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Energy Self-Subsistence of Agriculture in EU Countries

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Abstract: The paper's main purpose was to identify the level and factors influencing the consumption of bioenergy of agricultural origin in agriculture in EU countries. All EU countries were deliberately selected for research, as of 31 December 2018. The research period covered the years 2004 to 2018. The sources of materials were the subject literature, Eurostat data, and IEA (International Energy Agency) data. The following methods were used for the analysis and presentation of materials: descriptive, tabular, graphical, Gini concentration coefficient, Lorenz concentration curve, descriptive statistics, Kendall's tau correlation coefficient and Spearman's rank correlation coefficient. In the EU, there was a high level of concentration of renewable energy consumption in several countries. There was also no change in the use of bioenergy of agricultural origin in agriculture, but the concentration level was low. The degree of concentration has not changed for both parameters of renewable energy over a dozen or so years, which proves a similar pace of development of the use of renewable energy sources in individual EU countries. Higher consumption of bioenergy of agricultural origin in agriculture was shown to occur in economically developed countries, but with high agricultural production. There was a strong correlation between the consumption of bioenergy of agricultural origin in agriculture for the entire EU and individual economic parameters in the field of energy and agriculture. The relations were positive for all economic parameters, for total renewables and biofuels consumption and for agricultural production parameters. Negative relations concerned the total energy consumption and parameters related to the area of agricultural crops.

Keywords: renewable energy sources; agriculture; energy policy; energy in agriculture; bioenergy of agricultural origin

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1. Introduction

Preserving the natural environment for future generations is one of the most important goals facing the world [1–3]. This issue was presented at many conferences and discussions at the global and regional level [4–6]. This problem has also been dealt with in the European Union. In December 2008, the Council of the European Union adopted assumptions on counteracting climate change. The EU plan is commonly known as "3 × 20", but there were four proposals [7,8]. According to them, by 2020, the European Union should reduce greenhouse gas emissions by 20% (compared to 1990), increase the share of energy from renewable sources (RES) in its total consumption to 20%, and increase efficiency by 20% energy. It was also assumed that the share of biofuels in the total consumption of transport fuels would increase by at least 10%. For individual countries, different target shares of energy from renewable sources in gross final energy consumption have been defined for 2020 [9,10]. Its highest share was expected in Sweden (increase from 39.8% in 2005 to 49.0% in 2020), Latvia (from 32.6% to 40%) and Finland (from 28.5% to 38%). In other countries, the target share ranged from 10% in Malta, to 15% in Poland, to 31% in Portugal. In total, this share was to reach 20% or more in 12 countries, and up to 15% in 10 countries. In the remaining ones, it was lower than 15%. The next challenges posed by the European Union are even more ambitious, as they involve achieving a reduction by at least 40% of greenhouse gas emissions by 2030 (compared to the level from 1990), increasing the share of renewable energy in its total consumption to a minimum of 32% and an increase of at least 32.5% in energy efficiency [11–13]. The European Green Deal published by the Commission has set out a clear vision of how to achieve climate neutrality by 2050. It proposes to increase the EU's climate ambition for 2030 and 2050, a zero-pollution ambition for a toxic-free environment, supplying clean, affordable and secure energy, mobilizing industry for a clean and circular economy, building and renovating in an energy and resource efficient way, preserving and restoring ecosystems and biodiversity, a fair, healthy and environmentally friendly food system, accelerating the shift to sustainable and smart mobility [14].

For millennia, mankind has mostly used natural, reproducible energy sources. These were plants that provide food and fuel, animal products (including oils), and to some extent, water, wind, and especially the sun. Along with the socio-economic development, raw materials obtained from the depths of the earth, such as coal, oil and natural gas, were increasingly important. These are non-renewable resources and their combustion products pollute the environment. In this situation, mankind is forced to look for such energy sources that are constantly recreated. Such sources include solar energy [15], wind energy, water [16], including river currents, sea and ocean waves, nuclear energy [17], energy from biomass [18], biogas or bioliquids [19]. Renewable energy also includes the heat obtained from the ground (heat pumps, geothermal energy), air (aerothermal) and water (hydrothermal energy) [20–24].

The most important feature of renewable energy is its inexhaustibility. In addition, renewable energy sources have a much lower negative environmental impact than conventional fossil energy technologies. Most of the expenditure related to renewable energy is related to the materials and labor needed to build and maintain facilities. However, there are no costs of importing energy [25–27]. The main advantages of renewable energy include ensuring energy security for the future, which means a continuous and uninterrupted supply of energy necessary to run the economy [28]. There is a strong relationship between the level of energy intensity and socio-economic development. Renewable energy also creates additional jobs [20,29,30]. Another advantage of renewable energy sources is their availability. These sources are scattered around the world, making them easily accessible to everyone. Renewable energy reduces the electrification gap between rural and urban areas. As a result, it can affect the development of rural areas [31]. Where connection to the power grid is almost impossible, renewable energy is the most effective solution [32–34]. RES also reduces the negative effects on the environment and health. The emission of harmful substances to the atmosphere is reduced and the carbon footprint is reduced. This reduces the risk to human health as most diseases are related to air pollution [35–37].

Agriculture provides many types of renewable energy. It is easiest to identify energy produced only in agriculture, such as solid and liquid biofuels and biogas. Solid biofuels are defined as any plant material that is used directly as fuel or transformed into other forms prior to combustion. This includes many wood materials produced by an industrial process or supplied directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings; sulphite lyes, also known as black liquor; animal materials/waste, industrial waste (renewable) and others solid biofuels). Charcoal is not included in this category. Biogas are gases consisting mainly of methane and carbon dioxide, produced either by anaerobic digestion of biomass or by thermal processes. Liquid biofuel is primarily biodiesel, mixed or replaced with fossil gas or diesel fuel [38–41].

Agriculture is a significant producer of renewable energy and is considered by policy makers in this respect. Meanwhile, the consumption of renewable energy in this sector must also be encouraged. Ideally, this energy should be produced on farms themselves. The undertaken research topic is important as it shows the other and still underestimated side of renewable energy in agriculture, i.e., its consumption. Thus, the article fills the research gap.

The paper's main purpose was to identify the level and factors influencing the consumption of bioenergy of agricultural origin in agriculture in EU countries. Additional objectives were to define the conditions for the development of renewable energy sources in the EU, determine the directions of changes and the importance of renewable energy in individual EU countries, and present the consumption of bioenergy of agricultural origin in agriculture in EU countries.

Two research hypotheses were formulated in the paper:

Hypothesis 1. *The processes of the concentration of bioenergy of agricultural origin in agriculture entails a greater concentration of this energy consumption in the countries that are the largest agricultural producers in the EU.*

Hypothesis 2. *The use of bioenergy of agricultural origin in agriculture was closely correlated with the parameters of agricultural production*.

The organization of this paper is as follows: in Section 2, the literature review is elaborated. Section 3 proposes methods to identify the level and factors influencing bioenergy consumption of agricultural origin in agriculture. In Section 4, the results of the research were presented. In Section 5, Discussion, reference is made to other research results that dealt with the relationships tested. Finally, Section 6 concludes this paper.

2. Literature Review

Agriculture has many functions. In this sector, natural resources are somewhat limited, as is the land stock. Thus, there is a competition between the use of land for food production and energy purposes. The production and use of renewable energy represent a secondary transformation in the agricultural sector [42–47]. The production and consumption of renewable energy may result from the reluctance of farmers to use environmentally harmful fuels and as a way to diversify agricultural production. The biophysical features of the farm are also important, as they determine the investment in the production of renewable energy [48–51]. In addition, for example, the production of agricultural biogas or electricity from agricultural biogas is a regulated activity requiring the registration of energy companies operating in the production of agricultural biogas. The external factor for developing small-scale agricultural biogas plants is the system of subsidies on this account. Financial aid in the EU is granted to farmers for projects to diversify into non-agricultural activities, including agricultural biogas production and energy production from agricultural biogas. Internal factors concern human and financial resources and the level of marketization of agriculture and the agrarian structure in a given area. The size of farms mainly determines the development of agricultural biogas plants. It is easier to obtain the raw material for agricultural biogas production in large farms [52,53]. One way to produce and consume renewable energy in the agricultural sector is to use crop residues from existing crops [54]. Biomass production can, in principle, apply to all types of agricultural products. The potential for energy use is therefore very large [55].

Biofuels can be one of the sources that meet the global energy demand. Their advantage is environmental neutrality [56–58]. Agriculture is one of the most important sectors that supply various forms of biofuels. The production of first-generation biofuels relies heavily on energy crops such as maize and sugarcane. In Europe, biodiesel production is dominant, such as in the USA—of ethanol [59,60]. Second-generation biofuels are made of cellulose, hemicellulose or lignin. The lignocellulosic raw materials are mainly maize straw, rice husk, wheat straw and sugar cane bagasse [61]. Second generation biofuels can be blended with gasoline, which can be burned in internal combustion engines and distributed via existing infrastructure or engines slightly modified for internal combustion. An example of second-generation biofuel is cellulose ethanol, which is produced biochemically [62]. Third-generation biofuels come from algae biomass. The production of biofuel from algae is usually dependent on the lipid content. Algae are used, among others, for the production of biodiesel [63–67]. Fourth-generation biofuels use inexhaustible, cheap and widely available raw materials to convert solar energy into solar biofuels. The production of photobiological solar biofuel or electrofuel uses the synthetic biology of algae and cyanobacteria [68–70].

Biofuel production systems competing with farmland may to some extent threaten food production, but also increase environmental pressure and affect biodiversity and ecosystem services [71,72]. The production of biofuels by agriculture is part of the concept of sustainable agriculture [73]. On the other hand, agriculture should also use the energy produced in this sector, e.g., biofuels. Then, in a sense, the agricultural sector would supply itself with energy [74,75]. Such activities would also be beneficial for sustainable agriculture and the environment [76,77]. In agriculture, renewable energy can be used for heating and cooling. The problem here is the existence of low-capacity installations that convert this energy and supply the farm directly. An example is the use of biogas, the production of which is unlimited by climatic conditions. Biogas is used in agriculture for cooking and heating. Another possibility is to produce biofuels in small factories on the farm. Then, such fuel can be directly used in agricultural machinery operating on a farm. Optionally, it can be used as a percentage additive to conventional fuel [78–83].

Increasing the use of renewable energy can be achieved by initiating effective policies by governments. Policymakers should encourage domestic and foreign investors to invest in renewable energy projects, including providing tax breaks to produce renewable energy [84,85]. Investments are the main factor driving the increase in renewable energy consumption in all sectors, including agriculture [86,87].

3. Materials and Methods

EU countries were deliberately selected for research, as of 31 December 2018. The research period covered the years 2004 to 2018. The sources of materials were the literature on the subject, Eurostat data, and IEA (International Energy Agency) data.

The first stage presents issues related to renewable energy in the EU. The aim was to show the similarities and differences between EU countries. The differentiation between individual countries regarding the declared share of renewable energy in total energy until 2020 was presented. Subsequently, the degree of concentration of renewable energy consumption in the EU and changes in this regard were determined. Gini's associate was used for this purpose. The degree of concentration is measured by the amount of renewable energy consumed in the EU. If these values concern only one country, the coefficient would be 1. If they are spread over more countries, the coefficient becomes lower; the closer to 0, the more even the distribution of the volume of renewable energy consumption among EU countries. The Lorenz curve is a graphical representation of the degree of concentration of the volume of renewable energy consumption in EU countries.

The Gini coefficient is a measure of unevenness (concentration) of distribution of a random variable. When the observations are sorted in ascending order, the coefficient can be represented by the formula [88]:

$$G(y) = \frac{\sum_{i=1}^{n}(2i - n - 1) \times y_i}{n^2 \times \overline{y}} \tag{1}$$

where:

n—number of observations,
y_i—value of the "i-th" observation,

$\overline{y}$—the average value of all observations, i.e., $\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$.

The Lorenz curve determines the degree of concentration of a one-dimensional random variable distribution [89]. With sorted observations y_i, which are non-negative values $0 \le y_1 \le y_2 \le \cdots \le y_n$, $\sum_{i=1}^{n} y_i > 0$, the Lorenz curve is a polyline whose apexes (x_h, z_h), for h = 0, 1, . . . , n, have the following coordinates:

$$x_0 = z_0 = 0, \quad x_h = \frac{h}{n}, \quad z_h = \frac{\sum_{i=1}^{h} y_i}{\sum_{i=1}^{n} y_i} \tag{2}$$

The Gini coefficient determines the area between the Lorenz curve and the diagonal of a unit square multiplied by 2.

EU countries were deliberately selected for research, as of 31 December 2018. The research period covered the years 2004 to 2018. The sources of materials were the literature on the subject, Eurostat data, and IEA (International Energy Agency) data.

In the second stage of the research, descriptive statistics relating to the share of renewable energy in individual EU countries were presented. This part of the research aimed to obtain information on regularities occurring in individual EU countries and in the entire EU. Statistics analyzed include the average, median, minimal, maximal, standard deviation, coefficient of variation, skewedness, curtosis.

The third stage focused on the use of renewable energy in agriculture. As the Eurostat data do not contain precise data on renewable energy consumption in individual sectors (including agriculture), it was decided to use IEA (International Energy Agency) data. The consumption of renewable energy in the agricultural sector is presented, but it refers only to renewable energy produced in agriculture (primary solid biofuels, biogases and liquid biofuels). Originally, data was collected for all EU countries. After verification, it turned out that in six countries the data was incomplete. In Croatia, Ireland, Malta and Slovenia, the consumption of bioenergy of agricultural origin in agriculture was not recorded but was generated in this sector. In Cyprus and Portugal, the consumption of bioenergy of agricultural origin in agriculture was not recorded in the first years of the period considered. Therefore, it was decided not to include these countries in the analysis. As a result, 22 EU countries were subjected to the study. At this stage of the research, the degree of concentration of bioenergy of agricultural origin consumption in agriculture in individual EU countries was shown. The Gini coefficient was used for this purpose. Graphically, the concentration level is represented by the Lorenz curve. These methods have been described earlier.

In the fourth stage, the dynamics of changes in bioenergy consumption of agricultural origin in agriculture in individual EU countries were determined. As a result, the following trends were observed. Additionally, the research period was divided into three- to four-year periods. As a result, changes in particular periods were more visible. The dynamics indices with a constant base were used for the research. The constant-based dynamics index has the following formula [90]:

$$i = \frac{y_n}{y_0} \text{ or } i = \frac{y_n}{y_0} \times 100\% \tag{3}$$

where:

y_n—the level of the phenomenon in a certain period,
y_0—level of the phenomenon during the reference period.

In the fifth stage, descriptive statistics concerning the share of renewable energy consumption in agriculture (coming only from primary solid biofuels, biogases and liquid biofuels) in the total consumption of renewable energy from this sector were presented. Thanks to this, it is possible to identify regularities occurring in individual countries, as in the entire EU. Agriculture contributes to renewable energy production but is generally responsible for the low consumption of this energy type, especially produced in this sector.

In the sixth 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 means no match of ordering, and value -1 means 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 by the formula [91]:

$$\tau = P[(x_1 - x_2)(y_1 - y_2) > 0] - P[(x_1 - x_2)(y_1 - y_2) < 0] \tag{4}$$

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

P—compatible pairs, when the compared variables within two observations fluctuate in the same direction, i.e., either in the first observation both are greater than in the second, or both are smaller,

Q—incompatible pairs, when the variables change in the opposite direction, i.e., one of them is greater for this observation in the pair, for which the other is smaller,

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

The Kendall tau estimator is then calculated from the formula:

$$\tau = \frac{P - Q}{P + Q - T} \tag{5}$$

Additionally,

$$P + Q + T = \binom{N}{2} = \frac{N(N-1)}{2} \tag{6}$$

where:

N—sample size.

The pattern can be represented as:

$$\tau = 2\frac{P - Q}{N(N-1)} \tag{7}$$

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 [92]:

$$r_S = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} \tag{8}$$

where:

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

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 one, the stronger the correlation between the examined variables.

The following methods were used to present the materials: descriptive, tabular and graphic.

4. Results

In 2019, most of the energy in the world came from crude oil—33.1% (in 2010 it was 34.7%), then coal—27% (29.8%) and natural gas—24% (22.4%), while nuclear energy provided 4.3% (5.2%). Renewable energy accounted for 11.4% (7.8% in 2010) of sources, of which 6.4% (unchanged) was hydropower. Overall, it can be said that changes in the structure of global energy consumption are small, but are in the generally desirable direction, i.e., a decrease in the share of fossil fuels (by 5.5 percentage points) and an increase in renewable sources (by 3.6%) [93,94].

4.1. Renewable Energy in EU Countries

There was a large variation in the share of energy from renewable sources in the total energy consumption in the EU countries (Figure 1). Countries were using renewable energy to a very large extent (Sweden, Latvia, Finland), but also to a small extent (Malta, Luxembourg, The Netherlands). Each country submitted declarations of achieving a certain share of renewable energy in total energy consumption. Based on the 2018 data, it can be concluded that slightly more than half of the countries will achieve their targets. Natural and economic factors may cause the existing differentiation in goals and the possibility of achieving them.

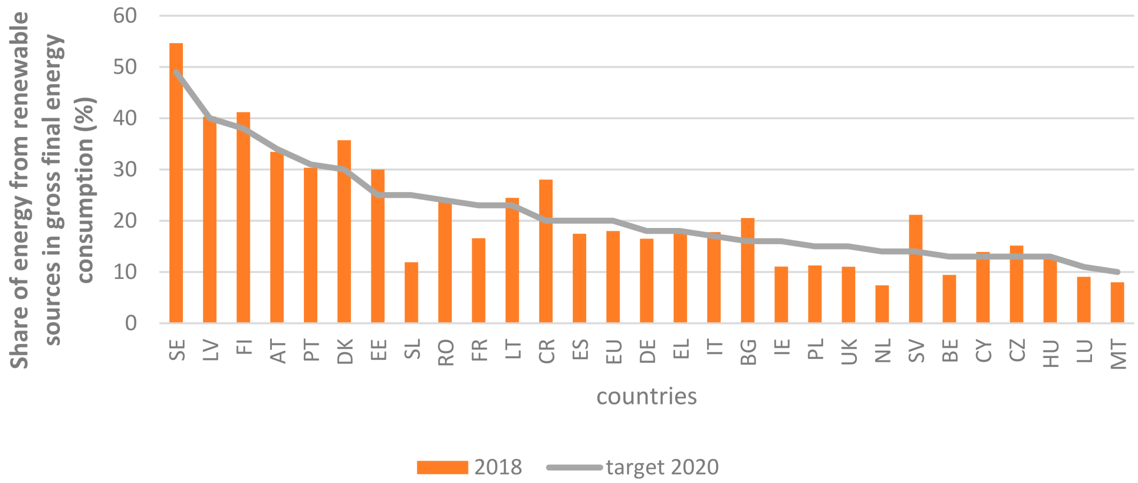

Figure 1. Share of energy from renewable sources in gross final energy consumption in EU countries in 2018.

Then, the degree of concentration of renewable energy consumption in the EU countries was determined. For this purpose, the Gini coefficient was used. This coefficient is a correct and commonly used measure of inequality because it meets all the postulated axioms in this respect. It assumes values in the range from 0 to 1. A result close to 1 means that there is a very high concentration of energy consumption in one country, and close to 0 means that consumption is dispersed across many countries. The number of observations was 28 (all EU countries). The results are presented for the consumption of renewable energy. The Gini coefficient for total renewable energy consumption in 2004, calculated from the sample, was 0.57, and the estimated coefficient for the population was 0.59. This meant quite a high concentration of renewable energy consumption in several EU countries. In the case of repeating the research for 2018, the results were virtually identical (sample coefficient 0.56 and estimated for the population 0.58). Therefore, there have been no significant changes in the distribution of renewable energy consumption in EU countries. The existing differentiation was also presented by means of the Lorenz concentration curve (Figure 2). In 2018, most renewable energy was consumed in Germany, France, Italy, Sweden and Spain. In these five countries, the combined use of renewable energy accounted for 54% of total renewable energy consumption in the EU. In total, the top 10 countries used 79% of the total EU renewable energy consumption. As a rule, most renewable energy was consumed in economically developed countries and the largest countries in terms of socio-economic potential. Concentration ratios were also calculated for the earlier periods, with a frequency of every three or four years. As a result, the results concern the years 2005 to 2018. Such a combination allows to determine the direction and pace of changes in the concentration of renewable energy consumption. Generally, it can be noticed that the concentration of renewable energy consumption is maintained in several countries (Table 1). One of the reasons may be a fairly stable rate of increase in the consumption of renewable energy in individual countries and the use of technologies that ensure similar energy efficiency.

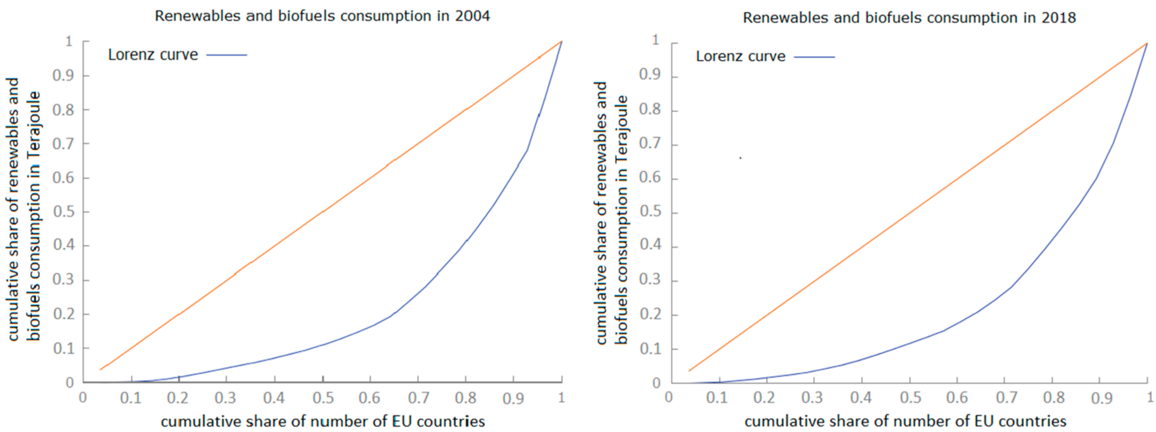

Figure 2. Lorenz concentration curves for renewables and biofuels consumption in the EU countries in 2004 and 2018.

Table 1. Gini coefficients for renewables and biofuels consumption in the EU countries in 2004 to 2018.

Type of Coefficient	Gini Coefficients in Years				
	2004	**2008**	**2011**	**2014**	**2018**
from the sample	0.57	0.58	0.56	0.56	0.56
estimated	0.59	0.60	0.58	0.58	0.58

The share of energy from renewable energy sources changed from 2004 to 2019 (Table 2). The highest average share of energy from renewable energy sources were in Sweden (48.45%), Latvia (34.99%) and Finland (34.90%). It is worth mentioning that the average in Poland was 9.74% and it increased 21.22% (Table 1). The lowest share of energy from renewable energy sources was found in the analyzed period in Malta (3.14%), Luxemburg (3.85%) and The Netherlands (4.73%). The average share of energy from renewable sources for the EU 28 was 13.93%. It is worth mentioning that Iceland (70.55%) and Norway (64.66%) achieved a much higher share than the EU.

We have also analyzed the minimal share of energy from renewable sources. As we can see from Table 1, the lowest minimal share of energy from renewable sources was in 2004 in Malta (0.10%), Luxemburg (0.90%), and United Kingdom (1.10%). The highest minimal share of energy from renewable sources in 2004 was in Latvia (29.62%), Finland (28.81%), and Sweden (38.68%). These countries also had the highest maximal share of energy from renewable sources in 2019, respectively (40.98%, 43.08%, and 56.39%).

The coefficient of variation informs about the changes that were in the analyzed variable. The biggest changes were observed in Malta (99.00%), United Kingdom (67.32%), Luxemburg (56.98%), and Ireland (45.68%). The smallest changes were found in Slovenia (6.75%), Croatia (9.71%), and Latvia (10.78%).

Skewedness was positive in the following countries: Denmark, Ireland, Greece, France, Cyprus, Latvia, Lithuania, Luxemburg, Malta, The Netherlands, Slovakia, Finland, and

United Kingdom. It means that the tail on the right side of the distribution is longer than the left side. Other countries reached negative skewedness.

Kurtosis is also an asymmetry measure. The data proved that the kurtosis reached a positive value for 2004 to 2019 only in Luxemburg and Slovakia. The vast majority of the EU countries achieved a negative value, indicating that the measure was different in 2004 to 2019 in relation to the mean.

Table 2. Descriptive statistics of share of energy from renewable sources (%) in the EU in 2004 to 2019. Red font indicates the lowest results. Bold font indicates the highest scores.

Countries	Average	Median	Minimal	Maximal	Range	Standard Deviation	Coefficient of Variation	Skewedness	Curtosis
Austria	30.65	32.11	22.55	33.81	11.25	3.58	11.70	−1.08	−0.11
Belgium	6.16	6.68	1.89	9.92	8.03	2.76	44.76	−0.25	−1.39
Bulgaria	14.88	14.99	9.10	21.56	12.47	4.50	30.24	−0.08	−1.51
Croatia	25.73	26.07	21.99	28.97	6.98	2.50	9.71	−0.21	−1.53
Cyprus	7.48	6.70	3.07	13.90	10.83	3.51	46.96	**0.43**	−0.81
Czechia	11.70	11.88	6.77	16.24	9.47	3.41	29.11	−0.18	−1.55
Denmark	25.05	24.43	14.84	37.20	22.36	7.53	30.07	**0.18**	−1.35
Estonia	24.11	25.33	15.97	31.89	15.92	5.13	21.29	−0.27	−1.24
Finland	**34.90**	33.50	**28.81**	**43.08**	14.27	4.88	13.99	**0.25**	−1.44
France	12.95	12.97	9.34	17.22	7.88	2.63	20.34	**0.05**	−1.32
Germany	12.37	13.00	6.21	17.35	11.15	3.34	26.97	−0.34	−0.92
Greece	12.45	12.45	7.16	19.68	12.52	4.35	34.92	**0.13**	−1.48
Hungary	11.76	12.68	4.36	16.21	11.84	3.50	29.78	−0.71	−0.69
Ireland	6.76	6.79	2.38	11.98	9.61	3.09	**45.68**	**0.10**	−1.22
Italy	13.79	14.23	6.32	18.27	11.95	4.11	29.78	−0.49	−1.15
Latvia	**34.99**	35.01	**29.62**	**40.98**	11.36	3.77	10.78	**0.01**	−1.33
Lithuania	21.24	20.69	16.48	26.04	9.56	3.61	17.00	**0.04**	−1.54
Luxembourg	3.85	3.02	0.90	8.97	8.07	2.19	**56.98**	**0.82**	**0.01**
Malta	3.14	2.36	0.10	8.49	8.39	3.10	**99.00**	**0.47**	−1.28
The Netherlands	4.73	4.59	2.03	8.77	6.74	1.81	38.22	**0.55**	−0.18
Poland	9.74	10.66	6.89	12.16	5.28	2.07	21.22	−0.39	−1.54
Portugal	25.64	24.59	19.21	30.87	11.66	4.21	16.42	−0.02	−1.39
Romania	21.88	22.83	16.81	25.03	8.22	2.98	13.63	−0.63	−1.14
Slovenia	20.68	20.93	18.37	22.86	4.49	1.40	6.75	−0.40	−0.82
Slovakia	10.07	10.24	6.36	16.89	10.53	2.81	27.88	**0.60**	**0.26**
Spain	13.71	14.07	8.34	18.35	10.01	3.49	25.48	−0.31	−1.31
Sweden	**48.45**	49.08	**38.68**	**56.39**	17.71	5.46	11.27	−0.32	−1.09
United Kingdom	5.47	4.43	1.10	12.34	11.24	3.69	**67.32**	**0.49**	−1.05
European Union	13.93	14.03	8.56	18.88	10.32	3.35	24.06	−0.18	−1.27

4.2. Consumption of Bioenergy of Agricultural Origin in Agriculture

Agriculture is one of the many sectors that can benefit from renewable energy. The article presents energy consumption in agriculture, but coming from primary solid biofuels, biogases, and liquid biofuels, i.e., agricultural energy. The Gini coefficient was used to determine the degree of concentration of such energy consumption in the agricultural sector. In 2004, the Gini coefficient calculated from the sample was 0.32, and the estimated coefficient for the population was 0.33. This meant a relatively low concentration of bioenergy of agricultural origin consumption in agriculture in several EU countries. In the case of repeating the research for 2018, the results were identical. Therefore, there have been no significant changes in the distribution of bioenergy of agricultural origin consumption in agriculture in the EU countries. The existing differentiation was also presented by means of the Lorenz concentration curve (Figure 3). In 2018, most bioenergy of agricultural origin was used in agriculture in Germany, Poland, France, Finland and The Netherlands. In these five countries, combined use of bioenergy of agricultural origin in agriculture accounted for 65% of total renewable energy consumption in the EU agricultural sector. The top 10 countries used 90% of total bioenergy of agricultural origin consumption in agriculture in the EU. As a rule, most renewable energy in agriculture was used in economically developed countries and countries with large agricultural production and those developing energy from non-renewable sources. The latter factor may even be decisive. Concentration coefficients were also calculated for the earlier periods, with a frequency of every three or four years. As a result, the results relate to the years 2004 to 2018. Such a statement allows determining the direction and pace of changes in the concentration of bioenergy of agricultural origin consumption in agriculture. Generally, it can be noticed that the concentration of bioenergy of agricultural origin consumption in agriculture is maintained in a dozen or so countries, of which usually two to three countries consumed this energy the most (Table 3). Individual countries changed at the positions of leaders. In 2004, Sweden consumed the most bioenergy of agricultural origin in agriculture; in 2008 and 2011, it was Poland; in 2014 and 2018, it was Germany. Despite these changes between countries, the level of concentration has remained unchanged. One of the reasons may be a certain stabilization in agricultural production and a fairly stable pace of growth in renewable energy consumption in individual countries. This is because countries use technology that provides similar energy efficiency.

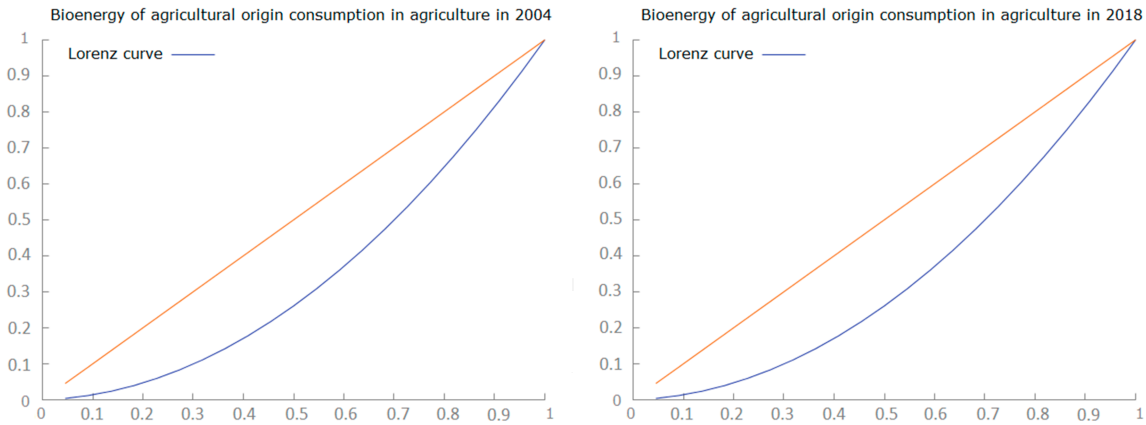

Figure 3. Lorenz concentration curves for bioenergy of agricultural origin consumption in agriculture in the EU countries in 2018.

Table 3. Gini coefficients for bioenergy of agricultural origin consumption in agriculture in the EU countries in 2004 to 2018.

Type of Coefficient	Gini Coefficients in Years				
	2004	2008	2011	2014	2018
from the sample	0.32	0.32	0.32	0.32	0.32
estimated	0.33	0.33	0.33	0.33	0.33

The use of bioenergy of agricultural origin in agriculture varied across countries. The dynamics of changes was also different (Table 4). The use of bioenergy of agricultural origin in agriculture was the fastest in The Netherlands, Italy and Belgium. In the years 2004 to 2018, in these countries, there was an increase of several dozen times. Of these, only The Netherlands has achieved a high volume of bioenergy of agricultural origin consumption in agriculture. In Italy and Belgium, the starting level in 2004 was low, so despite the high dynamics, the level in 2018 was still relatively low. Only in Sweden has the consumption of bioenergy of agricultural origin in agriculture decreased. Despite this, the country was characterized by a high volume of bioenergy of agricultural origin consumption in agriculture. High growth dynamics were achieved among the countries with the highest volume of bioenergy of agricultural origin consumption in agriculture, i.e., in Germany (increase by 427%) and Poland (by 187%). In most countries, the highest increases in the consumption of bioenergy of agricultural origin in agriculture were recorded in 2004 to 2008, and the lowest in 2014 to 2018. It can therefore be concluded that bioenergy of agricultural origin is introduced more and more slowly in agriculture. In some countries, there was stagnation or a decrease in the consumption of this energy.

Table 4. Dynamics indicators for the consumption of bioenergy of agricultural origin in agriculture in the EU countries in 2004 to 2018.

Countries	Dynamics of Changes in the Years				
	2004–2008	2011–2008	2014–2011	2018–2014	2004–2018
Austria	92.24	110.50	109.34	100.19	103.54
Belgium	1357.14	188.27	155.99	90.83	170.31
Bulgaria	63.38	166.67	192.00	71.18	139.96
Czechia	86.98	280.73	235.99	110.42	428.73
Denmark	110.72	94.34	97.35	101.83	526.89
Estonia	118.75	107.24	151.53	88.26	348.70
Finland	103.35	108.93	126.80	98.04	132.86
France	271.62	122.21	108.55	118.98	6230.43
Germany	212.08	164.10	136.15	111.19	182.64
Greece	176.81	189.51	89.45	116.34	190.09
Hungary	91.84	124.22	68.69	169.53	232.91
Italy	113.04	273.08	1259.15	160.29	7594.44
Latvia	56.04	123.23	138.52	190.93	286.50
Lithuania	124.02	127.12	95.05	126.85	335.38
Luxembourg	245.57	87.11	63.91	170.37	1674.32
The Netherlands	2238.89	157.77	138.88	154.81	540.69
Poland	260.00	126.34	81.30	107.27	39.85
Romania	863.08	35.47	129.65	84.50	212.90
Slovakia	154.05	730.70	28.57	520.59	228.95
Spain	237.96	208.21	112.82	96.74	103.54
Sweden	104.30	46.87	91.97	88.64	170.31
United Kingdom	189.99	112.14	291.59	34.27	139.96
EU 22	158.40	118.28	123.25	99.15	428.73

Individual EU countries differed in terms of the level of bioenergy of agricultural origin consumption in agriculture. Indicators can also be used to determine the importance of bioenergy of agricultural origin in agriculture. One of them is the share of bioenergy of agricultural origin consumption in agriculture (coming only from primary solid biofuels, biogases and liquid biofuels) in the total consumption of renewable energy from this sector. Particular descriptive statistics allowed for the identification of regularities occurring in individual countries and the entire EU (Table 5). In 2004 to 2018, the highest average share of bioenergy of agricultural origin in agriculture was recorded in The Netherlands and Poland (over 10%). In turn, it was the lowest in Italy, Romania and Bulgaria. In most EU countries, the median was most often close to the arithmetic mean value. The lowest minimum share of bioenergy of agricultural origin consumption in agriculture in the total consumption of renewable energy from agriculture was in Italy (0.01%) and Romania (0.05%), and the highest in Luxembourg (4.75%) and Poland (4.52%). In the case of the maximum values, the lowest share was in Italy (0.52%) and Romania (1.16%), and the highest in The Netherlands (20.56%) and the United Kingdom (16.72%). The smallest difference between the maximum and minimum value was in the case of Italy (0.52 percentage points) and Romania (1.11), and the largest in The Netherlands (20.12) and the United Kingdom (13.35).

Table 5. Descriptive statistics of share of energy consumption from bioenergy of agricultural origin in agriculture (%) in the EU in 2004 to 2019. Red font indicates the lowest results. Bold font indicates the highest scores.

Countries	Average	Median	Minimal	Maximal	Range	Standard Deviation	Coefficient of Variation	Skewedness	Curtosis
Austria	5.05	5.13	4.37	6.24	1.88	0.48	9.47	**0.85**	**1.43**
Belgium	2.37	2.81	0.21	3.77	3.56	1.26	53.30	−0.80	−0.77
Bulgaria	0.62	0.48	0.29	1.73	1.44	0.38	60.89	**2.14**	**5.06**
Czechia	3.24	2.53	1.01	5.99	4.98	1.99	61.31	**0.18**	−1.96
Denmark	5.01	4.94	4.03	6.87	2.84	0.73	14.58	**1.10**	**1.84**
Estonia	1.00	0.90	0.25	2.50	2.25	0.51	51.10	**1.81**	**5.35**
Finland	3.13	3.13	2.63	3.91	1.29	0.37	11.85	**0.38**	−0.36
France	1.51	1.51	0.47	2.03	1.57	0.40	26.29	−1.21	**2.25**
Germany	4.18	4.06	1.79	6.71	4.92	1.75	41.83	**0.17**	−1.38
Greece	2.14	2.15	0.89	3.37	2.48	0.81	37.85	−0.07	−1.39
Hungary	0.86	0.86	0.43	1.89	1.45	0.34	39.64	**1.88**	**5.62**
Italy	0.17	0.02	0.01	0.52	0.52	0.23	**133.36**	**0.87**	−1.35
Latvia	1.50	1.44	0.76	3.01	2.25	0.59	39.11	**1.28**	**1.92**
Lithuania	1.63	1.70	0.92	2.43	1.51	0.44	27.04	**0.08**	−0.06
Luxembourg	7.78	7.92	**4.75**	11.71	6.96	1.85	23.74	**0.02**	**0.34**
The Netherlands	**11.36**	**12.01**	0.44	**20.56**	**20.12**	6.26	55.13	−0.44	−0.83
Poland	**10.75**	**11.13**	**4.52**	12.67	8.15	1.92	17.82	−2.65	**8.72**
Romania	0.30	0.18	0.05	1.16	1.11	0.34	**112.68**	**2.21**	**3.77**
Slovakia	3.11	1.52	0.54	7.87	7.33	2.94	94.54	**0.70**	−1.36
Spain	1.32	1.67	0.38	1.95	1.57	0.59	44.98	−0.77	−1.34
Sweden	4.41	3.86	1.90	7.31	5.41	2.07	47.02	**0.12**	−2.03
United Kingdom	9.67	9.74	3.38	**16.72**	**13.35**	4.56	47.15	−0.05	−1.25
EU 22	3.25	3.34	1.63	4.06	2.43	0.63	19.55	−1.28	**1.89**

The variability of the examined index of the share of bioenergy of agricultural origin in agriculture was also determined. The greatest stabilization was in Austria (the coefficient of variation was 9.47%) and Finland (11.85%), and the greatest in Italy (133.36%) and Romania (112.68%). In most EU countries, volatility was very high. For the entire EU, the coefficient of variation was around 20%.

Skewness was positive in most EU countries, which means that the results were higher than the average for most of the years studied. Particularly high results were achieved in Romania and Bulgaria. On the other hand, most of the below-average results were achieved in Poland and France. Kurtosis is a measure of how results are concentrated around the mean. Results were positive in about half of the countries and negative in another half. A lot of results concentrated around the average were recorded in Poland and Hungary, and the lowest in Sweden and the Czech Republic. In general, it can be stated that there was a large variation between EU countries in the share of bioenergy of agricultural origin consumption in agriculture (coming only from primary solid biofuels, biogases and liquid biofuels) in the total consumption of renewable energy from this sector.

To establish the relationship between the amount of energy consumption from bioenergy of agricultural origin in agriculture in the EU countries and the basic parameters of the economy, energy and agriculture, Kendall's tau correlation coefficient and Spearman's rank correlation coefficient were calculated (Table 6). $p = 0.05$ 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 (28 countries) for the entire 2004 to 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.

Table 6. Kendall's tau correlation coefficients and Spearman's rank correlation coefficients between the volume of bioenergy of agricultural origin consumption in agriculture in the EU countries and the parameters of the economy, energy and agriculture. Bold font indicates the highest scores.

Tested Parameters	Kendall's Tau Correlation Coefficient		Spearman's Rank Correlation Coefficient	
	τ	*p*-Value	r_s	*p*-Value
Correlation coefficients between bioenergy of agricultural origin consumption in agriculture and				
Value of GDP	**0.810**	**0.001**	**0.925**	**0.001**
Final consumption expenditure of households	**0.810**	**0.001**	**0.925**	**0.001**
Export of goods and services	**0.810**	**0.001**	**0.929**	**0.001**
Import of good and services	**0.771**	**0.001**	**0.911**	**0.001**
GDP per capita	**0.790**	**0.001**	**0.914**	**0.001**
Final consumption expenditure of households per capita	**0.790**	**0.001**	**0.914**	**0.001**
Total energy consumption	**−0.771**	**0.001**	**−0.925**	**0.001**
Total renewables and biofuels consumption	**0.867**	**0.001**	**0.932**	**0.001**
Total energy consumption in agriculture	−0.105	0.553	−0.136	0.010
Gross value added of agriculture, forestry and fishing	**0.657**	**0.001**	**0.821**	**0.001**
Area of agricultural crops	**−0.733**	**0.001**	**−0.857**	**0.001**
Area of grain sowing	**−0.505**	**0.008**	**−0.686**	**0.001**
Raw cows' milk delivered to dairies	**0.829**	**0.001**	**0.946**	**0.001**

In the case of Kendall's tau correlation, significant positive relations were found for almost all parameters with the amount of bioenergy of agricultural origin consumption in agriculture in the EU. The strength of the relationship was very great for the economic parameters. These relationships were very strong for both the global performance and per-capita performance parameters. Energy-related parameters were also strongly correlated with the consumption of bioenergy of agricultural origin in agriculture. The only exception was the parameter on total energy consumption in agriculture. The dependencies were varied, as a positive correlation was found in relation with the total consumption of renewable energy, and a negative correlation in the total energy consumption. This means that changes in the consumption of bioenergy of agricultural origin in agriculture follow the same direction as changes in the renewable energy consumption in the economy. There is an overall reduction in energy consumption in the EU; therefore, there was a negative correlation for this parameter. The parameters related to agriculture had less correlation with bioenergy consumption of agricultural origin in the agricultural sector. A strong positive relationship was observed for gross value added of agriculture, forestry and fishing, and a very strong positive one for raw cows' milk delivered to dairies. Both parameters showed an upward trend. Negative strong and average relations were found for the total agricultural area and agricultural area of grain, respectively. Overall, these areas slightly decreased, while the consumption of bioenergy of agricultural origin in agriculture increased. The presented correlation results indicate that there were very strong relationships between the volume of bioenergy of agricultural origin consumption in agriculture and the economic potential and the level of economic development. 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, the consumption of bioenergy of agricultural origin in agriculture grew, including the more and more common use of this type of energy, cheaper technologies, and the promotion of renewable energy. In animal production, milk production increased, which was positively correlated with bioenergy consumption of agricultural origin in agriculture. It should also be noted that there were also various correlations with different parameters of energy consumption in the economy. It all depended on the existing trend. Total energy consumption was falling, so it was negatively correlated with bioenergy of agricultural origin in agriculture. In turn, the consumption of renewable energy in the economy increased, which meant a positive correlation.

The analysis carried out with the use of Spearman's rank correlation coefficients gave very similar results. However, the strength of the relation was much greater. Both tests confirm the close relation between bioenergy of agricultural origin consumption in agriculture and economic and energy-related parameters, and a smaller one with agricultural parameters.

5. Discussion

Kazar and Kazar [95] stated that, in the long term, economic development will lead to the production of renewable energy. In a short time, there is a two-way causal link between renewable energy production and economic development. The study covered 154 countries between 1980 and 2010. In turn, Apergis and Payne [96] found that this relationship is bidirectional in both the short and long term. The study was conducted for a panel of 20 OECD countries over the period of 1985 to 2005. Sadorsky [97] also found such relationships based on a study of 18 economies of developing countries. Over the long term, a 1% increase in real per capita income has increased the per capita renewable energy consumption by around 3.5% in these economies. Similar two-way relationships were found in the studies by Pao and Fu [98] examining Brazil, Lin and Moubarak [99] studying China, Shahbaz et al. [100] examining Pakistan, and Khoshnevis Yazdi [101] studying Iran. The one-way causality between renewable energy and economic growth was stated by Leitão [102] in the Portuguese economy. This study was conducted for the period of 1970 to 2010, using time series (OLS, GMM, unit root test, VEC model, and Granger causality). The Granger causality reports a unidirectional causality between renewable energy and economic growth. Bhattacharya et al. [103] carried out studies on 38 countries with the highest renewable energy consumption. Renewable energy consumption has had a significant positive impact on economic performance in most of the countries surveyed. Similar results were obtained in the study by Saidi and Omri [104] on the example of 15 countries with the highest consumption of renewable energy. The fully modified ordinary least square (FMOLS) and the vector error correction model (VECM) techniques were used. A bidirectional causality between economic growth and renewable energy in the short- and long-run for both models was found. Menegaki [105] performed research on a sample of 27 European countries. The empirical results do not confirm a causal relationship between renewable energy consumption and GDP. However, this study covered the period of 1997 to 2007, before the targets for 20% of renewable energy in total energy were set. A study from 2004 to 2017 by Busu [106] confirmed the relationship between renewable energy and economic growth in 28 EU countries. Biomass production has had the most significant impact on economic growth of all renewable energy sources. According to the author, in the analyzed period, an increase in the basic production of biomass by 1% would affect the economic growth by 0.15%. Similar results were obtained by Armeanu et al. [107] for the years 2003 to 2014. The 1% increase in primary production of solid biofuels increased GDP per capita by 0.16%. The vast majority of studies have found a two-way relationship between renewable energy production and economic growth. In particular, such results were achieved when the share of renewable energy in the studied countries was already significant. In addition, it must also be remembered that almost all of its production is spent on domestic consumption in the case of renewable energy. There was little trade in this type of energy.

Similarly, as in other sectors, agriculture is also closely related to energy. The increase in agricultural production is positively correlated with energy consumption. In most EU countries, the technical and technological modernization of agriculture directly affects the lower energy consumption of production [108–112]. In the case of agriculture, the studies by Alola and Alola [113] found a one-sided relationship between the use of agricultural land and the consumption of renewable energy. There was no feedback. The research results concerned 16 countries of the Mediterranean coast in the years 1995 to 2014. Ben Jebli and Ben Youssef [114] found in their research a long-term two-way causal relationship between renewable energy consumption and agricultural value added (AVA). The study concerned Tunisia in the years 1980 to 2011. The research was repeated in Morocco [115] and five North

African countries [116]. In this case, too, a two-way relationship in consumption between renewable energy consumption and agricultural value added (AVA) was found. Khan et al. [117] obtained similar results on in their study of Pakistan. They showed a multilateral relationship between AVA, renewable energy consumption, and carbon dioxide emissions. The research covered the years 1981 to 2015. According to these authors, Rehman et al. [118] and Ali et al. [119], the government in Pakistan should support the growth of the AVA, because it will contribute to a greater use of renewable energy and, consequently, lower emissions of pollutants into the environment. Additionally, it is necessary to introduce modern technologies [120]. The authors suggest that increasing international economic exchange will allow the agricultural sector to develop and benefit from the transfer of renewable energy technologies. Aydoğan and Vardar [121] argue that increasing the share of renewable energy may increase production in the agricultural sector. The balanced panel data set of E7 countries (Emerging Seven—Brazil, China, India, Indonesia, Mexico, Russia and Turkey) over the period 1990 to 2014 was used. Liu et al. [122] suggest that the development of sustainable agriculture can promote renewable energy. The research in four selected countries of the Association of Southeast Asian Nations (ASEAN-4: Indonesia, Malaysia, the Philippines, and Thailand) in 1970 to 2013 was made.

Jebli and Youssef [123], using data from Argentina in 1980 to 2013, found that agriculture and renewable energy production are substituting and competing for land use. Such substitution and competition should be limited by encouraging R&D in the production of second- or third-generation biofuels and new technologies for renewable energy, or the increase in agricultural productivity per unit area. Quite a controversial statement was made by Al-Mulali et al. [124]; according to these authors, the production of renewable energy increases the inefficiency of land and water use. The research was performed in 58 developed and developing countries in the years 1980 to 2009. Destek and Sinha [125] thought the opposite. Consuming renewable energy reduces environmental impacts. The authors studied OECD countries in 1980 to 2014. Similar results were obtained in the study by Destek et al. [126], which concerned the EU countries in 1980 to 2013. In the studies of Solarin et al. [127], it was noted that there are differences between types of renewable energy. To reduce carbon dioxide emissions, there is a need to replace fossil fuels with other renewable energy sources (e.g., hydropower) rather than energy from biomass. The research covered 80 developed and developing countries in the period 1980 to 2010. In a study by Wang [128] on Brazil, Russia, India, China and South Africa (BRICS countries), a high impact of biomass in reducing environmental pollution was found. Energy from biomass was treated as a clean energy source. The research covered the years 1992 to 2013. Based on the presented review, it can be concluded that the perception of renewable energy also depended on the period covered by the research. More recent data show that renewable energy has a significant environmental impact. Therefore, it is purposeful to promote this energy on farms instead of conventional energy. An example is the largest biogas market in the world. The development of the German biogas sector has mainly been triggered and driven by consecutive versions of the Renewable Energy Act (REA) and accompanying regulations [129]. It was similar in the USA, where new tax incentives were introduced [130]. Piwowar [131] stated that in Poland, institutional support is necessary and increases the awareness of farmers. The low propensity of farmers to use renewable energy technologies was also found in other EU countries. An example was, among others, Ireland [132]. Energy self-subsistence of agriculture is particularly desirable in European agriculture, where the individual farm sizes are average [133].

6. Conclusions

Maintaining the natural environment in a proper condition requires an energy transformation. There is a need for an increased use of renewable energy sources. The EU has adopted targets for the share of these energy sources in total energy consumption. Each country has different limits that it has pledged to meet by 2020. The declarations resulted from the current state of development of renewable energy in a given country and technical possibilities and the level of economic growth. In the years 2004 to 2019, the production of renewable energy in the EU was relatively high and increased in each country at a similar pace. However, the starting potentials were different, and there are still significant differences between countries.

There has been a relatively high concentration of renewable energy consumption in several countries. The level of concentration has not changed, but there have been some changes in the order of countries. The reason is the development of renewable energy production in all countries and the use of similar technology. There was some stabilization in countries with a high share of renewable energy in total energy consumption. The dynamics of changes were slight, but these countries already had an established position. Countries with less renewable energy increased their consumption volumes very quickly but started far below the leaders. Therefore, very high dynamics of changes can be misleading. As a result, there were still disproportions.

The use of bioenergy of agricultural origin in agriculture, but produced in this sector, was quite dispersed across many countries. The level of concentration has not changed. There have been some changes in the positions of individual countries. Thus, the first research hypothesis was not confirmed. As a rule, most renewable energies was used in agriculture in economically developed countries, but with large agricultural production, such as Germany, Poland, France, Finland, and Spain. The factor related to the development of obtaining energy from non-renewable sources can be a decisive factor. One of the reasons was changes in the level of concentration of non-renewable energy consumption in agriculture. It may stabilize in agricultural production and a relatively stable rate of increase in renewable energy consumption in individual countries. The agricultural sector changes relatively slowly compared to other sectors of the economy. For faster changes, large investment outlays are necessary, but also greater project support.

There were very large differences between EU countries in terms of basic statistics on the share of bioenergy of agricultural origin in agriculture but coming from energy produced in this sector. The average percentage in a few countries was above 10%, and in a few countries, it was below 1%. In addition, in the years 2004 to 2018, there were large differences between the maximum and minimum share of bioenergy of agricultural origin in agriculture in countries such as The Netherlands and the United Kingdom, and small ones in Italy and Romania. Interestingly, Italy and Romania were the countries with the most significant variability in the share of bioenergy of agricultural origin in agriculture. The reason was the very low shares in these countries, not exceeding 1.2%. There were also differences between countries in terms of measures of asymmetry and concentration. Overall, there was a very wide variation between EU countries in the share of bioenergy of agricultural origin in agriculture. It was more significant than for the entire sector of the economy. This may indicate that the agricultural sector is less innovative and less willing to introduce changes than the whole economy.

A correlation was found between the consumption of bioenergy of agricultural origin in agriculture for the entire EU and individual economic parameters in the field of energy and agriculture. The strength of the relationship varied. Only in the case of total energy consumption in agriculture was there no relationship. There was a high positive correlation in the relationship between bioenergy of agricultural origin consumption in agriculture and economic parameters. This means that economic development contributes to the greater use of bioenergy of agricultural origin in agriculture. In the case of energy-related parameters, the relationships were not clear. Total energy consumption, i.e., a parameter that tended to decrease, was negatively correlated with bioenergy consumption of agricultural origin in agriculture. The parameter of total renewables and biofuels consumption, which showed an upward trend, was positively correlated. There was also a differentiation in the parameters related to agriculture. The dependencies here were similar to those for energy. A positive correlation was found for gross value added of agriculture, forestry, and fishing, as well as for raw cows' milk delivered to dairies. The production parameters of agriculture increased. On the other hand, the negative correlation was with parameters with a downward trend, such as the area of agricultural crops and area of grain sowing. The second hypothesis was confirmed, according to which the consumption of bioenergy of agricultural origin in agriculture was closely related to the parameters of agricultural production. However, it should be added that the relations were positive or negative depending on the trend in the case of a given parameter related to agriculture.

Overall, it must be stated that the consumption of bioenergy of agricultural origin in agriculture from this sector was at a low level and was growing very slowly. This is due to the low propensity to innovate in the agricultural sector. It can also be stated that the potential of agriculture related to the production of renewable energy for energy consumption on a farm is not used. There is much to be carried out in this regard. Apart from the appropriate information campaign, it is necessary to financially support initiatives contributing to the self-supply of farms with energy.

The limitation of the research is the poor availability of data. Information is aggregated. It is difficult to obtain data on the type of renewable energy used in agriculture that is produced in agriculture. For example, solar energy can be used in a farmer's household and on a farm. There is a need to perform micro-level research concerning farms in one locality or individual farms. The results may differ from one EU country to another.

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