agriculture

Article

An Assessment of the Spatial Diversification of Agriculture in the Conditions of the Circular Economy in European Union Countries

Renata Matysik-Pejas [1], Małgorzata Bogusz [1], Kamila Daniek [1,*], Monika Szafrańska [1], Łukasz Satoła [1], Andrzej Krasnodębski [1] and Paweł Dziekański [2,*]

[1] Department of Management and Economics of Enterprises, Faculty of Agriculture and Economics, University of Agriculture in Krakow, A. Mickiewicza 21, 31-120 Krakow, Poland; renata.matysik-pejas@urk.edu.pl (R.M.-P.); malgorzata.bogusz@urk.edu.pl (M.B.); monika.szafranska@urk.edu.pl (M.S.); lukasz.satola@urk.edu.pl (Ł.S.); andrzej.krasnodebski@urk.edu.pl (A.K.)

[2] Department of Economics and Finance, Faculty of Law and Social Sciences, Jan Kochanowski University in Kielce, Uniwersytecka 15 Str., 25-406 Kielce, Poland

* Correspondence: kamila.daniek@urk.edu.pl (K.D.); pawel.dziekanski@ujk.edu.pl (P.D.)

Abstract: The level of agricultural development in European Union countries is characterized by great diversity. This is due to differences in natural conditions, the type of agricultural production, agrarian fragmentation, and the level of economic development. The concept of a circular economy is the latest vision of changing the current economic systems, the assumptions of which constitute an alternative to the linear model of resource use. The implementation of the principles of a circular economy aims to create a system that will contribute to the implementation of sustainable development. This could be a strategy to support agriculture in the absence of agricultural land and water resources. This research aimed to identify and assess the spatial diversification of agricultural production-economic conditions and their links with the circular economy at the level of EU countries. The basis for grouping countries was synthetic measures obtained in the areas of agriculture and the circular economy. The analyses were performed for 2012 and 2020. The obtained results indicate the existence of significant spatial dependencies in the development of agriculture and the circular economy. Countries with a higher level of agricultural development were also higher in the ranking of the advancement of the implementation of the circular economy concept.

Keywords: agriculture production; circular economy; linear system; European Union countries; synthetic measure; TOPSIS method

Citation: Matysik-Pejas, R.; Bogusz, M.; Daniek, K.; Szafrańska, M.; Satoła, Ł.; Krasnodębski, A.; Dziekański, P. An Assessment of the Spatial Diversification of Agriculture in the Conditions of the Circular Economy in European Union Countries. *Agriculture* **2023**, *13*, 2235. https://doi.org/10.3390/agriculture13122235

Academic Editor: Sanzidur Rahman

Received: 29 September 2023
Revised: 28 November 2023
Accepted: 30 November 2023
Published: 3 December 2023

1. Introduction

Agriculture is an economic sector that receives special treatment, particularly in the European Union (EU). This somewhat different treatment of agriculture compared to other sectors of the economy is largely the result of the natural, cultural, and socio-economic conditions in which it operates. These realities, together with historical conditions, mean that the level of agricultural development in individual EU countries is characterized by large spatial differences, both in terms of potential [1,2] and in terms of the degree to which it is exploited [3]. These characteristics, in turn, influence the level of competitiveness of the agricultural sector [4].

Nowadays, agriculture in EU countries is facing a number of challenges, and its prospects are dependent upon new concepts that can significantly influence the way in which societies and economies think and operate. The currently adopted directions for the development of European agriculture under the Common Agricultural Policy (CAP) take into account the paradigm of economic and social development in line with the concept of sustainable development [5].

The 2003 CAP reform led to the separation of subsidies from production. This direction of change in the CAP was linked to the introduction of new obligations for agricultural producers, focusing on the management of land in an environmentally and climate-friendly way. Research shows that agriculture is also responsible for environmental pollution, and its role in greenhouse gas emissions has recently been highlighted [6]. The next CAP reform in 2013 included the promotion of sustainable agriculture and innovation, support for employment and economic growth in rural areas, and financial support for efficient land use [7].

Agriculture is highly dependent on resources and natural cycles. Resources such as water, soil, nutrients, and biodiversity are fundamental to the functioning of ecosystems. As the demand for these resources in the economy grows, there is a risk that they will be overexploited, hampering key economic sectors in the future and limiting the benefits they provide to society. It is therefore necessary to move towards a more efficient use of resources and their reuse, which forms the basis of the concept of a circular economy [8].

The depletion of non-renewable resources poses a very serious threat to the continuation of the current economic development model based mainly on their exploitation. The challenge has been and continues to be to develop a model for using resources that would effectively meet the growing needs without causing irreversible environmental losses. In this way, future generations will also have the opportunity to meet their needs without drastically reducing them. This assumption fulfills one of the basic principles of sustainable development, namely meeting the needs of current generations in such a way as to not reduce the ability of future generations to meet them.

Europe generates 1.3 billion tons of waste per year, of which 700 million tons are agricultural waste. With the world's population expected to increase by a third by 2050, the best estimates suggest that agricultural and food production will need to increase by two-thirds by 2050 in order to adequately feed an additional two billion people [9]. This need is exacerbated by the impact of climate change on agricultural systems; higher temperatures and changes in global rainfall patterns increase the likelihood of reduced crop yields and the spread of weeds and pests on agricultural land. These challenges present a major opportunity for the development of a circular economy (CE), using innovative technologies and profitable business practices to manage agricultural waste and by-products. The development of CE requires the introduction of functioning closed-loop systems with the aim of improving economic and environmental sustainability [10].

In relation to agriculture (as well as many other sectors of the economy), the circular economy is associated with specific benefits. The most important of these are environmental, including reduced use of materials and energy, as well as reduced waste and pollutant emissions. At the same time, this translates into economic benefits, specifically a reduction in the cost of raw materials and energy used and a reduction in the cost of waste management and pollutant emissions [11]. There are several key aspects that need to be considered in order to achieve circularity in agriculture. The first is the efficient use of inputs and the prevention of waste, and the second is the promotion of sustainable environmental, economic, and social development [12].

The aim of this study was to identify and assess the spatial diversification of agricultural production-economic conditions and their links with the circular economy at the level of EU countries. In this research process, a synthetic measure was constructed for both study areas. In addition, an attempt was made to identify the determinants of the relationship between the indicated areas affected by polarization in terms of the main criterion and the strength of their interaction in the changing pattern of inequalities in 2012 and 2020. In addition to the main objective, the authors formulate the following research questions: how is the degree of spatial differentiation between agriculture and the circular economy determined by the diagnostic variables, and to what extent do agriculture and the circular economy influence each other?

2. Literature Review

Agriculture in the European Union is highly diversified, which is the result of both natural factors (soil conditions, climate, relief) and other determinants, including the level of the country's socio-economic development, the level of agrarian culture, the technology used, patterns of specialization, proximity to consumption centers, and the ability to introduce innovations [2,13]. These differences concern, among other factors, the agrarian structure, the scale of plant and animal production, and the level of employment in this sector. The above-mentioned features are often used as partial variables to construct proprietary measures, enabling the assessment of the spatial differentiation of agricultural potential and international comparisons.

Different sectors of the national economy show varying dependence on factor resources. Today, for some of them, the resources of labor and capital seem to be of the greatest importance. A significant proportion of industries and functioning economic entities rely less and less on the land factor for their operations. Agriculture, as traditionally the first sector of national economies, is directly and irrevocably linked to land resources. Its abundance therefore determines, to a significantly greater extent than in other sectors, the success and economic and production effects of agricultural activity [14].

Access to land that can be used for agriculture is one of the basic elements determining the production capacity of the agricultural sector. In addition to the size of the agricultural land, its quality is also an important factor, which largely determines the possibility of producing certain plant species and limits the yield potential, which in turn determines the economic results of the activity [15].

From an agro-economic point of view, an important indicator for international comparisons is the share of the total area of a country serving as agricultural land. Agricultural land makes up he largest part of the territories of EU countries such as Denmark, Ireland, Romania, and The Netherlands. In all these countries, the share of agricultural land exceeds 53%, and in Ireland and Denmark, it is as high as 65.5%. The Netherlands, Denmark, and Ireland are long-standing members of the EU, and it is worth noting that they belong to a group of countries with a very high level of agricultural development and professional production in this branch of the national economy. Romania joined the EU in 2007 and is, among those mentioned, the country with the largest area and therefore with a high potential for developing agricultural production. It is a country with a high polarization of agricultural structures, where, alongside large, professionally managed farms, there is also a very large population of small and low-performing family farms [16].

Sweden and Finland have the smallest share of "area devoted to agricultural land" (just over 7%), and in Cyprus, this value is 14.5%. This is due to the lack of favorable natural conditions for agricultural activities. The reasons are mainly the terrain and, in the case of Scandinavian countries, the location of a significant part of the territory in the northern polar area, which makes it impossible to cultivate crops due to low temperatures and the length of the growing season. In the analyzed period (2012–2020), in the vast majority of countries, there were no significant changes in the share of agricultural land in the total area, which proves the relative stabilization of the conditions for conducting agricultural activities. An exception in this respect was Greece, where the share of agricultural land decreased by almost eleven percent [17,18].

One of the categories of partial variables that are taken into account in the measures used to assess the spatial diversity of agricultural potential are the yields of individual crops or the percentage share of the analyzed group of plants in the country's agricultural land [19,20]. Since the European Union is the largest producer of cereals in the world [21], data regarding this group of crops are often taken into account in analyses characterizing the spatial diversity of agriculture.

According to Eurostat, more than half of the cereals grown in the EU are wheat. About 30% of European cereal crops are maize and barley. The remainder is made up of cereals grown in smaller quantities, such as rye, oats, and spelt. Cereals in the EU are mostly used as animal feed (almost two-thirds). One-third is for human consumption. Only 3% of the cereals produced are used for biofuels [22].

Legumes are another group of plants that are included in measures of the spatial diversity of agriculture. These plants play an increasingly important role in agri-food systems. Primarily, they are used as animal feed (e.g., alfalfa, clover, and soy) [23]. Moreover, agronomic, nutritional, and environmental benefits are being increasingly highlighted [24]. The increased use of legumes is seen as a promising option for mitigating climate change because they are a source of protein that can replace animal protein [25]. Additionally, legumes also provide nitrogen to the soil [26]. According to L. Ditzler et al. [27], this group of plants can also contribute to a greater diversification of the currently simplified crop rotations that are prevalent in Europe and increase the sustainability of European farming systems. Despite the numerous benefits, only between 0.5% and 6.5% of the agricultural area in EU countries is sown with legumes [28].

When assessing the country's agricultural potential, it is also worth taking into account rapeseed production. Rapeseed has many uses, including as food for humans and animal feed. Furthermore, it is used for industrial purposes as a source of biodiesel and bioethanol [29]. Germany, France, and Poland are the main producers of rapeseed in the EU. The share of these countries in EU rapeseed production is over 40%. In 2021, its average percentage share in the agricultural area of the European Union was slightly over 3%. The largest share of UAA in EU countries is sown with rapeseed in the Czech Republic (10% of UAA), Lithuania (10%), Estonia (8%), and Latvia (7.5%) [28].

According to the literature on the subject, a feature often taken into account in international comparisons regarding the spatial differentiation of agricultural potential are data on the scale of animal production. This variable was used in research conducted by, among others, W. Poczta and N. Bartkowiak [30] and A. Jezierska-Thöle et al. [19].

EU countries have large livestock populations, with animal products accounting for 44% of the total value of agricultural production [31]. In 2021, there were over 141 million swine, over 75 million dead cattle, and approximately 20 million dairy cows on EU farms. Most EU farm animals are kept in just a few Member States. Almost a quarter of the EUs cattle population is found in France, and a similar share of the EUs pig and sheep population is found in Spain. Greece and Spain had more than half of all goats in the EU. It was noted that the highest livestock density measured per 100 ha of agricultural area among Member States was recorded in The Netherlands, Malta, and Belgium. In contrast, livestock farming was relatively extensive in the Baltic Member States and Bulgaria, where there were less than 0.3 livestock units per hectare of agricultural land [28].

The idea of sustainable development proposes a new form of responsible life for the individual and society based on development together with the social and environmental surroundings, with particular respect for ecological limitations and social expectations. The concept of sustainable development is understood as conducting economic and social development that will not take place at the expense of future generations and will take ecological limits into account. The essence is to reconcile economic, social, and ecological reasons, and the mechanism of its functioning comes down to three key goals [32]:

- Economic, which is expressed in meeting the material needs of the population while using technology that protects the environment;
- Social and humanitarian, assuming the provision of a social minimum, health protection, human development in the spiritual dimension, as well as security and education;
- Ecological, which involves stopping the destruction of the environment and eliminating the resulting threats.

In recent years, there has been a dynamic increase in interest in the topic of sustainable development, and with it, various paths aimed at achieving the seventeen Sustainable Development Goals have been developed. The circular economy that is currently the most important in national and international policies is the circular economy, the assumptions of which constitute an alternative to the linear model of using raw materials [33]. The circular economy, which is at the forefront of domestic and international policy agendas, is founded on principles that offer an alternative to the linear approach to raw material consumption [34]. The linear model of production and consumption involves extracting raw materials, using them once, and then throwing them away [35–37], which is no longer possible on a planet with limited resources and the ability to absorb the generated waste [38]. In turn, the circular economy is based on the "cradle to cradle" model, and the core of this concept is the life cycle of raw materials based on the 3R principle (ang. reduce, reuse, recycle) [39], creating an alternative closed loop [40]. The *reduce* principle involves reducing raw material inputs while increasing production efficiency. The *recycle* principle refers to the *reuse* of waste, as expressed by the reuse principle [41]. In this way, the circular economy develops around a fundamental change in systems regarding resource extraction, waste generation, pro-ecological awareness, and innovative business models [42]. R-framework is often expanded to include further aspects, e.g., rethink (thinking how to use a product to increase its reusability), refurbish (refreshing an older product), or recover (recovering energy by burning materials) [43].

The literature suggests over 200 definitions of this economic model, commonly referred to as a circular economy, closed-loop economy, or circularity economy [44]. The diversity of those definitions implies that various stakeholders understand the concept of a circular economy differently [41]. The research subject is also distinguishing sustainable development [45] from the circular economy and their mutual connections. Some researchers believe their differences are blurred and indicate difficulties in defining their conceptual relationship [46]. An example of this is that J. Kirchherr et al., in their research, showed that of all 114 definitions examined, only 12% of them contained clear links with sustainable development [39]. Moreover, M. Geissdoerfer and others noticed that the authors of the definition do not take into account all three dimensions of sustainable development, which is the foundation of this idea [47]. In the circular economy literature, the definition that is most often quoted is the definition of the Ellen MacArthur Foundation: *A circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment. In contrast to the 'take-make-waste' linear model, a circular economy is regenerative by design and aims to gradually decouple growth from the consumption of finite resources* [48].

Definitional chaos is not the only controversy introduced by the proposed new economic system—issues related to the possibilities of measuring the implementation of the circular economy are of equal interest.

Various international organizations (e.g., OECD [49] identified 474 circular economy-related indicators, and the UN Environment developed a "heat map" of 31 global indicator frameworks [50]) and researchers from various scientific fields (e.g., G. Moraga et al. [51], De Pascale et al. [52], J. Sánchez-Ortiz et al. [53], S. Pauliuk [54], F. Syu [55], P. Núñez-Cacho et al. [56], A. L. Bîrgovan et al. [57]) have undertaken the effort to propose measures of the circular economy. However, it should be emphasized that there is no "one-size-fits-all" indicator.

The evolving landscape of circular economy (CE) research within the EU-28 has increasingly recognized the complexity of measuring CE advancement due to its multidimensional nature. Reflecting this shift, a variety of studies have adopted synthetic measures to provide a more nuanced and holistic assessment of progress in circularity. One such example is the fact that the development of the Index of Development of Circular Economy (IDCE) by E. Mazur-Wierzbicka, based on a comprehensive evaluation of EU Member States across various CE indicators proposed by the European Commission, signifies a concerted effort to move beyond isolated metrics [58]. Concurrently, the work of B. Fura and colleagues has embraced a multidimensional comparative analysis leveraging 17 Eurostat indicators to dissect the CE across production and consumption, waste management, secondary materials, and competitiveness and innovation sectors, offering a temporal synthetic snapshot from 2010 to 2016 [59]. Similarly, A. Kasztelan has introduced an aggregate index of national economies' circularity (INEC), utilizing a taxonomic linear ordering method that distills multiple CE indicators into a singular synthetic metric, thereby simplifying the comparison across twenty-four EU countries [60]. Taking a slightly different approach,

M. M. Martínez Moreno and colleagues have constructed the Composite Index of Economic Circularity (CECI), which employs Principal Component Analysis to encapsulate the transition towards CE from 2014 to 2020, allowing for an annual ranking of Member States based on their CE performance [61]. Extending this line of inquiry, J.-L. Alfaro Navarro has proposed a new index utilizing a principal component analysis that retains all relevant information without succumbing to the pitfalls of dimensionality reduction. This index not only measures CE but also juxtaposes it against the Sustainable Development Goals, acknowledging the interplay between CE and broader sustainability targets [62]. Another example is that Ł. Nazarko's employment of Data Envelopment Analysis (DEA) and factor analysis have provided an objective comparative evaluation of Member States' adherence to CE principles, identifying clusters of countries by relative efficiency in CE goal implementation [63]. The consistent thread among these studies is the clear consensus on the necessity of synthetic measures to accurately capture the multifaceted nature of CE.

The implementation of the principles of a circular economy is aimed at creating a system in which the economic, social, and environmental dimensions would allow achieving the assumptions of sustainable development [64–66]. In 2014, the European Commission emphasized the need to move to a more circular economy, which will support initiatives for sustainable development and social inclusion. The communication also includes the circular economy as one that will maximize the added value of raw materials while eliminating waste through the reuse of materials [67]. In 2018, the European Commission recognized the circular economy as a global and irreversible megatrend that should constitute the foundation of the industrial strategies of the entire European Union [67].

The CE is based on the three principles of protecting and enhancing natural capital, optimizing resource efficiency, and promoting system efficiency. However, the application of the CE strategy in agriculture is aimed at reducing the use of external consumables in agricultural production, closing nutrient cycles, minimizing waste, and recovering agri-food residues [68]. Therefore, CE in relation to agriculture can be defined as "a set of activities designed not only to ensure economic, environmental, and social sustainability in agriculture through practices that seek the efficient and effective use of resources at all stages of the value chain but also guarantee regeneration and biodiversity in agroecosystems and surrounding ecosystems." Therefore, achieving efficiency in circular farming models involves optimizing processes to minimize resource consumption and avoid waste [69].

Previous research, although dealing with the importance of the assumptions of the circular economy in relation to individual economic sectors, did not address the issue of the regional diversification of agriculture. This article aims to fill this research gap. An indication of the spatial differentiation of agriculture and the development of a circular economy is intended to allow the identification of the relationships forming between them. In this way, it would be possible to take appropriate actions in economic policy aimed at implementing circular economy solutions as a response to emerging challenges resulting from the depletion of resources.

3. Materials and Methods

This research process was multi-staged. The initial stage of this study was a literature review. This is a process of targeted searching for scientific information from different sources in order to identify the most relevant information related to the subject of this study. The authors searched for information in databases such as Scopus, WOS, and Google Scholar. The selection criteria included the following keywords: agriculture, agricultural production, circular economy, European Union countries, synthetic measure, and TOPSIS method.

After the literature review, the next steps were the selection of this study area (Figure 1) and the choice of diagnostic variables.

Number of countries: 27
Area: 4 233 262 km²
Population (2020): 447 706 209
Population density: 105.8 people/km²

Figure 1. Research area. Source: own elaboration.

Selected diagnostic variables, meeting both substantive and statistical criteria and characterizing the complex phenomenon under study, are presented in Table 1. The variables formed the basis for the development of two synthetic measures (the agricultural production-economic synthetic measure and the circular economy development synthetic measure).

Table 1. Selected diagnostic variables for constructing the agricultural production-economic synthetic measure and the circular economy development synthetic measure.

Variable	Agriculture Indicators	Unit	S/D ****
X1	output of the agricultural industry—basic prices *	thousand euro/1 person employed in agriculture	S
X2	share of employment in agriculture	percentage	D
X3	gross value added of the agricultural industry	thousand euro/1 person employed in agriculture	S
X4	number of dairy cows	head/100 ha of UAA **	S
X5	number of bovine animals	head/100 ha of UAA	S
X6	number of swine	head/100 ha of UAA	S
X7	wheat and spelt	percentage of UAA	S
X8	barley	percentage of UAA	S
	Circular economy indicators	Unit	S/D
X9	private investment and gross added value related to circular economy sectors ***	million euro/1 person employed in circular economy sectors	S
X10	resource productivity	euro per kilogram, chain-linked volumes (2015)	S
X11	generation of municipal waste	kilograms per capita	D
X12	generation of packaging waste	kilograms per capita	D
X13	generation of plastic packaging waste	kilograms per capita	D
X14	recycling rate of packaging waste by type of packaging	percentage	S
X15	recycling of bio-waste	kilograms per capita	S

* Output is valued at basic prices. The basic price is defined as the price received by the producer after the deduction of all taxes on products, including all subsidies on products. The output of the agricultural industry is made up of the sum of the output of agricultural products and agricultural services and of the goods and services produced in inseparable non-agricultural secondary activities [Eurostat] ** UAA = Utilized Agricultural Area *** The indicator includes "Gross investment in tangible goods" and "Value added at factor costs" in the recycling sector, the repair and reuse sector, and the rental and leasing sector [Eurostat] **** S—stimulant; D—destimulant. Source: my own elaboration based on Eurostat data.

Selected sets of diagnostic variables (complete and available from Eurostat at the EU country level) were selected for universality, measurability, availability, completeness, comparability, sufficient variability (according to the coefficient of variation), and lack of excessive correlation of the variables (according to the inverse correlation matrix method). The preliminary statistical analysis of the diagnostic variables also included the elimination of quasi-constant variables. The coefficient of variation and highly correlated variables (using the inverse correlation matrix method) were used to select the diagnostic variables. A. Malina notes that a high value of the correlation coefficient results in the duplication of information about the analyzed phenomenon and may produce incorrect conclusions. Two highly correlated characteristics carry similar information, so one of them is redundant [70].

The selection of diagnostic variables and their substantive and/or statistical verification allowed them to be defined and described in the form of a matrix of observations (1):

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix}, \quad (1)$$

where: X_{ij}—denotes the values of the j-th variable for the i-th object, data matrix of objects, i—object number (i = 1, 2, ..., n), j—variable number (j = 1, 2, ..., m).

In the subsequent stage of this study, the zero unitarization method was applied. Variables were divided into stimulants and destimulants [71]. The studies were conducted dynamically by determining min{x ij } and max{x ij } values for 2012 and 2020. The selected variables were subjected to the zero unitarization procedure using the formula for stimulant (2) and destimulant (3):

$$Z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{ when } x_i \in S, \quad (2)$$

$$Z_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{ when } x_i \in D, \quad (3)$$

where: S-stimulant, i = 1, 2. . .n; j = 1, 2. . .m, $\max_{xij}$—maximum value of the j-th variable; $\min_{xij}$—minimum value of the j-th variable; x_{ij}—denotes the value of the j-th variable for the i-th object [72]; Z_{ij} denotes the normalized value of the j-th variable for the i-th object (falls within the range [0;1]).

As a result of unitarization, we obtain the matrix of feature values, Z_{ij} (4):

$$Z_{ij} = \begin{bmatrix} z_{11} & z_{12} & \dots & z_{1m} \\ z_{21} & z_{22} & \dots & z_{2m} \\ \dots & \dots & \dots & \dots \\ z_{n1} & z_{n2} & \dots & z_{nm} \end{bmatrix}, \quad (4)$$

where: Z_{ij}—the unitarized value of the j-th variable for the i-th object.

The studies also employed the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method, which was originally proposed by C. Hwang and K. Yoon [73]. The foundation of the TOPSIS method is defining a solution—pattern and a solution—anti-pattern [74–77]. Within the adopted method, a synthetic measure was constructed separately for each country, considering the distance of the unit from the pattern (5) and the anti-pattern (6) according to the formulas:

- distances of objects from the pattern:

$$d_i^+ = \sqrt{\frac{1}{n} \sum_{j=1}^{m} \left(z_{ij} - z_j^+\right)^2}, \quad (5)$$

- distances of objects from the anti-pattern:

$$d_i^- = \sqrt{\frac{1}{n}\sum_{j=1}^{m}\left(z_{ij} - z_j^-\right)^2}, \quad (6)$$

where: n—denotes the number of variables constituting the pattern or anti-pattern, z_{ij}—denotes the unitarized value of the j-th feature for the examined unit (or the normalized value of the j-th variable of the i-th object), z_j^+ / z_j^- – denotes the pattern or anti-pattern object.

The synthetic measure (7) for individual objects in countries was determined based on the formula:

$$q_i = \frac{d_i^-}{d_i^- + d_i^+}, \; when\ 0 \le q_i \le 1,\ i = 1,\ 2,\ \ldots,\ n, \quad (7)$$

when: $q_i \in [0; 1]$; d_i^- –denotes the distance of the object from the anti-pattern (from 0), d_i^+ denotes the distance of the object from the pattern (from 1). A higher value of the measure indicates a better situation for the unit in the examined area [78–85].

In the final stage of this study, spatial differentiation maps based on synthetic measures were presented, and the objects were divided into statistically similar groups. Pearson's linear correlation coefficients and regression analysis (synthetic measure of agriculture—dependent variable; diagnostic variables of the circular economy—independent variables; performed in the Statistica and Gretl program) were used to analyze and evaluate the strength of the relationship between the variables and the synthetic measure of the areas studied.

4. Results and Discussion

One of the most difficult challenges facing modern societies is the limited availability of resources. This situation is intensified by the large amount of waste generated. A paradigm shift is therefore required to ensure the more efficient use of resources. This means rethinking processes so that resources are used more efficiently and in a closed-loop system [86]. In the current context of resource scarcity, global climate change, environmental degradation, and the increasing demand for food, the circular economy (CE) is a promising strategy to support sustainable agriculture [69].

The indicator that relatively effectively describes the level of agricultural development and, in a broader sense, also characterizes the level of socio-economic advancement of a country is the share of individuals employed in agriculture out of the total number of employed individuals. The level of employment directly affects productivity and work efficiency, and consequently, the competitiveness of agricultural production on the domestic and international markets [87]. As the processes of economic development progress, the percentage of individuals pursuing the farming profession decreases in favor of an increase in the share of individuals working in other sectors of the national economy [88].

The largest share of individuals employed in agriculture out of the total number employed is found in Romania (20.5% in 2020; −0.31 in relation to 2020/2012)—Table 2. The next highest shares relate to Greece and Poland (respectively, 9.5%; −0.25). Romania and Poland are two countries that joined the EU relatively late (2007 and 2004, respectively) and are characterized by an exceptionally large number of agricultural holdings in general, with a particularly numerous dominance of small agricultural holdings. It is worth noting that significant changes in employment structure have occurred during the analyzed period and over a longer time horizon. Relatively the fastest against the background of other EU countries, the number of those employed in agriculture is decreasing, which was conditioned by historical factors, including the centrally planned economy in the period after World War II.

The calculation of the synthetic indicator of the agricultural production-economic synthetic measure for the year 2012 enabled the ranking of the European Union Member States. Denmark, The Netherlands, Belgium, Luxembourg, France, and Germany qualified in the first group (Table 3). It is important to note that these countries are characterized by a relatively stable situation. All these countries were in high positions in 2012 and formed the best group in the ranking in 2020 (Table 4). This indicates a high level of agricultural development in these countries, measured primarily by the highest labor resource productivity. The average value of this indicator calculated for these countries in 2020 amounted to 167.19 thousand EUR and was over 2.5 times higher than the average value calculated for the countries of the second group and over seven times higher in comparison with the fourth group.

Table 2. Output of the agricultural sector and the share of workers employed in agriculture in the member states of the European Union in 2012 and 2020.

Specification	Output of the Agricultural Industry—Basic Prices (Thousand Euro/1 Employed in Agriculture)				Share of Workers Employed in Agriculture (%)			
	2012	2020	2020–2012 (+/−)	2020/2012 (2012 = 1)	2012	2020	2020–2012 (+/−)	2020/2012 (2012 = 1)
Austria	37.932	45.622	7.690	0.20	4.70	3.90	−0.80	−0.17
Belgium	168.391	203.094	34.703	0.21	1.20	0.90	−0.30	−0.25
Bulgaria	23.412	19.563	−3.849	−0.16	6.40	6.60	0.20	0.03
Croatia	14.508	22.666	8.159	0.56	12.20	6.40	−5.80	−0.48
Cyprus	64.132	66.591	2.459	0.04	2.90	2.70	−0.20	−0.07
Czechia	32.586	41.223	8.637	0.27	3.10	2.60	−0.50	−0.16
Denmark	169.537	195.070	25.532	0.15	2.60	2.10	−0.50	−0.19
Estonia	32.532	51.148	18.616	0.57	4.50	3.00	−1.50	−0.33
Finland	47.154	48.555	1.400	0.03	4.10	3.60	−0.50	−0.12
France	102.125	122.482	20.357	0.20	2.90	2.30	−0.60	−0.21
Germany	93.384	106.229	12.845	0.14	1.60	1.30	−0.30	−0.19
Greece	22.549	29.251	6.702	0.30	13.00	10.60	−2.40	−0.18
Hungary	38.692	39.582	0.890	0.02	5.10	4.80	−0.30	−0.06
Ireland	62.929	86.623	23.694	0.38	5.80	4.50	−1.30	−0.22
Italy	65.259	63.393	−1.866	−0.03	3.70	4.00	0.30	0.08
Latvia	18.104	26.844	8.741	0.48	8.40	7.20	−1.20	−0.14
Lithuania	26.492	45.114	18.622	0.70	8.80	5.70	−3.10	−0.35
Luxembourg	133.915	206.498	72.583	0.54	1.30	0.70	−0.60	−0.46
Malta	70.232	42.045	−28.187	−0.40	1.00	1.10	0.10	0.10
The Netherlands	131.502	169.787	38.285	0.29	2.50	1.90	−0.60	−0.24
Poland	11.855	16.841	4.986	0.42	12.60	9.50	−3.10	−0.25
Portugal	13.472	32.487	19.015	1.41	10.80	5.40	−5.40	−0.50
Romania	5.636	9.629	3.993	0.71	29.70	20.50	−9.20	−0.31
Slovakia	31.800	35.941	4.141	0.13	3.20	2.60	−0.60	−0.19
Slovenia	14.834	34.360	19.526	1.32	8.30	4.10	−4.20	−0.51
Spain	56.438	67.667	11.229	0.20	4.20	4.00	−0.20	−0.05
Sweden	66.301	70.972	4.672	0.07	2.00	1.70	−0.30	−0.15

Source: study based on Eurostat data.

The subsequent indicator, which significantly differentiates individual countries and determines their affiliation to specific typological classes, is employment in agriculture. The average indicator of employment share in the primary sector of the economy, calculated for the countries in the first group, amounted to 1.53% and was over twice as low as the value for the second group. The top group consists of countries characterized by, among other features, high labor productivity in agriculture and a favorable agrarian structure. Such parameters facilitated significant labor market transformations in the past, and currently, the employment share in the primary sector of the economy is maintained at a low level. This enabled many individuals to find employment in other sectors of the national economy, which consequently also facilitated the elevation of the socio-economic development level of entire countries.

The second group in 2012 comprised seven countries with a markedly lower gross value added generated per employed individual in agriculture (24.6 thousand euros versus 54.6 thousand euros in the first group). The difference between this group and the next one (III) in terms of this indicator is not as large, although still significant (16.9 thousand euros in group III). These two groups included countries with a diversified agrarian structure, which is also characterized by a slightly lower intensity of agricultural production (measured, for instance, by cattle and swine stocking rates per ten hectares of agricultural land).

Table 3. Ranking of European Union member states according to the value of the agricultural production-economic synthetic measure in 2012.

Number of Group	Countries	Output of the Agricultural Industry—Basic Prices (Thousand Euro/1 Employed in Agriculture)	Share of Employment in Agriculture (%)	Gross Value Added of the Agricultural Industry (Thousand Euro/1 Employed in Agriculture)	Number of Dairy Cows (Head/100 ha of UAA)	Number of Bovine (Head/100 ha of UAA)	Number of Swine (Head/100 ha of UAA)	Wheat and Spelt (Percentage of UAA)	Barley (Percentage of UAA)	The Agricultural Production-Economic Synthetic Measure
I	Denmark	169.54	2.60	53.90	13.78	60.33	461.07	0.23	0.27	0.61
	The Netherlands	131.50	2.50	44.28	83.68	216.39	657.25	0.08	0.02	0.60
	Belgium	168.39	1.20	53.29	37.75	182.78	483.37	0.16	0.03	0.59
	Luxembourg	133.92	1.30	36.66	34.24	143.28	67.43	0.10	0.05	0.46
	Cyprus	64.13	2.90	29.66	20.87	49.09	340.87	0.07	0.25	0.45
	Malta	70.23	1.00	29.99	55.20	136.16	394.85	0.00	0.00	0.44
	Germany	93.38	1.60	29.46	3.47	75.04	169.98	0.18	0.10	0.43
II	France	102.12	2.90	40.01	12.57	65.69	47.51	0.18	0.06	0.42
	Czechia	32.59	3.10	9.06	10.41	37.47	43.50	0.23	0.11	0.37
	Italy	65.26	3.70	35.95	16.01	49.82	69.03	0.15	0.02	0.37
	Sweden	66.30	2.00	18.80	11.40	47.62	48.61	0.12	0.12	0.37
	Finland	47.15	4.10	13.03	12.25	39.44	55.60	0.10	0.20	0.36
	Spain	56.44	4.20	28.69	3.53	24.77	107.62	0.09	0.11	0.35
	Slovakia	31.80	3.20	7.67	7.77	24.44	32.76	0.20	0.08	0.34
III	Ireland	62.93	5.80	16.41	23.39	137.97	32.95	0.02	0.04	0.34
	Hungary	38.69	5.10	13.27	4.78	14.24	55.99	0.20	0.05	0.33
	Austria	37.93	4.70	15.61	18.28	68.29	104.18	0.11	0.05	0.33
	Estonia	32.53	4.50	13.02	10.13	25.73	39.24	0.13	0.11	0.33
	Lithuania	26.49	8.80	10.41	11.65	25.66	28.41	0.22	0.08	0.33
	Bulgaria	23.41	6.40	8.80	5.75	10.45	10.36	0.23	0.04	0.32
IV	Latvia	18.10	8.40	4.40	8.94	21.35	19.30	0.19	0.05	0.30
	Slovenia	14.83	8.30	4.94	23.15	95.92	61.73	0.07	0.04	0.28
	Poland	11.86	12.60	4.65	16.15	37.99	76.62	0.14	0.08	0.27
	Croatia	14.51	12.20	6.12	13.60	33.96	88.81	0.14	0.04	0.26
	Greece	22.55	13.00	11.77	2.57	13.34	20.33	0.11	0.02	0.22
	Portugal	13.47	10.80	4.69	6.46	40.86	55.23	0.02	0.01	0.21
	Romania	5.64	29.70	2.43	8.47	14.63	38.11	0.15	0.03	0.16

Source: study based on Eurostat data.

The last group primarily comprises countries that relatively recently joined the European Union, along with Greece and Portugal. Despite geographical diversification, a common trait among these countries is the highest employment in agriculture (averaging 9%, with countries like Romania having an agricultural employment rate of 20.5%). These countries have a long road ahead in terms of transforming and adjusting their economic structures to match those of the more developed European states. One possible direction for such changes could be the implementation of the circular economy concept. The skillfully managed transformation towards the circular economy could thus provide these countries with an opportunity to make a "developmental leap" towards modernity, akin to, yet in lieu of, the industrialization undertaken in Western European countries in the second half of the twentieth century.

Table 4. Ranking of European Union member states according to the agricultural production-economic synthetic measure in 2020.

Number of Group	Countries	Output of the Agricultural Industry—Basic Prices (Thousand Euro/1 Employed in Agriculture)	Share of Employment in Agriculture (%)	Gross Value Added of the Agricultural Industry (Thousand Euro/1 Employed in Agriculture)	Number of Dairy Cows (Head/100 ha of UAA)	Number of Bovine Animals (Head/100 ha of UAA)	Number of Swine (Head/100 ha of UAA)	Wheat and Spelt (Percentage of UAA)	Barley (Percentage of UAA)	The Agricultural Production-Economic Synthetic Measure
I	The Netherlands	169.79	1.90	63.57	86.47	203.42	636.06	0.06	0.02	0.63
	Denmark	195.07	2.10	61.08	13.63	57.25	511.11	0.19	0.25	0.61
	Belgium	203.09	0.90	55.43	39.35	170.83	454.86	0.14	0.03	0.59
	Luxembourg	206.50	0.70	59.19	41.04	144.31	62.15	0.09	0.05	0.52
	Germany	106.23	1.30	38.67	3.40	68.10	157.09	0.17	0.10	0.44
	France	122.48	2.30	49.41	11.79	61.65	46.35	0.16	0.07	0.43
II	Cyprus	66.59	2.70	31.78	30.90	64.98	281.00	0.10	0.10	0.42
	Malta	42.05	1.10	18.54	56.64	133.55	374.67	0.00	0.00	0.41
	Lithuania	45.11	5.70	19.41	7.91	21.39	19.72	0.30	0.06	0.38
	Ireland	86.62	4.50	31.92	32.27	144.73	37.21	0.01	0.04	0.38
	Czechia	41.22	2.60	14.16	10.13	38.03	43.87	0.23	0.09	0.38
	Sweden	70.97	1.70	19.87	10.13	46.28	46.22	0.15	0.10	0.37
	Spain	67.67	4.00	36.38	3.32	27.16	134.22	0.08	0.11	0.36
III	Estonia	51.15	3.00	13.19	8.55	25.70	32.13	0.17	0.13	0.36
	Italy	63.39	4.00	35.59	14.26	48.77	65.10	0.13	0.02	0.36
	Finland	48.56	3.60	15.95	11.26	36.80	48.63	0.09	0.17	0.35
	Slovakia	35.94	2.60	9.82	6.39	23.16	28.18	0.20	0.07	0.35
	Austria	45.62	3.90	18.66	19.83	70.10	106.03	0.11	0.05	0.34
	Latvia	26.84	7.20	9.17	6.91	20.26	15.58	0.25	0.04	0.34
	Hungary	39.58	4.80	16.12	4.93	18.67	57.02	0.19	0.05	0.33
IV	Bulgaria	19.56	6.60	8.50	4.79	11.67	11.73	0.24	0.03	0.32
	Slovenia	34.36	4.10	14.77	20.50	100.32	47.41	0.06	0.05	0.32
	Poland	16.84	9.50	6.57	14.41	42.55	79.48	0.16	0.05	0.29
	Croatia	22.67	6.40	10.79	7.30	28.08	68.58	0.10	0.04	0.28
	Portugal	32.49	5.40	12.78	5.86	42.60	56.72	0.01	0.00	0.26
	Greece	29.25	10.60	15.10	1.71	11.99	14.11	0.07	0.03	0.23
	Romania	9.63	20.50	4.74	8.60	14.37	29.00	0.17	0.03	0.21

Source: study based on Eurostat data.

Agriculture is one of the sectors that significantly contributes to the planet's greenhouse gas emissions [89]. Sustainable production in the agricultural system is very important to address social concerns about environmental impacts while maintaining economic levels of production. The comprehensive importance of sustainability in the agricultural ecosystem is to meet food requirements, improve environmental and economic sustainability, and promote social sustainability [90].

Calculations conducted using the TOPSIS method for the synthetic circular economy development measure facilitated the division of the European Union's member states into four groups. Countries with a synthetic measure value exceeding 0.46 were included in the first typological group. This group comprised eight countries: Austria, Belgium, France, Luxembourg, The Netherlands, Germany, Sweden, and Italy (Table 5). These are primarily Western European countries characterized by a high level of economic development and the associated good material standing of their inhabitants. Six of these countries were part of the creation of the European Coal and Steel Community (an institution that initiated European economic integration) right from the outset (Belgium, France, Luxembourg, The

Netherlands, Germany, and Italy). Therefore, these are countries that have sought to integrate at least a portion of their economic policies for around sixty years. Starting in the nineteen-sixties, they developed a series of mechanisms and institutional-economic solutions that addressed the continually emerging challenges of a globalizing and evolving world.

Table 5. Ranking of European Union member states according to the value of the circular economy development synthetic measure in 2012.

Number of Group	Countries	Private Investment and Gross Added Value Related to Circular Economy Sectors (Million Euro/1 Employed in Circular Economy Sectors)	Material Reuse Rate (Euro per Kilogram, Chain-Linked Volumes (2015)	Generation of Municipal per Capita (Kilograms per Capita)	Generation of Packaging Waste per Capita (Kilograms per Capita)	Generation of Plastic Packaging Waste per Capita (Kilograms per Capita)	Recycling Rate of Packaging Waste by Type of Packaging (Percentage)	Recycling of Bio-Waste (Kilograms per Capita)	The Circular Economy Development Synthetic Measure
I	Austria	10.635	2.0319	579	148.7	32.24	65.9	196	0.56
	Belgium	8.855	2.5895	445	154.46	28.85	80.3	93	0.56
	The Netherlands	4.779	3.7416	549	164.07	27.39	69.3	140	0.55
	Sweden	2.469	1.9422	454	111.17	22.44	69.6	65	0.51
	Luxembourg	18.118	4.3728	652	202.67	45.73	62.5	128	0.50
	Slovenia	0.744	1.4568	362	98.2	21.8	66.9	21	0.49
	Bulgaria	0.417	0.3433	460	45	13.16	66.5	13	0.47
	Croatia	0.433	1.0786	391	46.52	11.31	59.7	6	0.47
	Czechia	0.386	0.9991	308	91.56	20.14	69.9	8	0.47
	Germany	2.154	2.3026	619	206.23	35.27	71.3	110	0.47
	Romania	0.801	0.4006	251	52.82	14.86	56.8	29	0.47
II	Slovakia	0.728	1.145	306	82.91	19.33	68.1	15	0.46
	France	4.091	2.7273	527	187.3	30.53	64.9	87	0.45
	Spain	0.997	2.513	468	143.73	27.89	65.5	48	0.44
III	Finland	1.718	1.1888	506	132.2	21.65	59.3	60	0.43
	Greece	0.395	1.1543	495	70.02	16.74	58.6	16	0.43
	Italy	1.096	2.827	504	190.55	34.46	66.6	73	0.43
	Lithuania	0.455	0.8918	445	101.12	19.98	62.2	17	0.43
	Denmark	7.31	1.9747	806	160.05	32.85	61.6	125	0.42
	Latvia	0.879	0.9812	323	105.13	18.18	51.1	6	0.42
IV	Hungary	0.425	1.1954	402	102.1	25.9	48.5	18	0.41
	Ireland	2.038	2.1475	585	176	36.65	74	34	0.4
	Cyprus	2.168	1.1352	664	86.75	17.62	55.3	8	0.39
	Estonia	1.834	0.5477	280	149.15	35.98	61.3	14	0.39
	Portugal	1.164	1.0243	453	145.34	33.31	56.9	66	0.39
	Poland	0.473	0.5995	317	122.69	21.86	41.4	5	0.38
	Malta	1.468	1.8024	612	125.12	25.82	46.6	12	0.34

Source: study based on Eurostat data.

The countries characterized by the lowest circular economy development synthetic measure were Malta, Portugal, and Cyprus (Table 5). These are countries located in Southern Europe in the Mediterranean basin. The economies of these nations rely on tourism activity to a significantly greater extent than most other EU member states. Another distinguishing feature of these countries is the small significance of industrial activity in the national economy. Among other factors, these issues contribute to the relatively low level of advancement in processes related to the circular economy.

In 2020, thus, after eight years, the ranking of countries did not experience significant changes (Table 6). There were indeed minor shifts between groups; however, they were not of a breakthrough nature. The parameters determining a given country's position in terms of the circular economy development synthetic measure are relatively stable and do not undergo large changes, especially in the largest economies of the European Union. The wealthiest EU countries continue to lead the ranking, focusing on sustainable development and adapting economic policies to counter climate change, including circular economy principles.

Table 6. Ranking of European Union member states by the value of the circular economy development synthetic measure in 2020.

Number of Group	Countries	Private Investment and Gross Added Value Related to Circular Economy Sectors (Million Euro/1 Employed in Circular Economy Sectors)	Material Reuse Rate (Euro per Kilogram, Chain-Linked Volumes (2015)	Generation of Municipal per Capita (Kilograms per Capita)	Generation of Packaging Waste per Capita (Kilograms per Capita)	Generation of Plastic Packaging Waste per Capita (Kilograms per Capita)	Recycling Rate of Packaging Waste by Type of Packaging (Percentage)	Recycling of Bio-Waste (Kilograms per Capita)	The Circular Economy Development Synthetic Measure
I	The Netherlands	7.88	4.918	533	170.42	30.15	80.7	156	0.61
	Luxembourg	32.429	4.3722	790	205.22	39.08	71.9	186	0.57
	Belgium	11.014	2.8048	729	167.28	32.0	79.7	137	0.52
	Slovenia	0.685	1.5764	487	118.16	23.68	67.9	70	0.51
	Austria	11.023	2.0446	834	157.34	33.55	63.7	179	0.50
	Italy	1.956	3.4292	487	208.77	37.16	72.8	116	0.50
	Bulgaria	0.734	0.35	408	79.49	23.36	61.2	5	0.49
	Slovakia	0.94	1.3186	478	103.67	23.49	70.8	65	0.49
II	Germany	3.89	2.6827	641	225.79	39.71	68.1	143	0.48
	Sweden	2.623	1.9008	431	132.06	24.03	60.9	78	0.48
	Croatia	0.746	1.0975	418	66.03	16.27	54.2	21	0.46
	Spain	1.29	2.5062	464	168.21	36.0	68.3	93	0.46
	Czechia	0.692	1.1617	543	124.21	24.72	67.9	70	0.45
	France	3.857	3.1375	538	187.6	35.69	60.3	97	0.45
	Lithuania	1.085	0.7741	483	136.79	30.81	61.8	100	0.45
III	Denmark	8.278	2.12	814	179.34	39.27	64	158	0.44
	Finland	1.735	1.2274	611	157.66	28.41	73.2	80	0.44
	Greece	0.267	1.5854	524	81.1	20.76	60.1	26	0.43
	Latvia	0.944	0.9414	478	142.81	24.58	61.4	35	0.42
	Cyprus	0.599	1.2738	609	92.31	20.63	66.8	6	0.41
IV	Poland	0.853	0.7794	346	172.19	34.19	55.5	42	0.4
	Estonia	1.39	0.6283	383	154.74	40.32	71.4	10	0.39
	Romania	1.197	0.3386	290	116.38	24.95	39.9	18	0.38
	Ireland	6.343	3.1629	644	224.45	61.52	62.4	70	0.36
	Hungary	0.965	0.9044	403	154.64	47.24	52.4	39	0.35
	Portugal	2.023	1.0928	513	174.26	40.29	59.8	72	0.35
	Malta	3.191	1.8638	643	139.81	27.43	40	0	0.31

Source: study based on Eurostat data.

A significant decline was observed for Hungary (which was in the last group in 2020). This was mainly due to a decrease in the country's position in categories such as material reuse rate and a decrease in the number of people employed in circular economy sectors.

Limiting the material reuse rate was also the cause of a significant drop in Romania's ranking. Many countries where a socialist economy prevailed after the Second World War are grappling with this issue. Reducing the use of resources and managing them efficiently has become one of the most critical challenges for economic entities and countries wishing to effectively compete in the global economy. Indeed, rising commodity prices and the depletion of some types of resources are major factors in international competitiveness.

The analyses performed to identify the relationship between the spatial variation in agricultural development and the level of circular economy implementation in different EU Member States allow some correlations to be observed (Figure 2). Some countries with the highest indices describing the state of the agricultural sector also rank highly on the basis of the synthetic measure of circular economy development. This group includes The Netherlands, Luxembourg, and Belgium (Table A1). These are some of the wealthiest EU Member States, which have been part of the organization since its inception. Long-term structural changes in these countries have accelerated the development of non-agricultural sectors of the economy. Environmental pressures from the changing and industrializing economies of these countries also began to emerge relatively early. As a result, questions about the sustainability of such development trends were raised earlier. Ongoing environmental degradation prompted steps to move away from the previous economic development model based on the intensification of agricultural production and industrialization. Given the relatively small land area and high population density, an alternative development model was sought to maintain a high standard of living and competitiveness for future generations. These requirements are directly in line with the goals of sustainable development. As a result, the foundations of a circular economy were laid relatively early in these countries.

It is worth noting that developing a circular economy means, among other things, creating new jobs related to this sector, which is very often characterized by innovation and high added value. The conditions outlined above have enabled some of the human capital resources to move to work in the so-called green economy. As a consequence, this created space on the labor market to supply subsequent sectors of the economy with the resources of the labor force that left agriculture. Such processes, on the other hand, forced mechanization, automation, and robotization in the agricultural sector, which had a positive impact on both labor productivity and resource productivity in the first sector of the national economy.

Poland and Portugal were countries that, both in 2012 and 2020, found themselves in groups with the lowest level of agricultural development and circular economy. These are countries that have been grappling with the problem of anachronistic area structures on agricultural farms for many years. The dominance of many small production entities in agriculture does not enable the exploitation of scale effects and significantly limits the possibilities and economic efficiency of applying the latest achievements in agricultural technology. These countries, along with a few others, mainly those that joined the EU relatively recently, are not sufficiently endowed with public and private financing sources to support a rapid pace of circular economy development. In this way, a vicious circle of development and economic stagnation is formed.

In order to assess the influence of the diagnostic variables of the circular economy on the spatial variation of the synthetic measure of agriculture, a regression model (classical least squares model) describing the dependence of the variables was estimated as:

F (synthetic measure of agriculture, dependent variable) = Σ (diagnostic variables of the circular economy, independent variables)

The model of interest has the form:

F (synthetic measure of agriculture) = 0.00234075 (private investment and gross added value related to circular economy sectors) + 0.000424679 (generation of municipal waste per capita) + 0.00919509 (circular material use rate) + 0.00255993 (recycling rate of packaging waste by type of packaging) − 0.000470763 (recycling of bio-waste) − 0.0600563

The regression analysis for the agricultural production-economic synthetic measure and diagnostic variables of the circular economy development synthetic measure suggests that the presented regression model can explain 71.58% of the model's variability. This variability was explained by the variability of independent variables (i.e., private investment and gross added value related to circular economy sectors, the generation of municipal waste, the circular material use rate, the recycling rate of packaging waste by type of packaging, and the recycling of bio-waste). It can be concluded that this model is well-fitting. The model fitting was measured using the multiple R^2 indicators (70.98%). The level of adjusted R^2 value and the improved R^2 may suggest that it is necessary to increase the multidimensionality of the model to include other areas that may influence the level of agricultural development. The F-statistic is 119.4039 and is statistically significant ($p < 0.0000$) (Table 7).

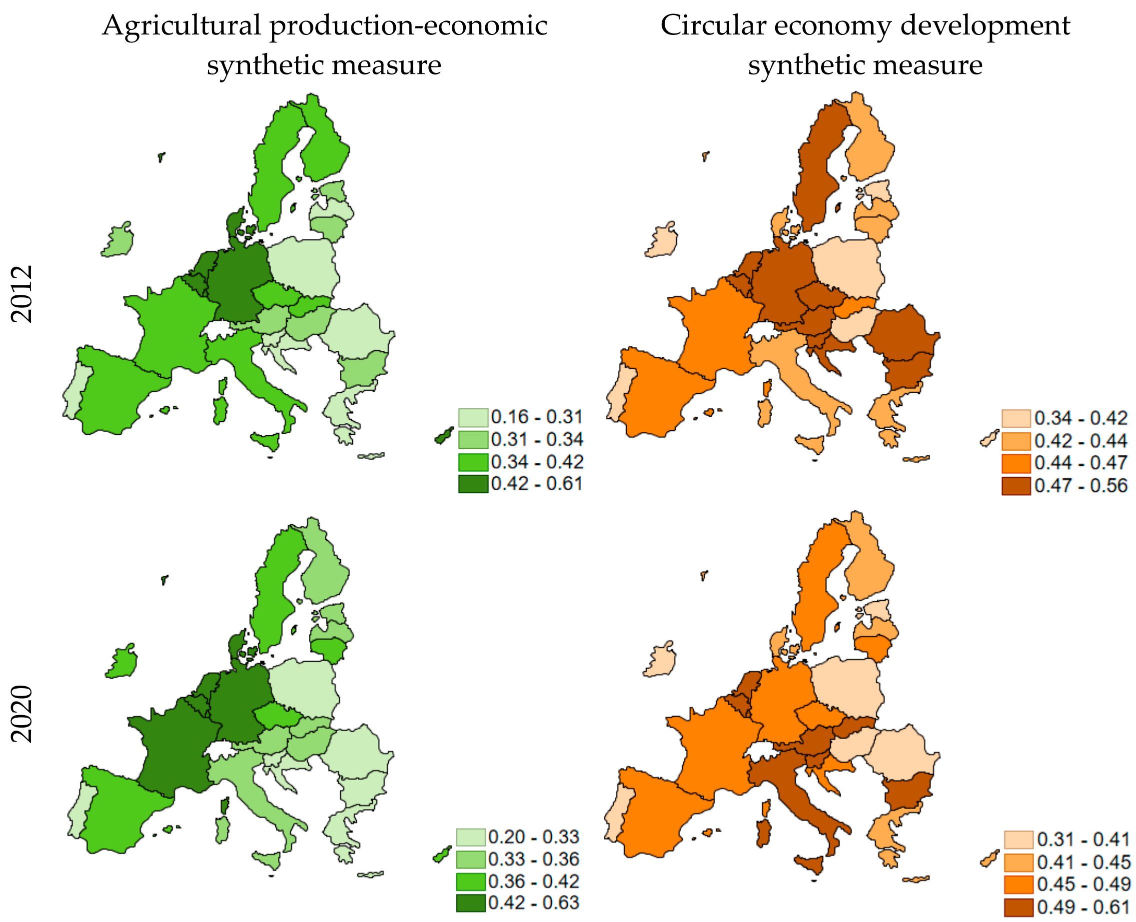

Figure 2. Spatial differentiation of the agricultural production-economic synthetic measure and the circular economy development synthetic measure in EU member states in 2012 and 2020. Source: own elaboration.

Food losses and agricultural waste continue to pose a challenge to agricultural sustainability. Most vegetable and dairy farmers do not properly manage agricultural waste. For this purpose, it is necessary to link the supply and demand for agricultural waste and to increase knowledge among farmers. To address food loss and agricultural waste issues, coordination and information sharing are required within and between supply chain participants [91].

Agriculture faces various challenges and barriers in the transition to a circular economy. Farmers' willingness to adopt circular practices depends on their location, legislation, and available incentives. Overcoming these barriers requires concerted efforts, innovative technologies, and effective communication between stakeholders. Integrating conversion technologies into existing infrastructure, designing sustainable supply chains, and developing appropriate analytical tools are key steps towards a successful circular agricultural economy [92].

Agriculture is closely connected with the natural ecosystem, which makes the agricultural economic system a harmonious process of matter circulation in the natural ecosystem. This shows the path to the development of a circular economy in agriculture [93].

Table 7. Results of the regression analysis of the relationship between diagnostic variables of the agricultural production-economic and the circular economy development indices in EU member states in 2012–2020.

Specification	Coefficient	Standard Error	*t*-Statistic	*p*-Value
const	−0.0600563	0.0326719	−1.838	0.0673
private investment and gross added value related to circular economy sectors	0.00234075	0.000878609	2.664	0.0082
generation of municipal waste per capita	0.000424679	3.65231×10^{-5}	11.63	<0.0001
circular material use rate	0.00919509	0.000693221	13.26	<0.0001
recycling rate of packaging waste by type of packaging	0.00255993	0.000473306	5.409	<0.0001
recycling of bio-waste	−0.000470763	0.000121833	−3.864	0.0001

The mean of the dependent variable	0.369967	Standard deviation of the dependent variable	0.103893
Sum of squared residuals	0.742261	Standard error of residuals	0.055963
Coefficient of determination (R^2)	0.715834	Adjusted R-squared	0.709839
F-statistic (5, 237)	119.4039	*p*-value for F-test	1.06×10^{-62}
Log-likelihood	358.8185	Akaike information criterion	−705.6370
Bayesian Schwarz criterion	−684.6786	Hannan–Quinn criterion	−697.1952

Classical estimation by the method of least squares, using observations 1–243, dependent variable (Y): the agricultural production-economic synthetic measure. Source: own elaboration.

5. Conclusions

The article attempts to look for the relationship between the economic and production characteristics of agriculture, its diversity in the EU Member States, and the level of development of the circular economy. The circular economy is one of the new concepts of change that responds to the current challenges of a changing world. This means, among other things, striving to reuse material factors of production in order to reduce the consumption of resources.

This study uses two proprietary indicators, calculated for 2012 and 2020. The first is a measure of the advancement of the development of the circular economy. This indicator makes it possible to assess the advancement of the implementation of the circular economy concept in the analyzed area. The analyzed indicator ranged from 0.34 to 0.56 in 2012 and from 0.31 to 0.61 in 2020. Due to the value of the calculated indicator, this research distinguished four typological groups of countries.

As the results of the analyses indicate, the development of the circular economy has occurred to a greater extent in wealthier EU countries. These countries have already carried out economic transformation, which, among other things, has meant increasing the efficiency of agriculture by reducing employment and increasing the productivity of basic production factors. Positive changes in this sector of the national economy took place in parallel with the modernization of other sectors. Earlier recognition of the problems of pressure exerted by human activity on the natural environment in more affluent countries resulted in the development of a circular economy.

The second of the author's measures—the indicator of the production and economic situation of agriculture—makes it possible to determine the potential of agriculture in a selected region/country. The value of the calculated indicator characterizing the production and economic situation of agriculture in individual countries in the first year of the analysis ranged from 0.16 to 0.60. In 2020, the indicator values for individual countries increased slightly and ranged from 0.21 to 0.63. Four categories of EU countries were distinguished based on the value of a synthetic measure characterizing the production and economic situation in agriculture.

The conducted analyses provide grounds for the claim that countries characterized by a higher level of agricultural development were also in higher positions in the ranking of the advancement of the implementation of the circular economy concept. Projects to develop the circular economy are the next stage in the implementation of innovation. The effective implementation of new economic concepts requires a developed economy in which more modern industries and specialized services are considered more important.

Finally, it should be emphasized that, taking into account the constant changes in the production and economic situation in agriculture in individual European Union Member States and changes in the level of advancement of the development of the circular economy, it would be interesting to continue research in this area in the coming years in order to determine the directions of the changes taking place.

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

Funding: This article was funded by the University of Agriculture in Krakow.

Data Availability Statement: Data presented in this paper are contained within the manuscript and Appendix A.

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

Appendix A

Table A1. A comparative summary of the values of the agricultural production-economic synthetic measure and the circular economy development synthetic measure in member states of the EU in 2012 and 2020.

Number of Groups	Agricultural Production-Economic Synthetic Measure		Circular Economy Development Synthetic Measure	
	2012	**2020**	**2012**	**2020**
I	Denmark 0.61 The Netherlands 0.60 Belgium 0.59 Luxembourg 0.46 Cyprus 0.45 Malta 0.44 Germany 0.43 France 0.42	The Netherlands 0.63 Denmark 0.61 Belgium 0.59 Luxembourg 0.52 Germany 0.44 France 0.43 Cyprus 0.42	Belgium 0.56 Austria 0.56 The Netherlands 0.55 Sweden 0.51 Luxembourg 0.5 Slovenia 0.49 Bulgaria 0.47 Czechia 0.47 Germany 0.47 Croatia 0.47 Romania 0.47	The Netherlands 0.61 Luxembourg 0.57 Belgium 0.52 Slovenia 0.51 Italy 0.50 Austria 0.50 Bulgaria 0.49 Slovakia 0.49

Table A1. *Cont.*

Number of Groups	Agricultural Production-Economic Synthetic Measure		Circular Economy Development Synthetic Measure	
	2012	2020	2012	2020
II	Czechia 0.37 Italy 0.37 Sweden 0.37 Finland 0.36 Spain 0.35 Slovakia 0.34 Ireland 0.34	Malta 0.41 Czechia 0.38 Ireland 0.38 Lithuania 0.38 Sweden 0.37 Estonia 0.36 Italy 0.36 Spain 0.36	Slovakia 0.46 France 0.45 Spain 0.44	Germany 0.48 Sweden 0.48 Spain 0.46 Croatia 0.46 Czechia 0.45 France 0.45 Lithuania 0.45
III	Hungary 0.33 Austria 0.33 Estonia 0.33 Lithuania 0.33 Bulgaria 0.32	Finland 0.35 Slovakia 0.35 Austria 0.34 Latvia 0.34 Hungary 0.33	Greece 0.43 Italy 0.43 Lithuania 0.43 Finland 0.43 Denmark 0.42 Latvia 0.42	Denmark 0.44 Finland 0.44 Greece 0.43 Latvia 0.42 Cyprus 0.41
IV	Latvia 0.30 Slovenia 0.28 Poland 0.27 Croatia 0.26 Greece 0.22 Portugal 0.21 Romania 0.16	Bulgaria 0.32 Slovenia 0.32 Poland 0.29 Croatia 0.28 Portugal 0.26 Greece 0.23 Romania 0.21	Hungary 0.41 Ireland 0.40 Estonia 0.39 Cyprus 0.39 Portugal 0.39 Poland 0.38 Malta 0.34	Poland 0.40 Estonia 0.39 Romania 0.38 Ireland 0.36 Hungary 0.35 Portugal 0.35 Malta 0.31

Source: own elaboration.

References

1. Pawlak, K.; Smutka, L.; Kotyza, P. Agricultural Potential of the EU Countries: How Far Are They from the USA? *Agriculture* **2021**, *11*, 282. [CrossRef]
2. Tłuczak, A. Diversity of the selected elements of agricultural potential in the European Union countries. *Agric. Econ.—Czech* **2020**, *66*, 260–268. [CrossRef]
3. Barath, L.; Fertő, I. Productivity and Convergence in European Agriculture. *J. Agric. Ekon.* **2017**, *68*, 228–248. [CrossRef]
4. Nowak, A.; Różańska-Boczula, M. The Competitiveness of Agriculture in EU Member States According to the Competitiveness Pyramid Model. *Agriculture* **2022**, *12*, 28. [CrossRef]
5. Adamowicz, M. Agricultural development processes in the context of globalization challenges and new approaches to the concept of sustainable development. *Probl. Agric. Econ.* **2021**, *1*, 24–45. [CrossRef]
6. Tongwane, M.I.; Moeletsi, M.E. A review of greenhouse gas emissions from the agriculture sector in Africa. *Agric. Syst.* **2018**, *166*, 124–134. [CrossRef]
7. Tubiello, F.N.; Salvatore, M.; Rossi, S.; Ferrara, A.; Fitton, N.; Smith, P. The FAOSTAT database of greenhouse gas emissions from agriculture. *Environ. Res. Lett.* **2013**, *8*, 015009. [CrossRef]
8. Pichlak, M. Gospodarka o obiegu zamkniętym—Model koncepcyjny. *Ekonomista* **2018**, *3*, 335–346.
9. Nelson, G.C.; Rosegrant, M.W.; Koo, J.; Robertson, R.; Sulser, T.; Zhu, T.; Ringler, C.; Msangi, S.; Palazoo, A.; Batka, M.; et al. *Climate Change: Impact on Agriculture and Costs of Adaptation*; International Food Policy Research Institute: Washington, DC, USA, 2009; Volume 21.
10. Toop, T.A.; Ward, S.; Oldfield, T.; Hull, M.; Kirby, M.E.; Theodorou, M.K. AgroCycle—Developing a circular economy in agriculture. *Energy Proc.* **2017**, *123*, 76–80. [CrossRef]
11. Soliwoda, M.; Wieliczko, B.; Kulawik, J. Circular economy vs. Sustainability of agribusiness. *Probl. Agric. Econ.* **2020**, *1*, 3–13. [CrossRef]
12. Rodríguez-Espinosa, T.; Papamichael, I.; Voukkali, I.; Pérez Gimeno, A.; Almendro Candel, M.B.; Navarro-Pedreño, J.; Zorpas, A.A.; Gómez Lucas, I. Nitrogen management in farming systems under the use of agricultural wastes and circular economy. *Sci. Total Environ.* **2023**, *876*, 162666. [CrossRef]
13. Cuerva, M.C. Dynamics of European agricultural productivity: An analysis of regional convergence. *Rev. Agric. Environ. Stud.* **2011**, *92*, 237–258. [CrossRef]
14. Poczta, W.; Rowiński, J. *Struktura Polskiego Rolnictwa na tle Unii Europejskiej*; CeDeWu: Warszawa, Poland, 2019.
15. Kik, M.C.; Claassen, G.D.H.; Meuwissen, M.P.M.; Smit, A.B.; Saatkamp, H.W. The economic value of sustainable soil management in arable farming system—A conceptual framework. *Eur. J. Agron.* **2021**, *129*, 126334. [CrossRef]

16. Streimikis, J.; Miao, Z.; Balezentis, T. Creation of Climate-Smart and Energy-Efficient Agriculture in the European Union: Pathways Based on the Frontier Analysis. *Bus. Strategy Environ.* **2021**, *30*, 576–589. [CrossRef]
17. Statistical Yearbook of Agriculture. GUS: Warszawa, Poland, 2012. Available online: https://stat.gov.pl/obszary-tematyczne/roczniki-statystyczne/roczniki-statystyczne/rocznik-statystyczny-rolnictwa-2012,6,6.html (accessed on 3 November 2023).
18. Statistical Yearbook of Agriculture. GUS: Warszawa, Poland, 2022. Available online: https://stat.gov.pl/obszary-tematyczne/roczniki-statystyczne/roczniki-statystyczne/rocznik-statystyczny-rolnictwa-2022,6,16.html (accessed on 3 November 2023).
19. Jezierska-Thöle, A.; Kluba, M.; Biczkowski, M. Poziom rozwoju rolnictwa Polski i Niemiec wschodnich. *Rocz. Nauk. SERiA* **2014**, *16*, 182–188.
20. Janiszewska, D.; Ossowska, L. Zróżnicowanie rolnictwa krajów Unii Europejskiej na podstawie wybranych cech. *Zesz. Nauk. SGGW Warsz. Probl. Rol. Świat.* **2014**, *14*, 44–54. [CrossRef]
21. Nowak, A. Differentiation in cereal production among Member States of the European Union. *Pol. J. Agron.* **2020**, *40*, 7–15.
22. Cereals, Oilseeds, Protein Crops & Rice. Available online: https://agriculture.ec.europa.eu/farming/crop-productions-and-plant-based-products/cereals_en (accessed on 10 May 2023).
23. Cusworth, G.; Garnett, T.; Lorimer, J. Legume dreams: The contested futures of sustainable plant-based food systems in Europe. *Glob. Environ. Chang.* **2021**, *69*, 102321. [CrossRef]
24. Voisin, A.-S.; Guéguen, J.; Huyghe, C.; Jeuffroy, M.-H.; Magrini, M.-B.; Meynard, J.-M.; Mougel, C.; Pellerin, S.; Pelzer, E. Legumes for feed, food, biomaterials and bioenergy in Europe: A review. *Agron. Sustain. Dev.* **2014**, *34*, 361–380. [CrossRef]
25. Nemecek, T.; von Richthofen, J.-S.; Dubois, G.; Casta, P.; Charles, R.; Pahl, H. Environmental impacts of introducing grain legumes into European crop rotations. *Eur. J. Agron.* **2008**, *28*, 380–393. [CrossRef]
26. Prudhomme, R.; Brunelle, T.; Dumas, P.; Le Moing, A.; Zhang, X. Assessing the impact of increased legume production in Europe on global agricultural emissions. *Reg. Environ. Chang.* **2020**, *20*, 91. [CrossRef]
27. Ditzler, L.; van Apeldoorn, D.F.; Pellegrini, F.; Antichi, D.; Barberi, P.; Rossling, W.A.H. Current research on the ecosystem service potential of legume inclusive cropping systems in Europe. A review. *Agron. Sustain. Dev.* **2021**, *41*, 26. [CrossRef]
28. Eurostat database. Available online: https://ec.europa.eu/eurostat/data/database?gclid=CjwKCAiAxreqBhAxEiwAfGfndNIuH3qCjAedUzsuSeMNG8EdUgNJzvy0a6jl_XKTdMXPLZcvFPNNWBoCrqkQAvD_BwE (accessed on 10 May 2023).
29. Woźniak, E.; Waszkowska, E.; Zimny, T.; Sowa, S.; Twardowski, T. The Rapeseed Potential in Poland and Germany in the Context of Production, Legislation, and Intellectual Property Rights. *Front. Plant Sci.* **2019**, *10*, 1423. [CrossRef] [PubMed]
30. Poczta, W.; Bartkowiak, N. Regionalne zróżnicowanie rolnictwa w Polsce. *J. Agribus. Rural Dev.* **2012**, *1*, 95–109.
31. Van der Linden, A.; de Olde, E.M.; Mostert, P.F.; de Boer, I.J.M. A review of European models to assess the sustainability performance of livestock production systems. *Agric. Syst.* **2020**, *182*, 102842. [CrossRef]
32. Machowski, J. *Ochrona Środowiska. Prawo i Rozwój Zrównoważony*; Wydawnictwo Akademickie Żak: Warszawa, Poland, 2003; p. 101.
33. Towards the Circular Economy. Economic and Business Rationale for an Accelerated Transition. Available online: https://www.werktrends.nl/app/uploads/2015/06/Rapport_McKinsey-Towards_A_Circular_Economy.pdf (accessed on 10 May 2023).
34. Morseletto, P. Targets for a circular economy. *Resour. Conserv. Recycl.* **2020**, *153*, 104553. [CrossRef]
35. Surówka, M.; Thier, A.; Tyli, I. Zastosowanie obiegów zamkniętych w zarządzaniu gospodarką wodną. *Zesz. Nauk. Pol. Częst. Zarz.* **2019**, *34*, 146–147. [CrossRef]
36. Stahel, W.R. The circular economy. *Nature* **2016**, *531*, 435–438. [CrossRef]
37. Roleders, V.; Oriekhova, T.; Zaharieva, G. Circular Economy as a Model of Achieving Sustainable Development. *Probl. Sustain. Dev.* **2022**, *17*, 178–185. [CrossRef]
38. Suárez, B.; Fernández, E.; Méndez, G.; Soto, D. Operational principles of circular economy for sustainable development: Linking theory and practice. *J. Clean. Prod.* **2019**, *214*, 952–961. [CrossRef]
39. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [CrossRef]
40. Sauvé, S.; Bernard, S.; Sloan, P. Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. *Environ. Dev.* **2016**, *17*, 48–56. [CrossRef]
41. Corona, B.; Shen, L.; Reike, D.; Carreón, J.R.; Worrell, E. Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resour. Conserv. Recycl.* **2019**, *151*, 104498. [CrossRef]
42. Dantas, T.; De-Souza, E.; Destro, I.; Hammes, G.; Rodriguez, C.; Soares, S. How the combination of Circular Economy and Industry 4.0 can contribute towards achieving the Sustainable Development Goals. *Sustain. Prod. Consum.* **2021**, *26*, 213–227. [CrossRef]
43. Zeiss, R. Information Flow in Circular Economy Practices. In Proceedings of the Twenty-Seventh European Conference on Information Systems (ECIS2019), Stockholm-Uppsala, Sweden, 8–14 June 2019.
44. Kulczycka, J.; Pędziwiatr, E. Gospodarka o obiegu zamkniętym—Definicje i ich interpretacje. In *Gospodarka o Obiegu Zamkniętym w Polityce i Badaniach Naukowych*; Kulczycka, J., Ed.; Wydawnictwo IGSMiE PAN: Kraków, Poland, 2019; pp. 10–17.
45. Dacko, M.; Płonka, A.; Satoła, Ł.; Dacko, A. Sustainable Development According to the Opinions of Polish Experts. *Energies* **2021**, *14*, 5325. [CrossRef]
46. Corvellec, H.; Stowell, A.F.; Johansson, N. Critiques of the circular economy. *J. Ind. Ecol.* **2022**, *26*, 421–432. [CrossRef]

47. Geissdoerfer, M.; Savaget, P.; Bocken, N.; Hultink, E.J. The circular economy—A new sustainability paradigm? *J. Clean. Prod.* **2017**, *143*, 757–768. [CrossRef]
48. The Circular Economy in Detail. Deep Dive. Available online: https://ellenmacarthurfoundation.org/the-circular-economy-in-detail-deep-dive (accessed on 24 May 2023).
49. The OECD Inventory of Circular Economy Indicators. Available online: https://www.oecd.org/cfe/cities/InventoryCircularEconomyIndicators.pdf (accessed on 10 May 2023).
50. Circular Economy Indicators: What Do They Measure? Available online: https://www.unep.org/news-and-stories/blogpost/circular-economy-indicators-what-do-they-measure (accessed on 15 May 2023).
51. Moraga, G.; Huysveld, S.; Mathieux, F.; Blengini, G.A.; Alaerts, L.; Van Acker, K.; De Meester, S.; Dewulf, J. Circular economy indicators: What do they measure? *Resour. Conserv. Recycl.* **2019**, *146*, 452–461. [CrossRef]
52. De Pascale, A.; Arbolino, R.; Szopik-Depczyńska, K.; Limosani, M.; Ioppolo, G. A systematic review for measuring circular economy: The 61 indicators. *J. Clean. Prod.* **2021**, *281*, 124942. [CrossRef]
53. Sánchez-Ortiz, J.; Rodríguez-Cornejo, V.; Del Río-Sánchez, R.; García-Valderrama, T. Indicators to measure efficiency in circular economies. *Sustainability* **2020**, *12*, 4483. [CrossRef]
54. Pauliuk, S. Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. *Resours Conserv. Recyc.* **2018**, *129*, 81–92. [CrossRef]
55. Syu, F.S.; Vasudevan, A.; Despeisse, M.; Chari, A.; Bekar, E.T.; Gonçalves, M.M.; Estrela, M.A. Usability and Usefulness of Circularity Indicators for Manufacturing Performance Management. *Procedia CIRP* **2022**, *105*, 835–840. [CrossRef]
56. Núñez-Cacho, P.; Gorecki, J.; Molina, V.B.; Corpas-Iglesias, F.A. New Measures of Circular Economy Thinking in Construction Companies. *J. EU Res. Bus.* **2018**, *16*, 909360. [CrossRef]
57. Bîrgovan, A.L.; Lakatos, E.S.; Szilagyi, A.; Cioca, L.I.; Pacurariu, R.L.; Ciobanu, G.; Rada, E.C. How should we measure? A review of circular cities indicators. *Int. J. Environ. Res. Public Health* **2022**, *19*, 5177. [CrossRef] [PubMed]
58. Mazur-Wierzbicka, E. Towards Circular Economy—A Comparative Analysis of the Countries of the European Union. *Resources* **2021**, *10*, 49. [CrossRef]
59. Fura, B.; Stec, M.; Miś, T. Statistical Evaluation of the Level of Development of Circular Economy in European Union Member Countries. *Energies* **2020**, *13*, 6401. [CrossRef]
60. Kasztelan, A. How Circular Are the European Economies? A Taxonomic Analysis Based on the INEC (Index of National Economies' Circularity). *Sustainability* **2020**, *12*, 7613. [CrossRef]
61. Martínez Moreno, M.M.; Buitrago Esquinas, E.M.; Yñiguez, R.; Puig-Cabrera, M. A global and comparative assessment of the level of economic circularity in the EU. *J. Clean. Prod.* **2023**, *425*, 138759. [CrossRef]
62. Alfaro Navarro, J.-L.; Andrés Martínez, M.-E. A proposal to measure the circular economy implementation and sustainable development goals achievement using objectively weighted indices. *Int. J. Sustain. Dev. World Ecol.* **2023**. [CrossRef]
63. Nazarko, J.; Chodakowska, E.; Nazarko, Ł. Evaluating the Transition of the European Union Member States towards a Circular Economy. *Energies* **2022**, *15*, 3924. [CrossRef]
64. Xuan, L.I.; Baotong, D.E.N.G.; Hua, Y.E. The research based on the 3-R principle of agro-circular economy model-the Erhai lake basin as an example. *Ener. Proc.* **2011**, *5*, 1399–1404. [CrossRef]
65. Murray, A.; Skene, K.; Haynes, K. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *J. Bus. Ethics* **2015**, *140*, 369–380. [CrossRef]
66. Hofmann, F. Circular business models: Business approach as driver or obstructer of sustainability transitions? *J. Clean. Prod.* **2019**, *224*, 361–374. [CrossRef]
67. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Towards a Circular Economy. A Zero Waste Programme for Europe. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:50edd1fd-01ec-11e4-831f-01aa75ed71a1.0005.01/DOC_1&format=PDF (accessed on 15 May 2023).
68. Banaitė, D. Towards Circular Economy: Analysis of Indicators in the Context of Sustainable Development. In Proceedings of the International Scientific Conference for Young Researchers, Social Transformations in Contemporary Society, Mykolas Romeris University, Vilnius, LA, USA, 2–3 June 2016.
69. The Circular Path to a Sustainable Future. Available online: https://www.triodos-im.com/articles/2017/the-circular-path-to-a-sustainable-future (accessed on 15 May 2023).
70. Malina, A. *Wielowymiarowa Analiza Przestrzennego Zróżnicowania Struktury Gospodarki Polski Według Województw*; Wyd. Akademii Ekonomicznej w Krakowie: Kraków, Poland, 2004.
71. Kukuła, K. *Metoda Unitaryzacji Zerowanej*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 2000.
72. Wysocki, F.; Lira, J. *Statystyka Opisowa*; Wydawnictwo AR: Poznań, Poland, 2005.
73. Hwang, C.L.; Yoon, K. *Metody i Aplikacje do Podejmowania Decyzji na Podstawie Wielu Atrybutów*; Springer: Berlin, Germany, 1981.
74. Zhao, D.-Y.; Ma, Y.-Y.; Lin, H.-L. Using the Entropy and TOPSIS Models to Evaluate Sustainable Development of Islands: A Case in China. *Sustainability* **2022**, *14*, 3707. [CrossRef]
75. Qin, X.S.; Huang, G.H.; Chakma, A.; Nie, X.H.; Lin, Q.G. A MCDM-based expert system for climate change impact assessment and adaption planning—A case study for the Georgia Basin, Canada. *Expert Syst. Appl.* **2008**, *34*, 2164–2179. [CrossRef]

76. Gürlük, S.; Uzel, G. An Evaluation of Agri-Environmental Indicators through a Multi-Criteria Decision-Making Tool in Germany, France, The Netherlands, and Turkey. *Pol. J. Environ. Stud.* **2016**, *25*, 1523–1528. [CrossRef]
77. Roszkowska, E. Multi-Criteria Decision Making Models by Applying the TOPSIS Method to Crisp and Interval Data. Available online: http://www.mcdm.ue.katowice.pl/files/papers/mcdm11(6)_11.pdf (accessed on 10 May 2023).
78. Huang, M.J. A novel design research based on fuzzy Kano-TOPSIS exploring the local culture on innovative campus product. In Proceedings of the 2020 13th International Symposium on Computational Intelligence and Design (ISCID), Hangzhou, China, 12–13 December 2020.
79. Li, T.; Jin, J.; Li, C. Refractured Well Selection for Multicriteria Group Decision Making by Integrating Fuzzy AHP with Fuzzy TOPSIS Based on Interval-Typed Fuzzy Numbers. *J. Appl. Math.* **2012**, *2012*, 304287. [CrossRef]
80. Wang, W.; Qi, Y.; Jia, B.; Yao, Y. Dynamic prediction model of spontaneous combustion risk in goaf based on improved CRITIC-G2-TOPSIS method and its application. *PLoS ONE* **2021**, *16*, e0257499. [CrossRef]
81. Ozkaya, G.; Erdin, C. Evaluation of smart and sustainable cities through a hybrid MCDM approach based on ANP and TOPSIS technique. *Heliyon* **2020**, *6*, e05052. [CrossRef]
82. Behzadian, M.; Khanmohammadi Otaghsara, S.; Yazdani, M.; Ignatius, J. A state-of the-art survey of TOPSIS applications. *Expert Syst. Appl.* **2012**, *39*, 13051–13069. [CrossRef]
83. Chen, C.T.; Lin, C.T.; Huang, S.F. A fuzzy approach for supplier evaluation and selection in supply chain management. *Int. J. Prod. Econ.* **2006**, *102*, 289–301. [CrossRef]
84. Salih, M.M.; Zaidan, B.B.; Zaidan, A.A.; Ahmed, M.A. Survey on fuzzy TOPSIS state-of-the-art between 2007 and 2017. *Comput. Oper. Res.* **2019**, *104*, 207–227. [CrossRef]
85. Ertugrul, I.; Karakasoglu, N. Fuzzy TOPSIS method for academic member selection in engineering faculty. In *Innovations in E-learning, Instruction Technology, Assessment and Engineering Education*; Iskander, M., Ed.; Springer: Berlin/Heidelberg, Germany, 2007; pp. 151–156.
86. Morone, P.; Yilan, G. A paradigm shift in sustainability: From lines to circles. *Acta Innov.* **2020**, *36*, 5–16. [CrossRef]
87. Pawlak, K. Typology of the EU countries according to the competitive potential of agricultural sector. *Rocz. Ekon. Rol. Roz. Obszar. Wiej.* **2013**, *100*, 9–22.
88. Kozera, A.; Standar, A.; Satoła, Ł. Managing rural areas in the context of the growing debt of polish local government units. *Agriculture* **2020**, *10*, 376. [CrossRef]
89. Barros, M.V.; Salvador, R.; de Francisco, A.C.; Piekarski, C.M. Mapping of research lines on circular economy practices in agriculture: From waste to energy. Renew. *Sustain. Energy Rev.* **2020**, *131*, 109958. [CrossRef]
90. Shah, S.M.; Liu, G.; Yang, Q.; Casazza, M.; Agostinho, F.; Giannetti, B.F. Sustainability assessment of agriculture production systems in Pakistan: A provincial-scale energy-based evaluation. *Ecol. Model.* **2021**, *455*, 109654. [CrossRef]
91. Perdana, T.; Kusnandar, K.; Perdana, H.H.; Hermiatin, F.R. Circular supply chain governance for sustainable fresh agricultural products: Minimizing food loss and utilizing agricultural waste. *Sustain. Prod. Consum.* **2023**, *41*, 391–403. [CrossRef]
92. Haque, F.; Fan, C.; Lee, Y.-Y. From Waste to Value: Addressing the Relevance of Waste Recovery to Agricultural Sector in Line with Circular Economy. *J. Clean. Prod.* **2023**, *415*, 137873. [CrossRef]
93. Han, J.; He, X. Development of circular economy is a fundamental way to achieve agriculture sustainable development in China. *Energy Procedia* **2011**, *5*, 1530–1534.