18*, 165–183. [[CrossRef](#)]
114. Cheng, B.S.; Lai, T.W. An investigation of co-integration and causality between energy consumption and economic activity in Taiwan. *Energy Econ.* **1997**, *19*, 435–444. [[CrossRef](#)]
115. Naqvi, F. A computable general equilibrium model of energy, economy and equity interactions in Pakistan. *Energy Econ.* **1998**, *20*, 347–373. [[CrossRef](#)]
116. Apergis, N.; Payne, J.E. Energy consumption and economic growth: Evidence from the Commonwealth of Independent States. *Energy Econ.* **2009**, *31*, 641–647. [[CrossRef](#)]
117. Ozturk, I.; Aslan, A.; Kalyoncu, H. Energy consumption and economic growth relationship: Evidence from panel data for low and middle income countries. *Energy Policy* **2010**, *38*, 4422–4428. [[CrossRef](#)]
118. Ouedraogo, N.S. Energy consumption and economic growth: Evidence from the economic community of West African States (ECOWAS). *Energy Econ.* **2013**, *36*, 637–647. [[CrossRef](#)]
119. Aslan, A.; Apergis, N.; Yildirim, S. Causality between energy consumption and GDP in the US: Evidence from wavelet analysis. *Front. Energy* **2014**, *8*, 1–8. [[CrossRef](#)]
120. Huang, B.N.; Hwang, M.J.; Yang, C.W. Causal relationship between energy consumption and GDP growth revisited: A dynamic panel data approach. *Ecol. Econ.* **2008**, *67*, 41–54. [[CrossRef](#)]
121. Narayan, P.K.; Narayan, S.; Popp, S. A note on the long-run elasticities from the energy consumption–GDP relationship. *Appl. Energy* **2010**, *87*, 1054–1057. [[CrossRef](#)]
122. Kasman, A.; Duman, Y.S. CO₂ emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis. *Econ. Model.* **2015**, *44*, 97–103. [[CrossRef](#)]
123. Costantini, V.; Martini, C. The causality between energy consumption and economic growth: A multi-sectoral analysis using non-stationary cointegrated panel data. *Energy Econ.* **2010**, *32*, 591–603. [[CrossRef](#)]

124. Belke, A.; Dobnik, F.; Dreger, C. Energy consumption and economic growth: New insights into the cointegration relationship. *Energy Econ.* **2011**, *33*, 782–789. [[CrossRef](#)]
125. Coers, R.; Sanders, M. The energy–GDP nexus; addressing an old question with new methods. *Energy Econ.* **2013**, *36*, 708–715. [[CrossRef](#)]
126. Wolde-Rufael, Y. Energy consumption and economic growth: The experience of African countries revisited. *Energy Econ.* **2009**, *31*, 217–224. [[CrossRef](#)]
127. Kahsai, M.S.; Nondo, C.; Schaeffer, P.V.; Gebremedhin, T.G. Income level and the energy consumption–GDP nexus: Evidence from Sub-Saharan Africa. *Energy Econ.* **2012**, *34*, 739–746. [[CrossRef](#)]
128. Śmiech, S.; Papież, M. Energy consumption and economic growth in the light of meeting the targets of energy policy in the EU: The bootstrap panel Granger causality approach. *Energy Policy* **2014**, *71*, 118–129. [[CrossRef](#)]
129. Dogan, E.; Sebri, M.; Turkekul, B. Exploring the relationship between agricultural electricity consumption and output: New evidence from Turkish regional data. *Energy Policy* **2016**, *95*, 370–377. [[CrossRef](#)]
130. Raeni, A.A.G.; Hosseini, S.; Moghaddasi, R. How energy consumption is related to agricultural growth and export: An econometric analysis on Iranian data. *Energy Rep.* **2019**, *5*, 50–53. [[CrossRef](#)]
131. Altinay, G.; Karagol, E. Electricity consumption and economic growth: Evidence from Turkey. *Energy Econ.* **2005**, *27*, 849–856. [[CrossRef](#)]
132. Lee, C.C.; Chang, C.P. Energy consumption and economic growth in Asian economies: A more comprehensive analysis using panel data. *Resour. Energy Econ.* **2008**, *30*, 50–65. [[CrossRef](#)]
133. Adebola, S.S. Electricity consumption and economic growth: Trivariate investigation in Botswana with capital formation. *Int. J. Energy Econ. Policy* **2011**, *1*, 32–46.
134. Apergis, N.; Payne, J.E. Energy consumption and growth in South America: Evidence from a panel error correction model. *Energy Econ.* **2010**, *32*, 1421–1426. [[CrossRef](#)]
135. Apergis, N.; Payne, J.E. Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model. *Energy Econ.* **2012**, *34*, 733–738. [[CrossRef](#)]
136. Chen, X.; Shuai, C.; Zhang, Y.; Wu, Y. Decomposition of energy consumption and its decoupling with economic growth in the global agricultural industry. *Environ. Impact Assess. Rev.* **2020**, *81*, 106364. [[CrossRef](#)]
137. Eberhardt, M.; Vollrath, D. The effect of agricultural technology on the speed of development. *World Dev.* **2018**, *109*, 483–496. [[CrossRef](#)]
138. Marinoudi, V.; Sørensen, C.G.; Pearson, S.; Bochtis, D. Robotics and labour in agriculture. A context consideration. *Biosyst. Eng.* **2019**, *184*, 111–121. [[CrossRef](#)]
139. Rokicki, T.; Perkowska, A.; Klepacki, B.; Szczepaniuk, H.; Szczepaniuk, E.K.; Bereziński, S.; Ziółkowska, P. The Importance of Higher Education in the EU Countries in Achieving the Objectives of the Circular Economy in the Energy Sector. *Energies* **2020**, *13*, 4407. [[CrossRef](#)]
140. Fuglie, K.O. Is agricultural productivity slowing? *Glob. Food Secur.* **2018**, *17*, 73–83. [[CrossRef](#)]
141. Alene, A.D.; Manyong, V.M. The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: An endogenous switching regression analysis. *Empir. Econ.* **2007**, *32*, 141–159. [[CrossRef](#)]
142. Wang, S.L.; Schimmelpfennig, D.; Fuglie, K.O. Is agricultural productivity growth slowing in Western Europe. In *Productivity Growth in Agriculture: An International Perspective*; CABI: Oxfordshire, UK, 2012; pp. 109–125.
143. Baráth, L.; Fertő, I. Productivity and convergence in European agriculture. *J. Agric. Econ.* **2017**, *68*, 228–248. [[CrossRef](#)]
144. Kijek, A.; Kijek, T.; Nowak, A.; Skrzypek, A. Productivity and its convergence in agriculture in new and old European Union member states. *Agric. Econ.* **2019**, *65*, 1–9. [[CrossRef](#)]
145. Wu, Y. Energy intensity and its determinants in China’s regional economies. *Energy Policy* **2012**, *41*, 703–711. [[CrossRef](#)]
146. Saudi, M.H.M.; Sinaga, O.; Roespinoedji, D.; Jabarullah, N.H. Industrial, Commercial, and Agricultural Energy Consumption and Economic Growth Leading to Environmental Degradation. *Ekoloji* **2019**, *28*, 299–310.
147. Zhang, L.; Pang, J.; Chen, X.; Lu, Z. Carbon emissions, energy consumption and economic growth: Evidence from the agricultural sector of China’s main grain-producing areas. *Sci. Total Environ.* **2019**, *665*, 1017–1025. [[CrossRef](#)]
148. Gokmenoglu, K.K.; Taspinar, N.; Kaakeh, M. Agriculture-induced environmental Kuznets curve: The case of China. *Environ. Sci. Pollut. Res.* **2019**, *26*, 37137–37151. [[CrossRef](#)] [[PubMed](#)]
149. Nwaka, I.D.; Nwogu, M.U.; Uma, K.E.; Ike, G.N. Agricultural production and CO₂ emissions from two sources in the ECOWAS region: New insights from quantile regression and decomposition analysis. *Sci. Total Environ.* **2020**, *748*, 141329. [[CrossRef](#)] [[PubMed](#)]
150. Khan, R. Agricultural production and CO₂ emissions causes in the developing and developed countries: New insights from quantile regression and decomposition analysis. *bioRxiv* **2020**. [[CrossRef](#)]
151. Wang, C.; Zhang, L.; Zhou, P.; Chang, Y.; Zhou, D.; Pang, M.; Yin, H. Assessing the environmental externalities for biomass-and coal-fired electricity generation in China: A supply chain perspective. *J. Environ. Manag.* **2019**, *246*, 758–767. [[CrossRef](#)] [[PubMed](#)]
152. Burney, J.A.; Davis, S.J.; Lobell, D.B. Greenhouse gas mitigation by agricultural intensification. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 12052–12057. [[CrossRef](#)] [[PubMed](#)]
153. Lin, B.; Xu, B. Factors affecting CO₂ emissions in China’s agriculture sector: A quantile regression. *Renew. Sustain. Energy Rev.* **2018**, *94*, 15–27. [[CrossRef](#)]