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The Efficiency of Circular Economies: A Comparison of Visegrád Group Countries

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Abstract: Efficiency of circular economies is one of the most important areas of the improvement of economic growth in a circular way, that is, improving worldwide GDP. The issue of circular economies, namely their efficiency, is a current topic of evidence of many literary sources in the literature. This issue is solved in the conditions of the Czech Republic, Poland, Hungary and Slovakia. The goal of the study is to compare the circular efficiency within the Visegrád Group and efficiency of Visegrád Group countries to the European Union 28 average. Data envelopment analysis slack-based models are implemented to evaluate the output efficiencies of the selected subjects. Truncated regression is used to measure the impact of selected indicators on circular efficiency. The Visegrád Group countries are not among the most advanced in terms of recycling and the use of the circular economy, which was confirmed by this research. However, developments suggest significant improvements. The significance of this research lies in several benefits. One of the benefits is the perception of regional differences and the setting of EU cluster policies at the regional level. The idea of changing inputs is very significant since the outputs are oriented to the recycling rates of materials and waste. This research has shown that a higher level of GDP does not necessarily mean a higher level of efficiency of the circular economy.

Keywords: circular economy; DEA; visegrád group; efficiency

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1. Introduction

In 2014, the European Commission adopted the first circular economy package [1]. It consisted of communication on the transition to a circular economy, together with a legislative proposal to revise the targets in many waste management directives and several communications [2]. The Circular Economy Action Plan is intended to be the starting point of development in Europe leading to a move away from a linear economic model that is too resource-intensive. In a world where the satisfaction of needs is associated with an immense increase in pressure on resources such as land, water, food, feed, raw materials and energy, we cannot continue to rely on an economic approach based on the principle of "take, make, use, throw away" [3]. The circular economy must be a roadmap for fundamental change, which is not just an environmental necessity. It is the only model that makes sense for our European society and economy in the long run, but at the same time, it must not replace global competition for lower labor costs.

Based on projections, global demand for resources will triple by 2050 and further increases in demand for food, feed and fiber will cause an acceleration of about 70%. We already consume about 1.5 Earth of resources each year and would need about four planets full of resources, according to the estimates, to meet demand by 2050 under the "business as usual" scenario. Europe's almost extreme dependence on imported raw materials and energy leads to the following partial results: 40% of all materials used in the EU are imported and for some strategic resources the percentage is even higher. Almost 90% of European companies expect their material input costs to continue to rise, according to a Eurobarometer survey. As raw materials become scarce, Europe will either be hit hardest by resource scarcity or benefit most from resource efficiency [4].

An industrial transition to a well-functioning economic system in which materials are sustainably extracted, reused and recycled is essential to limit the amount of primary raw materials entering and eventually leaving the cycle. At the European level, just a 30% improvement in resource productivity by 2030 would increase GDP by nearly 1%, create more than 2 million additional jobs and put us on the path to a more resource-efficient Europe that reaps the associated environmental, economic and social benefits. The new circular economy package is a crucial tool for environmental protection, the competitiveness of the European economy and the promotion of sustainable reindustrialization [5].

Despite all this, Europe is trapped in a system where valuable materials end up in landfills or incinerators. There is still no functioning market for secondary raw materials. To change this fact, both legislative and economic incentives need to be derived to create leverage. The main issues are:

- support innovation in resource-efficient products and services through various financing mechanisms;
- supporting demand through public procurement and green taxes and introducing fees that discourage consumption of products and services that are not resource-efficient;
- establishing environmental design requirements for products. Ensuring that imported goods meet these requirements equally;
- ensuring that existing legislation does not hinder the development of resource-efficient products or services or business models—for example, in legislation on safety and competition;
- carefully evaluate the environmental impact of all subsidies (e.g., grants from the Cohesion Fund for the construction of new landfills or incinerators) [4].

This study consists of five sections. In the second section, we evaluate the state of the art based on the literature review, in the third section we describe the research subject, methodology and methods and the data used for computations. In section four we provide the results of our computations. In the final section, we discuss the obtained results and provide brief limitations and policy implications as the section of conclusions. At the very end of the study, we conclude future research possibilities.

2. Literature Review

Circular economics is also referred to be the reflection of the transition from the current model of a linear economy dependent on high consumption of non-renewable resources. This approach is economically, ecologically and socially unsustainable in the long run [6,7]. About this type of economy is also written by other authors and institutions. The circular economy represents a new economic model, based on the idea that all product and material flows can be recreated involved in their cycle after their use, where they become resources for new products and services. This means too, that the waste, as such, ceases to exist. The circular economy thus represents a higher principle concerning the utilization of natural resources [8]. European Union's initiatives focus on improving the environmental processes such as energy efficiency [9,10], environmental efficiency [11], etc.

Therefore, the increased resource effectiveness, efficiency and the transition to the circular model of the economy are of primary importance for the sustainable growth of the country and its increased prosperity. However, the issue of the transition to the green and circular economy is a part of the complex issues; therefore, the key to success is intensive involvement of all relevant ministries and key groups of the society, including the public [12,13]. The growth of industrial production, the generation of electric energy and heat result in increased requirements for natural resources, as well as influencing the quality of the environment. This influence has ceased to have the character of the local impact on the near territory around the place of its origin and has been increasingly showing itself on the global scale. To ensure sustainable growth on both the global scale as well as at the EU level, it is necessary to use resources more intelligently and sustainably. During the last one hundred years, the consumption of any materials other than biomass has multiplied more than 20 times. Approximately 50% of the European-generated waste still ends up at landfills or incineration plants. It is expected that the growing demand for foodstuff in combination with population growth and climate change will threaten considerably the accessibility of freshwater. To ensure sustainable growth on both the global scale as well as at the EU level, it is necessary to use resources more intelligently and sustainably [14]. The circular economy aims to maintain the value of products and materials if possible; thus, waste and new resource utilization are minimized. In the circular economy, the value of products, materials and resources is kept in the economy for as long as possible and the generation of waste is reduced quantitatively and improved qualitatively. Avoiding the generation of waste is closely related to improving production methods and to influencing consumers in searching for environmentally suitable products and reducing the number of packages used. Reducing the quantity of generated waste is the priority hand in hand with energy efficiency [12,15]. Circular economy is also connected with greenhouse emission, energy [16] and municipal solid waste [17]. According to [18], many of measures are related to energy sector, but the circular economy should be taken in the account too.

The basic concept of the circular economy is reflected in two identified key areas:

- technological changes in and support for the innovative potential;
- environmental and energy efficiency of the economy.

In the area of the energy efficiency of the economy, such measures are proposed as the support for using local renewable energy resources, stimulation of the development of technologies and infrastructure using alternative forms of fuels in the passenger motor transport to the competitive and affordable price level, the support for energy-efficient measures taking into consideration requirements for the environmental protection in all sectors of the national economy and ensuring the increase in the value of waste [19]. Circular economy measures could help also in energy-intensive industries, the costs of energy are rising and companies tend to be more energy-efficient [20]. As the recycling is one of the most used circular economy strategy [15] governments has to focus on the preparation of adequate policies. However, these policies are often so-called "end of pipe" [21] and are very slightly connected with socio-ecological implications. Recycling is not beneficial only for the environment but is also connected with food safety [22]. The circular economy in central Europe is developing very slowly, but the need for significant efforts is obvious, such as propose many of the previous studies [13,23]. Visegrád Group countries are ranked very low in many of the rankings connected to the circular economy [24,25].

Because there is insufficient research, which assesses the effects and circular efficiency on the regional basis in central Europe and the state of the circular economy implementation is weak, the goal of this study is to compare circular efficiency of Visegrád Group countries themselves and with EU 28 average and to evaluate the impact of selected variables on the performance of the circular economy of selected countries.

3. Materials and Methods

Many of the above-mentioned studies have used data envelopment analysis to measure efficiency related to circular economy politics. Some studies argue that DEA is a promising method for the evaluation of efficiency in the field of energy-connected efficiencies [10,26]. Some studies tend to use more sophisticated methods combined with DEA, such as the DEA SBM model combined with regression analysis [27], computing bias-corrected efficiencies [28], game networks [29] and Malmquist productivity index [30]. There are plenty of indicators, which can describe the circular economy status so that researchers are trying to develop the most suitable one [31,32]. Every indicator has some weaknesses.

Studies focus on many subjects such as industry [30], regions or countries [33,34] and political groupings [11,25].

3.1. Research Object

In this research, we focus on measuring and comparing the performance of the circular economies of four countries. These are the Czech Republic (CZ), Poland (PL), Hungary (HU) and Slovakia (SK). These countries and are located in the center of Europe and together form a political grouping called the Visegrád Group or Visegrád Four (V4). Many decisions concerning both external and internal policymaking are taken jointly by the governments of these countries. The importance of examining the circular economies of the countries lies in their common past, as they have long been part of the Soviet bloc. Therefore, we decided to examine the differences and success of existing policies that have been implemented to improve the state of the circular economy. Because of the data available we examine the efficiencies for the 8 years—from 2010 until 2017. Data were collected on an annual basis. We construct a panel of 32 observations, decision-making units—4 countries and 8 years of observations for each country. We use the window analysis approach, which means that every observation is counted as a unique decision-making unit [35]. Newer data of some variables were not available, so we decided not to shorten the number of variables, but to shorten the period researched. We will compare these countries also with the EU 28 average because we focus on the need of improving the circular economy from the European Union point of view.

3.2. Methods

As we suggested above, the main method we implement is DEA. Its theoretical background was proposed by [36] and it has been developed over many years. In this study, we use the output-oriented DEA CRS (CCR) and DEA VRS (BCC) slack-based models (SBM) [37]. We use the output-oriented model because the idea of changing inputs is not actual. In this study, we do not focus on the improvement (to lower) of capital formation and waste generated. Outputs are oriented on the recycling rates of materials and waste; which improvement is needed to help improve the state of the circular economies of researched countries. The mathematical expression DEA CRS output-oriented model is shown in Equation (1). Subsequently, the mathematical expression DEA VRS output-oriented model is shown in Equation (2).

$$
\begin{aligned}
\max_{\phi,\lambda,s^+,s^-} z_o &= \phi + \varepsilon.\vec{\mathbf{1}}s^+ + \varepsilon.\vec{\mathbf{1}}s^- \\
\text{s.t. } \phi Y_o - Y\lambda + s^+ &= 0 \\
X\lambda + s^- &\geq X_o \\
\lambda, s^+, s^- &\geq 0.
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
\max_{\phi,\lambda,s^+,s^-} z_o &= \phi + \varepsilon.\vec{\mathbf{1}}s^+ + \varepsilon.\vec{\mathbf{1}}s^- \\
\text{s.t. } \phi Y_o - Y\lambda + s^+ &= 0 \\
X\lambda + s^- &\geq X_o \\
\vec{1}\lambda &= 1 \\
\lambda, s^+, s^- &\geq 0.
\end{aligned} \tag{2}
$$

Input efficiency values are in the range <1; ∞> and the decision-making unit (DMU) which achieves a value one is efficient. In this study, we transform the output efficiencies to the interval range <0;1>, which can be done by using the reverse formula equation. These reversed values of efficiencies are input-oriented efficiencies, the only difference between input and output-oriented efficiencies is in slacks [38,39].

After computing efficiencies, we analyze the effect of explanatory variables on them. For this purpose, we need to resample the efficiency values using the double-bootstrap procedure proposed by [40]. Then, we implement truncated regression with the right truncation in point one. Then, we obtain robust and consistent estimates of regression models. The dependent variables will be double-bootstrapped reversed values of CRS and VRS output efficiencies.

3.3. Data and Variables

In this section, we justify and describe the selected input, output and explanatory variables used in our models. For basic DEA VRS and CRS output models, we use 2 input and 2 output variables. We chose the variables waste generated measured as kg per capita and gross capital formation measured as a ratio to gross domestic product. These inputs are representing the basis for the waste creation and economic development of the country. As the output variables, the recycling rate of MSW (municipal solid waste) and circular material use rate measured as the ratios in percentages units were used. Many of the studies [25,31,41] propose the use of three main production factors as the inputs. We use only capital indicator since we want to evaluate the impact of the labor force and land use on the efficiency in the regression model. Simplified DEA models could be more robust and we can detect the effect of production factors as the determinants, instead of including them in the basic DEA model. Circular economy models are strongly determined by labor factors, renewable energy and resource productivity [6]. We construct the truncated regression models as mentioned above. This regression model consists of eight variables.

- $X1$—recycling rate of plastic packaging (%);
- $X2$—recycling rate of glass packaging (%);
- $X3$—recycling rate of paper packaging (%);
- $X4$—trade of recyclable raw materials—imports extra EU (tone per 1000 capita);
- $X5$—trade of recyclable raw materials—exports extra EU (tone per 1000 capita);
- $X6$—GDP per capita (€);
- $X7$—unemployment (%);
- $X8$—area under organic farming (% of the total arable area).

Variables $X1$, $X2$ and $X3$ represent the recycling rates of selected forms of packaging. They help us to understand how the state of recycling is implemented in researched countries and how it determines the efficiency of circular economy processes. Variables $X4$ and $X5$ were chosen because the production and consumption of recyclable materials depends also on the import and export of some types of materials. Variables $X6$ and $X7$ are connected directly to the state of the national economy and could determine some circular economy processes. Variable $X8$ is connected to the state of organic farming. We assume that countries with more organic arable areas tend to be more circular oriented because they could be "greener" oriented.

Models of linear regression are then as follows—models 3 and 4:

$$\hat{\hat{\delta}}_{VRS} = \beta_0 + \beta_1 X1 + \beta_2 X2 + \beta_3 X3 + \beta_4 X4 + \beta_5 X5 + \beta_6 X6 + \beta_7 X7 + \beta_8 X8 + \varepsilon_i, \quad (3)$$

and

$$\hat{\hat{\delta}}_{CRS} = \beta_0 + \beta_1 X1 + \beta_2 X2 + \beta_3 X3 + \beta_4 X4 + \beta_5 X5 + \beta_6 X6 + \beta_7 X7 + \beta_8 X8 + \varepsilon_i, \quad (4)$$

where $\hat{\hat{\delta}}_{VRS}$ and $\hat{\hat{\delta}}_{CRS}$ are double-bootstrapped efficiencies computed as stated above. These variables are collected for 4 countries, we exclude the EU 28 average.

Data were collected from the public databases of Eurostat [42] and The World Bank [43]. The research period is 8 years (2010–2017).

4. Results

In this section, we will describe the results of both steps we set out in the chapter above. We provide an overview of the basic statistical indicators of the input and output variables of the DEA model in Table 1.

Table 1. Descriptive statistics of inputs and outputs of DEA models.

		Inputs		Outputs	
Country	**Statistics**	**Waste Generated (kg/cap)**	**Gross Capital Formation (% of GDP)**	**Recycling Rate of Municipal Waste (%)**	**Circular Material Use Rate (%)**
Czechia	Mean	320.25	25.90	25.38	6.65
	StDev	13.08	0.81	6.43	0.91
	Min	307.00	24.90	15.80	5.30
	Max	344.00	27.10	34.10	8.10
Hungary	Mean	386.38	20.71	28.24	5.91
	StDev	9.72	1.21	5.39	0.48
	Min	377.00	19.20	19.60	5.30
	Max	403.00	22.20	35.00	6.60
Poland	Mean	303.63	19.40	22.80	10.78
	StDev	16.06	1.07	9.49	1.07
	Min	272.00	17.50	11.40	9.20
	Max	319.00	20.70	34.80	12.50
Slovakia	Mean	326.88	21.43	15.26	4.80
	StDev	23.41	1.24	6.87	0.31
	Min	304.00	20.30	9.10	4.10
	Max	378.00	23.70	29.80	5.10
EU 28	Mean	487.75	19.79	42.63	11.46
	StDev	8.58	0.39	2.83	0.36
	Min	478.00	19.20	38.30	10.70
	Max	504.00	20.40	46.50	11.90

Source: own processing of data collected from Eurostat [42] and The World Bank [43].

Of the V4 countries, Hungary had the highest rate of generated waste, but all 4 countries did not reach the average value of generated waste within the entire European Union. Hungary had the highest rate of Recycling of MSW, but all countries were well below the EU average. On the contrary, the highest rate of circular material use rate is recorded in Poland, where they used on average more than 10% of circular material, in Slovakia, it was half this. However, none of the V4 countries reached the EU average. Descriptive statistics of explanatory variables used in the second step of the analysis are shown in Table 2.

As we did not include the averages of the EU 28 countries in the regression model, so that the results are not distorted, we present data for the V4 countries. The Czech Republic had the highest recycling rate of plastic, stained and paper packaging and relatively high values were also recorded in the case of Slovakia. On the contrary, the lowest values are recorded for Poland. The largest trader in recyclable materials is Hungary, whose export and import values are significantly higher than in other countries. Organic farming is mostly used in the Czech Republic, followed by Slovakia. On the contrary, Hungary showed the lowest average value of organically farmed land. Table 3 shows the result of efficiency measurement, in this case, we include the EU 28 average as a decision-making unit (DMU). Computations have been processed using the program RStudio.

If we also include the EU 28 average values in the calculations, we can assess the development of countries concerning other countries. Based on this methodology, it can be stated that only the Polish economy has achieved the EU average. On the contrary, the worst average efficiency is achieved by Slovakia, both in the case of the CRS and the VRS model. The table also shows the slacks of inputs (surplus) and outputs (non-sufficiency).

They are in absolute values. The models recommend a more significant reduction in waste generation and an increase in the rate of recycling and use of circular materials. Most significant improvements on the side of inputs have to be done in the Slovak Republic and Poland. On the contrary, the most significant improvement of the outputs must be made in the Hungary and Czech Republic. Table 4 shows the results of DEA models without the EU 28 average.

Table 2. Descriptive statistics of explanatory variables.

Country	Statistics	Recycling Rate (Plastic Packaging)	Recycling Rate (Glass Packaging)	Recycling Rate (Paper Packaging)	Imports Extra EU	Exports Extra EU	GDP per Capita	Unemployment	The Area under Organic Farming
Czechia	Mean	58.36	74.46	90.06	342.01	9990.31	19,684.36	5.74	13.43
	StDev	2.09	2.76	2.53	91.07	2953.41	1121.31	1.51	0.50
	Min	54.00	71.60	85.90	168.23	5878.43	17,715.62	2.89	12.40
	Max	61.70	81.10	93.70	462.05	13,744.66	21,717.46	7.28	14.09
Hungary	Mean	30.14	37.35	79.19	2681.93	16,045.48	13,527.21	8.40	2.70
	StDev	4.00	5.53	9.39	1395.57	2944.40	651.14	2.65	0.53
	Min	22.40	32.40	66.20	485.39	11,321.46	12,651.57	4.16	2.30
	Max	36.80	50.50	94.70	4651.57	20,904.56	14,457.61	11.17	3.73
Poland	Mean	28.10	53.18	65.66	1718.09	9112.45	13,328.55	8.40	4.04
	StDev	8.71	7.27	11.50	824.13	1382.15	687.72	1.88	0.49
	Min	19.70	43.60	50.00	354.13	6528.78	12,431.58	4.89	3.30
	Max	46.90	63.00	82.20	3213.47	10,605.83	14,347.91	10.33	4.65
Slovakia	Mean	52.66	65.84	75.59	1063.49	5707.92	17,469.85	12.33	9.11
	StDev	3.66	4.93	9.78	551.89	849.80	837.77	2.19	0.58
	Min	44.90	55.70	50.80	187.30	4813.64	16,309.07	8.13	8.18
	Max	57.00	72.90	84.70	1807.98	7337.12	18,670.93	14.38	9.90

Source: own processing of data collected from Eurostat [42] and The World Bank [43].

Table 3. Results of DEA, CRSand VRS efficiencies of V4 compared to EU 28 average.

Country	Statistics	1/"CRS Output ef."	sx_1	sx_2	sy_1	sy_2	1/"VRS Output ef."	sx_1	sx_2	sy_1	sy_2
CZ	Mean	0.69	0.00	3.39	0.00	3.15	0.71	0.00	7.32	0.00	0.98
	StDev	0.16	0.00	1.48	0.00	1.43	0.17	0.00	0.67	0.00	0.80
	Min	0.44	0.00	0.72	0.00	0.78	0.46	0.00	6.41	0.00	0.00
	Max	0.87	0.00	4.75	0.00	5.04	0.92	0.00	8.38	0.00	2.13
HU	Mean	0.68	0.00	0.00	0.00	2.81	0.71	0.00	1.65	0.00	2.26
	StDev	0.13	0.00	0.00	0.00	1.76	0.14	0.00	1.27	0.00	1.37
	Min	0.47	0.00	0.00	0.00	0.12	0.48	0.00	0.00	0.00	0.00
	Max	0.87	0.00	0.00	0.00	4.89	0.88	0.00	3.27	0.00	3.79
PL	Mean	0.92	19.09	0.00	5.22	0.02	0.93	17.00	0.19	3.87	0.00
	StDev	0.10	19.24	0.00	5.36	0.06	0.10	21.96	0.31	5.15	0.00
	Min	0.70	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00
	Max	1.00	43.63	0.00	12.41	0.19	1.00	47.00	0.90	12.35	0.00
SK	Mean	0.44	8.09	0.18	0.56	1.28	0.47	14.55	2.01	0.52	0.83
	StDev	0.12	14.10	0.31	1.48	1.76	0.13	19.39	1.10	1.39	1.48
	Min	0.34	0.00	0.00	0.00	0.00	0.37	0.00	0.57	0.00	0.00
	Max	0.71	35.58	0.83	4.47	4.87	0.76	47.00	3.65	4.20	4.05
EU 28	Mean	0.97	3.71	0.00	0.00	0.00	0.97	14.98	0.02	0.00	0.00
	StDev	0.04	8.55	0.00	0.00	0.00	0.04	22.45	0.04	0.00	0.00
	Min	0.89	0.00	0.00	0.00	0.00	0.89	0.00	0.00	0.00	0.00
	Max	1.00	26.14	0.00	0.00	0.00	1.00	65.46	0.12	0.00	0.00

Note: sx_1—slack of the waste generated, sx_2—slack of the gross capital formation, sy_1—slack of the recycling rate of the MSW, sy_2—slack of the circular material use. CRS—Constant returns to scale, VRS—Variable returns to scale. Source: own results using program RStudio.

Table 4. Results of DEA, CRS and VRS efficiencies of V4 group.

Country	Statistics	1/"CRS Output ef."	sx_1	sx_2	sy_1	sy_2	1/"VRS Output ef."	sx_1	sx_2	sy_1	sy_2
Czechia	Mean	0.69	0.00	3.39	0.00	3.15	0.73	5.83	7.06	0.00	0.58
	StDev	0.16	0.00	1.48	0.00	1.43	0.18	10.15	1.20	0.00	0.52
	Min	0.44	0.00	0.72	0.00	0.78	0.48	0.00	4.91	0.00	0.00
	Max	0.87	0.00	4.75	0.00	5.04	0.98	25.25	8.15	0.00	1.69
Hungary	Mean	0.70	33.32	0.00	0.00	3.17	0.81	33.85	0.26	0.00	0.58
	StDev	0.12	25.92	0.00	0.00	1.49	0.15	29.90	0.40	0.00	0.74
	Min	0.50	0.00	0.00	0.00	0.88	0.56	0.00	0.00	0.00	0.00
	Max	0.92	74.53	0.00	0.00	4.96	1.00	79.14	1.19	0.00	2.38
Poland	Mean	0.92	21.16	0.00	5.22	0.05	0.93	17.00	0.19	3.87	0.00
	StDev	0.11	17.92	0.00	5.36	0.13	0.10	21.96	0.31	5.15	0.00
	Min	0.70	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00
	Max	1.00	43.63	0.00	12.41	0.41	1.00	47.00	0.90	12.35	0.00
Slovakia	Mean	0.44	11.82	0.18	0.56	1.29	0.49	26.13	1.59	0.52	0.29
	StDev	0.13	14.05	0.31	1.48	1.79	0.16	17.69	1.42	1.39	0.53
	Min	0.34	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00
	Max	0.73	38.25	0.83	4.47	5.00	0.85	47.43	4.27	4.20	1.48

Note: sx_1—slack of the Waste generated, sx_2—slack of the Gross capital formation, sy_1—slack of the Recycling rate of the MSW, sy_2—slack of the Circular material use. Source: own results using program RStudio.

Therefore, if we compare only the V4 countries, the results are slightly different, but it is not a significant change. This is because Poland was relatively highly efficient even in the case of recalculations with the EU average. It is thus possible to observe a more significant diversion of countries. As a consequence of these phenomena, it can be stated that even though countries had the same position when joining the EU, countries such as Poland adapted circular economy policies faster and more consistently than, for example, Slovakia, the Czech Republic or Hungary. In this case, we can observe a higher need for the reduction of generated waste in Hungary. Figures 1 and 2 show the development of efficiencies among countries researched.

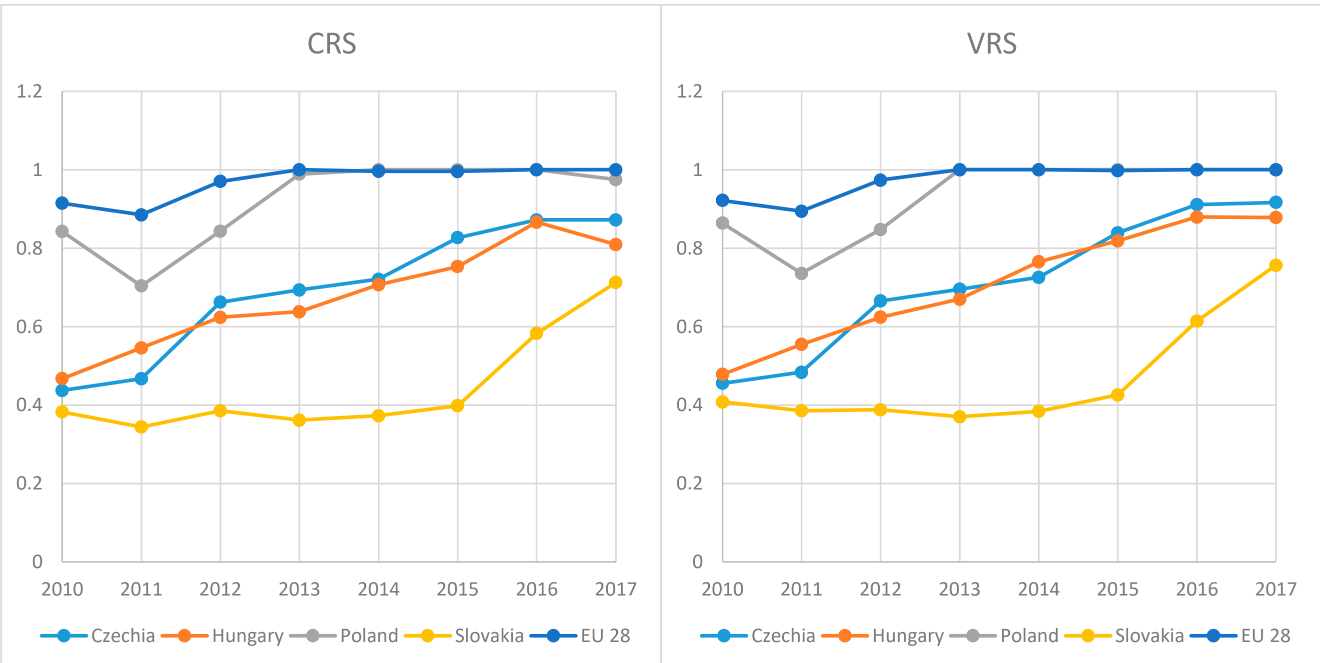

Figure 1. Circular efficiency results of V4 countries compared to EU 28 average.

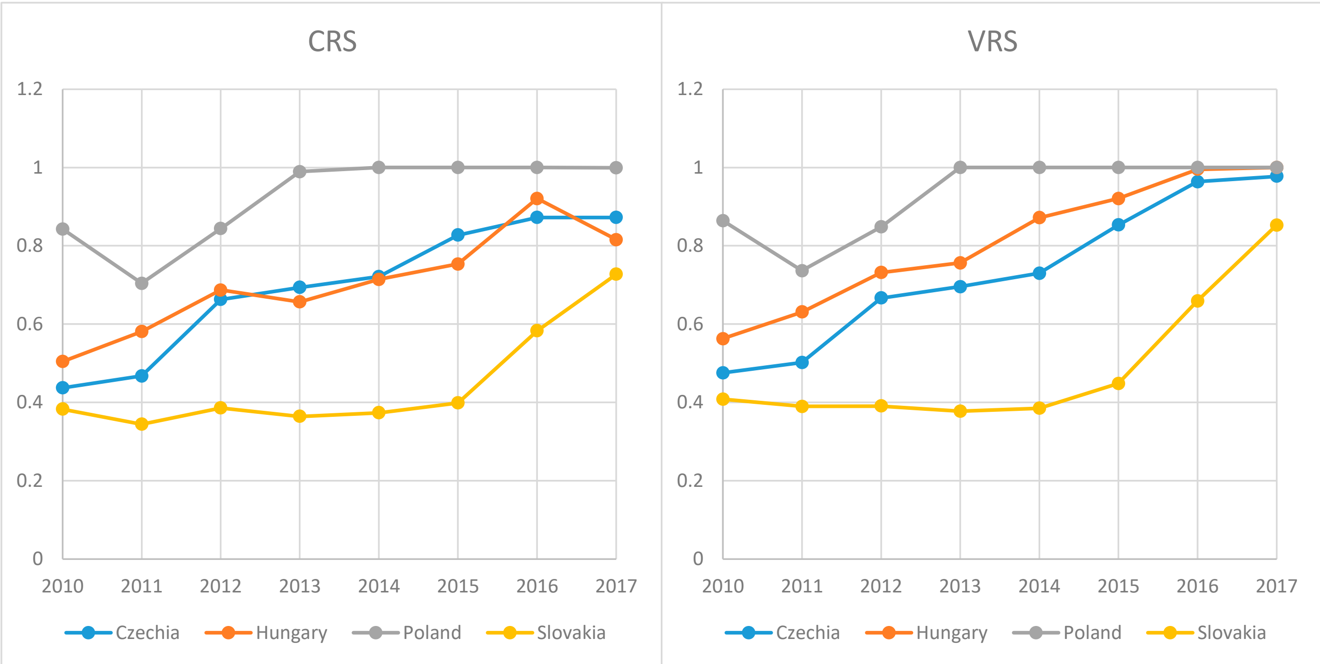

Figure 2. Circular efficiency results of V4 countries.

Based on Figure 1, it can be stated that in most countries there was a positive and significant increase in the improvement of the circular efficiency of the V4 countries during the observed development. Although Slovakia recorded the worst average results, developments suggest that the country is implementing EU policies appropriately and converging with other countries to the EU average. This phenomenon is particularly noticeable between 2015 and 2017. On the contrary, Poland is significantly more effective than other countries throughout the period under review. These results also indicate the suitability of our chosen DEA model and its variables. In the absence of some traditional inputs, we have not lost sight of the real situation that exists in the countries. Very similar results are shown in Figure 2, in the case of VRS efficiency in 2017, the Czech Republic and Hungary reach the level of efficiency as Poland. We can state that the change of returns to scale assumption, does not influence the computed efficiencies significantly. Only minor differences are observable. In addition, incorporating the EU 28 average does not have an impact on significant efficiency changes, which is obvious from the development of efficiencies in Figures 1 and 2.

Table 5 shows the regression results where the dependent variables were CRS and VRS circular efficiencies. We included V4 countries without the EU 28 average in these calculations.

In the models where we use double-bootstrapped VRS efficiency as a dependent variable, the results were not as significant as in the case of the CRS model. Based on the VRS model, only the variables recycling rate of glass packaging and Area under organic farming were statistically significant. In contrast, in the case of the model with the dependent variable double-bootstrapped CRS efficiency, only three variables were insignificant and its explanatory power was significantly higher than in the case of the model with VRS efficiency. The results suggest that the variables that are usually included in the DEA models and not in the regression influence the efficiency calculated without them. These are GDP and unemployment rate indicators. The results also suggest that countries with higher levels of organic farming are more efficient. Conversely, reducing unemployment can have a positive effect on increasing efficiency. An interesting result is that countries with higher GDP tend to have a lower value of the efficiency of the circular economy.

Table 5. Results of truncated regression models—estimates and significance.

Variable	Double Bootstrapped DEA VRS Efficiency (N = 32)		Double Bootstrapped DEA CRS Efficiency (N = 32)	
Intercept	1.0126	***	2.0617	***
X1—Plastic	9.0552×10^{-5}		-2.8462×10^{-3}	
X2—Glass	2.2026×10^{-3}	**	6.3752×10^{-3}	**
X3—Paper	-8.9590×10^{-4}		-3.9016×10^{-3}	**
X4—Imports	-1.2614×10^{-5}		-2.3407×10^{-5}	
X5—Exports	-2.7579×10^{-6}		3.5442×10^{-6}	
X6—GDP	-4.6344×10^{-6}		-5.6169×10^{-5}	***
X7—Unemployment	-2.2939×10^{-3}		-5.3346×10^{-2}	***
X8—Organic faming	-1.0975×10^{-2}	*	3.1819×10^{-3}	
Sigma	3.4865×10^{-2}	***	7.6556×10^{-2}	***
R-squared	0.4703		0.8408	
Log-likelihood	62.173		69.158	

Note: Signif. codes: '***' 0.01; '**' 0.05; '*' 0.01.

5. Discussion and Conclusions

The limitations of this study are the availability of the data. On the one hand, the researched period could be more actual but some of the variables were published only in 2017. Another issue and limitations are the unavailabilities of some data on a country basis. There are, e.g., variables reporting the number of investments (patents etc.) into the circular economies, but the Czech Republic does not report it. Many of the data should be available on the national level, not only in large databases like Eurostat, World Bank, OECD and others. We can argue that the state of the circular economy comes to hand to hand with data availability. Which could be true. Nowadays, all the policies and implications should be based on data analysis [44]. Other limitations are based on insufficient regionally based research. Many studies focus on large groupings of countries such as EU countries, European countries, OECD countries and others. However, if we want to compare the results of our study with other studies, there is a problem. In this study, research on the national basis is proposed, but it was emphasized that also urban structures has to deal with problems of circular economy [45].

Even though the amount of waste is growing, it can be shown that its recycling and use in the circular economy is growing similarly as is suggested in [46]. The V4 countries are not among the most advanced in terms of recycling and the use of the circular economy, which was confirmed by our research but also, for example, other studies [25,47]. However, developments suggest significant improvements. The significance of our research lies in several benefits. One of the benefits is the perception of regional differences and the setting of EU cluster policies at the regional level. There are countries whose similar historical development and mentality lead to certain common processes that need to be improved. A comparison of the whole grouping of countries, such as the EU, may not sufficiently indicate the problems of the partial processes. According to our measurements, the development of countries is positive in the area of the circular economy. However, the efficiency is still below the EU average in most countries. We have shown that only Poland was at the level of the EU average during the period reviewed. These results make this study important.

Another benefit is the use of a simpler constructed indicator, which brought similar results in the field of trends in the development of circular efficiency than other research but used a lower number of variables. We could then use the commonly used variables to quantify their impact on the state of the circular economy in the V4 countries.

The research uses various indicators and methods to capture the state of the circular economy, such as life cycle assessment, material flow analysis and many others [48]. The disadvantage of the research is the inability to compare the results of different studies. We are not saying that our indicator is the most reliable. but it is worth considering simplifying the indicator rather than complicating it even more. Subsequently, the results can become hard to interpret.

However, as far as the improvement of processes in the field of circular economy in the V4 countries is concerned, it is necessary to focus mainly on two main areas and that is the improvement of resource recycling processes in industry and households. If the EU or national governments focus on only one of these areas, respectively, do not exploit the synergy effect that results from the joint coordination of these two main actors of the circular economy, the circular economy will not be efficient. It is in the V4 countries to see the slow onset of measures aimed at improving MSW recycling, but also the use of circular economy methods in companies. However, the problem is that many citizens are still unaware that they too are part of these processes.

Our research has shown that a higher level of GDP does not necessarily mean a higher level of efficiency of the circular economy. This may have occurred to the allocation of resources to other areas of the national economy. However, the present trends show that investment in the environment, of which the circular economy is, is also crucial in terms of improving the quality of life of the population. One of the possible implications could be incorporating Environmental fiscal effort [49]. On the contrary, in the V4 countries, unemployment harms the efficiency of the circular economy. We have also shown that the partial recycling processes of individual materials have an impact on the change in the state of efficiency. Some studies have proven the importance of incorporating the CE also from point of view of the social impact [50,51]. If the people could observe the improvements in their life, they become more responsible and the "circle is closed". It all can start in the schools and universities, we need to teach young people to be environmentally responsible and one of the ways in implementing circular economy models [52]. Nowadays, as the pandemic of COVID-19 causes enormous economic problems, it is a good time to invest in processes which could lead to improvement of circular economy and in nature itself [13].

Some shortcomings of our models may suffer from a lower number of observations. One of the possibilities for future research is therefore, the possibility of research at the regional level of the regions of these countries. Depending on the availability of data, or vice versa, on a larger grouping of countries, such as the countries that joined the EU together with the V4 countries. Other possibilities of future research lie in the comparisons of regional groupings with more CE-developed countries, perhaps not only in Europe, but also with the countries from other continents. We can also modify the regression models, but it has limitations in data availability. Discussion based on the improvement of data collection should start immediately. In future research, it would be possible and interesting to assess the relationship of circular economy processes with the human development index, food security index and quality of life index, some of the studies attempt to study this topic already [53,54].

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References

1. *European Commission 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*; European Commission: Brussels, Belgium, 2014.
2. European Union. *Proposal for a Directive of the European Parliament and of The Council Amending Directives 2008/98/EC on Waste, 94/62/EC on Packaging and Packaging Waste, 1999/31/EC on the Landfill of Waste, 2000/53/EC on End-of-Life Vehicles, 2006/66/EC on Batteries and Accumulators and Waste Batteries and Accumulators, and 2012/19/EU on Waste Electrical and Electronic Equipment*. 2014. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52014PC0397 (accessed on 10 May 2020).
3. Schally, H.M. Einführung. In *Kreislaufwirtschaft in der EU. Eine Zwischenbilanz.*; Springer Fachmedien Wiesbaden GmbH: Wiesbaden, Germany, 2020; ISBN 978-3-658-27378-1.
4. Pietikäinen, S. Die Prozesse zur Kreislaufwirtschaft im Europäischen Parlament. In *Kreislaufwirtschaft in der EU. Eine Zwischenbilanz*; Springer Fachmedien Wiesbaden GmbH: Wiesbaden, Germany, 2020; ISBN 978-3-658-27378-1.
5. Bonafé, S. Die Bedeutung des Kreiswirtschaftsmodells. In *Kreislaufwirtschaft in der EU. Eine Zwischenbilanz.*; Springer Fachmedien Wiesbaden GmbH: Wiesbaden, Germany, 2020; ISBN 978-3-658-27378-1.
6. Busu, M. Adopting Circular Economy at the European Union Level and Its Impact on Economic Growth. *Soc. Sci.* **2019**, *8*, 159. [CrossRef]
7. van Capelleveen, G.; Amrit, C.; Zijm, H.; Yazan, D.M.; Abdi, A. Toward Building Recommender Systems for the Circular Economy: Exploring the Perils of the European Waste Catalogue. *J. Environ. Manag.* **2021**, *277*, 111430. [CrossRef]
8. Hartley, K.; van Santen, R.; Kirchherr, J. Policies for Transitioning towards a Circular Economy: Expectations from the European Union (EU). *Resour. Conserv. Recycl.* **2020**, *155*, 104634. [CrossRef]
9. Grondys, K.; Androniceanu, A.; Dacko-Pikiewicz, Z. Energy Management in the Operation of Enterprises in the Light of the Applicable Provisions of the Energy Efficiency Directive (2012/27/EU). *Energies* **2020**, *13*, 4338. [CrossRef]
10. Halkos, G.; Petrou, K.N. Analysing the Energy Efficiency of EU Member States: The Potential of Energy Recovery from Waste in the Circular Economy. *Energies* **2019**, *12*, 3718. [CrossRef]
11. Mavi, N.K.; Mavi, R.K. Energy and Environmental Efficiency of OECD Countries in the Context of the Circular Economy: Common Weight Analysis for Malmquist Productivity Index. *J. Environ. Manag.* **2019**, *247*, 651–661. [CrossRef] [PubMed]
12. Robaina, M.; Murillo, K.; Rocha, E.; Villar, J. Circular Economy in Plastic Waste—Efficiency Analysis of European Countries. *Sci. Total Environ.* **2020**, *730*, 139038. [CrossRef] [PubMed]
13. Zaleski, P.; Chawla, Y. Circular Economy in Poland: Profitability Analysis for Two Methods of Waste Processing in Small Municipalities. *Energies* **2020**, *13*, 5166. [CrossRef]
14. Türkeli, S.; Kemp, R.; Huang, B.; Bleischwitz, R.; McDowall, W. Circular Economy Scientific Knowledge in the European Union and China: A Bibliometric, Network and Survey Analysis (2006–2016). *J. Clean. Prod.* **2018**, *197*, 1244–1261. [CrossRef]
15. Mhatre, P.; Panchal, R.; Singh, A.; Bibyan, S. A Systematic Literature Review on the Circular Economy Initiatives in the European Union. *Sustain. Prod. Consum.* **2021**, *26*, e00384. [CrossRef]
16. 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]
17. Abis, M.; Bruno, M.; Kuchta, K.; Simon, F.-G.; Grönholm, R.; Hoppe, M.; Fiore, S. Assessment of the Synergy between Recycling and Thermal Treatments in Municipal Solid Waste Management in Europe. *Energies* **2020**, *13*, 6412. [CrossRef]
18. Janik, A.; Ryszko, A.; Szafraniec, M. Greenhouse Gases and Circular Economy Issues in Sustainability Reports from the Energy Sector in the European Union. *Energies* **2020**, *13*, 5993. [CrossRef]
19. Ranta, V.; Aarikka-Stenroos, L.; Ritala, P.; Mäkinen, S.J. Exploring Institutional Drivers and Barriers of the Circular Economy: A Cross-Regional Comparison of China, the US, and Europe. *Resour. Conserv. Recycl.* **2018**, *135*, 70–82. [CrossRef]
20. Gitelman, L.; Magaril, E.; Kozhevnikov, M.; Rada, E.C. Rada Rational Behavior of an Enterprise in the Energy Market in a Circular Economy. *Resources* **2019**, *8*, 73. [CrossRef]
21. Calisto Friant, M.; Vermeulen, W.J.V.; Salomone, R. Analysing European Union Circular Economy Policies: Words versus Actions. *Sustain. Prod. Consum.* **2021**, *27*, 337–353. [CrossRef]
22. Matthews, C.; Moran, F.; Jaiswal, A.K. A Review on European Union's Strategy for Plastics in a Circular Economy and Its Impact on Food Safety. *J. Clean. Prod.* **2021**, *283*, 125263. [CrossRef]
23. Kirchherr, J.; Piscicelli, L.; Bour, R.; Kostense-Smit, E.; Muller, J.; Huibrechtse-Truijens, A.; Hekkert, M. Barriers to the Circular Economy: Evidence From the European Union (EU). *Ecol. Econ.* **2018**, *150*, 264–272. [CrossRef]
24. Marino, A.; Pariso, P. Comparing European Countries' Performances in the Transition towards the Circular Economy. *Sci. Total Environ.* **2020**, *729*, 138142. [CrossRef]
25. Giannakitsidou, O.; Giannikos, I.; Chondrou, A. Ranking European Countries on the Basis of Their Environmental and Circular Economy Performance: A DEA Application in MSW. *Waste Manag.* **2020**, *109*, 181–191. [CrossRef]
26. Mardani, A.; Zavadskas, E.K.; Streimikiene, D.; Jusoh, A.; Khoshnoudi, M. A Comprehensive Review of Data Envelopment Analysis (DEA) Approach in Energy Efficiency. *Renew. Sustain. Energy Rev.* **2017**, *70*, 1298–1322. [CrossRef]
27. Lu, C.; Zhang, Y.; Li, H.; Zhang, Z.; Cheng, W.; Jin, S.; Liu, W. An Integrated Measurement of the Efficiency of China's Industrial Circular Economy and Associated Influencing Factors. *Mathematics* **2020**, *8*, 1610. [CrossRef]

28. Halkos, G.; Petrou, K.N. Assessing 28 EU Member States' Environmental Efficiency in National Waste Generation with DEA. *J. Clean. Prod.* **2019**, *208*, 509–521. [CrossRef]
29. Ding, L.; Lei, L.; Wang, L.; Zhang, L.; Calin, A.C. A Novel Cooperative Game Network DEA Model for Marine Circular Economy Performance Evaluation of China. *J. Clean. Prod.* **2020**, *253*, 120071. [CrossRef]
30. Ding, L.; Lei, L.; Wang, L.; Zhang, L. Assessing Industrial Circular Economy Performance and Its Dynamic Evolution: An Extended Malmquist Index Based on Cooperative Game Network DEA. *Sci. Total Environ.* **2020**, *731*, 139001. [CrossRef]
31. 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.* **2020**, *281*, 124942. [CrossRef]
32. 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]
33. Liu, X.; Guo, P.; Guo, S. Assessing the Eco-Efficiency of a Circular Economy System in China's Coal Mining Areas: Emergy and Data Envelopment Analysis. *J. Clean. Prod.* **2019**, *206*, 1101–1109. [CrossRef]
34. Silvestri, F.; Spigarelli, F.; Tassinari, M. Regional Development of Circular Economy in the European Union: A Multidimensional Analysis. *J. Clean. Prod.* **2020**, *255*, 120218. [CrossRef]
35. Wang, K.; Yu, S.; Zhang, W. China's Regional Energy and Environmental Efficiency: A DEA Window Analysis Based Dynamic Evaluation. *Math. Comput. Model.* **2013**, *58*, 1117–1127. [CrossRef]
36. Farrell, M.J. The Measurement of Productive Efficiency. *J. R. Stat. Soc. Ser. A (Gen.)* **1957**, *120*, 253. [CrossRef]
37. Cooper, W.W.; Seiford, L.M.; Tone, K. *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software*, 2nd ed.; Springer: New York, NY, USA, 2007; ISBN 978-0-387-45281-4.
38. Charnes, A.; Clark, C.T.; Cooper, W.W.; Golany, B. A Developmental Study of Data Envelopment Analysis in Measuring the Efficiency of Maintenance Units in the U.S. Air Forces. *Annals of Oper. Res.* **1984**, *2*, 95–112. [CrossRef]
39. Charnes, A.; Cooper, W.W.; Lewin, A.Y.; Seiford, L.M. *Data Envelopment Analysis: Theory, Methodology, and Applications*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2013; ISBN 978-94-011-0637-5.
40. Simar, L.; Wilson, P.W. Estimation and Inference in Two-Stage, Semi-Parametric Models of Production Processes. *J. Econom.* **2007**, *136*, 31–64. [CrossRef]
41. Wu, D.; Wang, Y.; Qian, W. Efficiency Evaluation and Dynamic Evolution of China's Regional Green Economy: A Method Based on the Super-PEBM Model and DEA Window Analysis. *J. Clean. Prod.* **2020**, *264*, 121630. [CrossRef]
42. Eurostat Database—Eurostat. Available online: https://ec.europa.eu/eurostat/data/database (accessed on 10 May 2020).
43. The World Bank World Bank Open Data. Available online: https://data.worldbank.org/ (accessed on 10 May 2020).
44. Czikkely, M.; Hoang, N.H.; Fogarassy, C. Circular Transformation of Current Business Solutions in Wastewater Management. *Pol. J. Manag. Stud.* **2019**, 15. [CrossRef]
45. Nogueira, A.; Ashton, W.; Teixeira, C.; Lyon, E.; Pereira, J. Infrastructuring the Circular Economy. *Energies* **2020**, *13*, 1805. [CrossRef]
46. Taušová, M.; Mihaliková, E.; Čulková, K.; Stehlíková, B.; Tauš, P.; Kudelas, D.; Štrba, L'. Recycling of Communal Waste: Current State and Future Potential for Sustainable Development in the EU. *Sustainability* **2019**, *11*, 2904. [CrossRef]
47. Kiani Mavi, R.; Saen, R.F.; Goh, M. Joint Analysis of Eco-Efficiency and Eco-Innovation with Common Weights in Two-Stage Network DEA: A Big Data Approach. *Technol. Forecast. Soc. Chang.* **2019**, *144*, 553–562. [CrossRef]
48. Merli, R.; Preziosi, M.; Acampora, A. How Do Scholars Approach the Circular Economy? A Systematic Literature Review. *J. Clean. Prod.* **2018**, *178*, 703–722. [CrossRef]
49. Rubio, E.V.; Rubio, J.M.Q.; Moreno, V.M. Esfuerzo Fiscal Medioambiental: Convergencia Espacial de la Política Económica en Materia Fiscal. *Rev. Econ. Mund.* **2017**, *15*, 87–101.
50. Padilla-Rivera, A.; Russo-Garrido, S.; Merveille, N. Addressing the Social Aspects of a Circular Economy: A Systematic Literature Review. *Sustainability* **2020**, *12*, 7912. [CrossRef]
51. Rokicki, T.; Perkowska, A.; Klepacki, B.; Szczepaniuk, H.; Szczepaniuk, E.K.; Bereziński, S.; Ziółkowska, P. The Importance of Higher Education in the EU Countries in Achieving the Objectives of the Circular Economy in the Energy Sector. *Energies* **2020**, *13*, 4407. [CrossRef]
52. Meseguer-Sánchez, V.; Abad-Segura, E.; Belmonte-Ureña, L.J.; Molina-Moreno, V. Examining the Research Evolution on the Socio-Economic and Environmental Dimensions on University Social Responsibility. *IJERPH* **2020**, *17*, 4729. [CrossRef]
53. Yumashev, A.; Ślusarczyk, B.; Kondrashev, S.; Mikhaylov, A. Global Indicators of Sustainable Development: Evaluation of the Influence of the Human Development Index on Consumption and Quality of Energy. *Energies* **2020**, *13*, 2768. [CrossRef]
54. Liczmańska-Kopcewicz, K.; Pypłacz, P.; Wiśniewska, A. Resonance of Investments in Renewable Energy Sources in Industrial Enterprises in the Food Industry. *Energies* **2020**, *13*, 4285. [CrossRef]