

Article

The Ecological Criteria of Circular Growth and the Rebound Risk of Closed Loops

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Abstract: The implementation practices of the circular economy (CE) put a strong emphasis on preventing material losses in economic processes. The general interpretation of the concept focuses on closing technological and biological cycles by reintegrating end-of-life products into production and consumption systems. Thus, “closed loops” have become a trademark of circular transition. However, this limited perception fails to cover the essence of the CE. Besides closure, the utility of material loops can be prolonged, and a conscious consumer attitude may even prevent the creation of unnecessary material flows. This paper aims at proving that the preference of closed loops would result in deadweight losses in the long run. The conducted analysis ranks EU member states according to the most anticipated material flow indicators. Then, the study presents a new methodology to measure circular efficiency based on the available ecological capacity of the countries. The outcomes show that the poorly performing actors are in fact not far from a sustainable operation. Meanwhile, the countries with the most efficient material flow values present the widest development gap to reach the ideal level of circularity.

Keywords: circular growth; rebound effect; ecological footprint; circular indicators; closed loops

1. Introduction

Circular economy (CE) is one of the most popular research areas in the field of sustainability. As a result of its recent popularity, many researchers have started to elaborate on the theoretical background of the concept [1–8]. While some of them consider it as a “new sustainability paradigm”, others find it is the reconceptualization of former environmental disciplines. According to the latter perception, the CE functions more like a collective umbrella for such ideas as “Cradle-to-cradle” [9], “Natural Capitalism” [10], “Industrial Ecology” [11], and “Blue Economy” [12]. Thus, the name “Circular Economy” is rather a symbol for previously neglected sustainable concepts which have started to draw attention lately. Their current emergence can be associated with the amending business environment. Ramkumar et al. [13] argue that the upcoming industrial era is not only an evolutionary step but also a whole new economic regime. Moreover, this paradigm shift will change the way humanity manages its resources. The preceding industrial ages have committed to growth, and the utmost importance of this goal has put any other reasons behind [14]. This resigning period is now labelled as a linear economy because that system has handled resources in a “take-make-dispose” perspective [15]. Brooks et al. [16] claim that this phenomenon has occurred because, earlier, it was cheaper to waste resources than to recover them. This was due to the illusion of abundance and the way developed countries could outsource their externalities to developing nations [17]. However, this epoch is coming to an end, since international waste trade markets are about to collapse. Horvath et al. [18] support

this finding and further state that international waste treatment has never fit circular disciplines. They have proved that the absorbing nations mostly come from the developing world and lack the appropriate capacity to support appropriate material circulation. Besides the deficiencies of waste trade, Ramkumar et al. [13] have collected several business-as-usual practices that were beneficial earlier but would be risk factors in the upcoming economic era. One of these so-called “linear risks” is the emerging resource scarcity which makes the recovery of secondary raw materials even more important to maintain the economic growth.

Regarding the perception of growth, the CE concept has a controversial position. In the case of previous sustainability approaches (e.g., environmental and ecological economics, etc.), the recognition of growth has been a decisive aspect [19]. By now, the borderline between such disciplines seems to fade away [20,21], and it would be difficult to define the place of the CE among them. Its diverse role lies in the awareness of resource scarcity [22,23] and offering growth [24,25] at the same time. Although the mixture of the two might sound appealing to policy and corporate decision-making, it has been a bottleneck throughout the implementation of former sustainable endeavors [26,27]. Enhancing the efficiency of using exhaustible resources has been a key pattern during the industrial development [28]. However, efficient use has failed to achieve its desired effect in some cases. It has provided easier access to resources, which has led to a higher exploitation than expected. This phenomenon has become known as “The Rebound Effect” [29,30]. Despite it is a widely researched topic, it barely appears in CE literature. Thus, the following will briefly elaborate on this concept and, more importantly, on its relevance in CE research.

The roots of the rebound effect come from the work of William Stanley Jevons, “The Coal Question” [31] published in the mid-18th century. The economist discovered in an early stage of industrialism that the improved efficiency of the Watt steam engine had made coal a cost-effective resource and therefore induced its intense utilization. This controversial effect has become known as the “Jevons paradox” [32,33]. Despite its significance, this finding has been neglected for a whole century. Then in 1979, Leonard Brookes reviewed the energy strategy of Great Britain and warned policymakers not to pursue lower energy use by increasing efficiency [34]. Later, Daniel Khazzoom provided practical evidence to this statement. He proved that fuel-saving cars and energy-efficient household appliances fail to reach the expected resource conservation. The enhanced efficiency results in cheaper production and consumption costs of energy, which incentivizes its use [35,36]. The findings of these researchers have extended the logic of the Jevons paradox towards all resources. Thus, the phenomenon was first referred to as the “Khazzoom–Brookes postulate” and then earned its currently name, the rebound effect [37]. However, in spite of its practical demonstration, the efficiency contradiction has remained a highly debated topic. Schipper and Grubb [38] argue that this inverse pattern should not be generally declared. Their argument relies on the case of the U.S. transportation sector where fuel intensity has been decreasing for decades without inducing a higher level of use. Evans and Hunt [39] stress that efficacy critics do not take into account the increasing welfare state which comes with economic growth and naturally stimulates energy utilization. Nevertheless, this statement fails to follow the logic of the debate. The claim behind rebound is, in fact, to prove that enhancing the efficiency is not the way to decouple energy use from economic growth [40]. Hajko et al. found [41] that, besides the original assumption of the rebound theory, improving energy efficiency has several indirect effects. The income saved on energy prices on an individual level would be spent on other goods or services, which also increases energy production on a macro level [42]. Thus, even a successfully decreased system would induce demand in other branches [43]. These indirect mechanisms imply that, although the rebound effect is mainly applied to industrial systems, consumers also play an important role in its appearance. Since urban spaces and their built environments are in the center of economic activity, the management of their energy demand will be essential to decouple production from utilization [44].

This short introduction indicates a controversial relationship between economic growth and energy use. The aim of enhancing the efficiency would be to make these two patterns independent from each other. However, such endeavors could easily have opposite results. Stern [45] has theoretically

challenged the Environmental Kuznets Curve which presumes that, by reaching a certain welfare state, economic activity can increase without degrading the environment. He argued that energy rebound is one of the reasons for this mechanism to come undone. Herring [46] stated that energy use would exceed energy savings whenever the economic growth surpasses the income savings from efficiency improvements. This form of rebound is called “backfire” and rarely occurs in the present times. Brockway et al. [47] could find practical evidence for that in China due to the enormous economic growth in the past two decades. Nevertheless, the general perception of the rebound effect is that it exists, even if it does not have a drastic impact [48]. Case studies in this field define the regular value of lost energy savings between 0 and 50% [49,50]. Moreover, an interesting aspect of the rebound theory is that it has recently attracted the attention of authors researching other fields than energy economics.

One of these areas is the case of household consumptions. According to the United Nations Environment Programme (UNEP) [51], that sector is the backbone of western economies, thus not even sustainable lifestyle policies aim at reducing its performance. They rather focus on establishing a more resource-efficient consumer culture [52,53]. However, Csutora [54,55] has concluded that there is no significant difference between the carbon footprint of environmentally conscious and non-conscious consumers. She finds that although conscious consumers might prefer goods with less environmental impact, they tend to buy more of them. This is in fact due to the perception that such products have a lower footprint, so buying them does less harm to nature. The author describes this phenomenon as the “Behavior-Impact-Gap”, which refers to the difference between the expected and the observed environmental impact of green consumption. This finding supports the one of Missemer [56] who claims that the original Jevonsian logic of resource depletion can be extended to other aspects than energy rebound. Moreover, it correlates with the statement of Zink et al. [57], who argue that there are no such things as green products. The authors have analyzed several green activities (e.g. recycling, refurbishing, reuse) and found that the secondary materials recovered by these methods do not replace the primary ones as much as it is expected. Therefore, resource savings would fail to reach the desired level [58,59]. This is the point where the rebound mechanism collides with the disciplines of the circular thinking. By the novel appearance of the CE, studies claimed that the utmost importance of the concept is not managing waste more efficiently but avoiding its occurrence [60,61]. However, concept reviews in this field conclude that many researchers still miss this argument [2,8]. Thus, Cramer [62] presented a hierarchy of activities based on their preference in circularity. The ranks clearly indicate that material recovery and recycling have the lowest priority, while the extension of useful product life and the reduction or refusal of consumption are the core interest.

Regarding circular misbeliefs, the study of Zink and Geyer [63] provide the most comprehensive picture. They argue that current circular approaches rely on single pieces of evidence regarding circular activities (e. g., recycling [64,65], virtualization [66,67]) which cannot be taken for granted in a general sense. Concerning recycling, the first delusion is that secondary materials do not always displace primary ones as it is presumed [68,69]. Furthermore, the lower prices of recycled resources can increase their demand and induce production over the original level [57,70]. The same thing may happen in the case of virtual services which offer easier access to goods and increase their consumption [71]. On the basis of such experiences, there is a chance that the recently preferred circular initiatives would result in less environmental gains than estimated. The authors even propose the emerging phrase of “Circular Economy Rebound” which refers to losses in expected benefits of circular development. However, the practical application of this concept has hardly been investigated yet, which leaves room for further research.

The present paper aimed at finding empirical evidence of the rebound mechanism related to circular measures. Since in the past several years CE has become a top priority of the EU [72,73], the research focused on the countries of the community. It conducted a statistical analysis using the material flow indicators of the EU and sought to find an answer for the following question: are the current European measures adequate to support policies for circular transitions? Moreover, the study offers a methodology which measures circular performance based on the ecological criteria of the examined systems. Concerning the structure of the paper, the following Section 2 describes the methods

and materials applied in the research. Section 3 presents the results of the analysis and introduces the circular methodology. Section 4 discusses its practical application and importance.

2. Materials and Methods

The analysis utilized ecological and material flow data of the EU member states. The former group consists of three different Ecological Footprint (EF) indicators: the biocapacity of the countries, the EF they use for production, and the EF they consume. Regarding the material flow, the research used the six most relevant measures of the EU grouped into three categories: input, output side of the economy, and cycle mechanism. The timeframe of the research was limited to 2014, since that year is the last when the Global Footprint Network [74] and the Eurostat [75–80] have data on all aspects. Table 1 shows the list of the presented indicators.

Table 1. The indicator list of the analysis.

Indicator	Description	Category
Biocapacity [74]	Regeneration capacity of local ecosystems, Global Hectare per capita	Ecological
Ecological Footprint (Prod) [74]	Total amount of Ecological Footprint (EF) used for the production of goods and services, Global Hectare per capita	
Ecological Footprint (Cons) [74]	Total amount of EF consumed through goods and services, Global Hectare per capita	
Domestic Material Consumption (DMC) [75]	Total amount of materials directly used in an economy (excluding exports), Tons per capita	Material flow (input)
Resource productivity [76]	Gross domestic product divided by DMC, EUR per kg	
Waste per DMC [77]	Share of all generated waste (excluding major mineral wastes) from DMC, %	Material flow (output)
Waste per GDP [78]	Ratio of generated waste (excluding major mineral wastes) to GDP, kg per EUR	
Recycling rate [79]	Ratio of recycled waste to all generated waste (excluding major mineral wastes), %	Material flow (cycle)
Circular material use rate (CMU) [80]	Ratio of recycled materials to the overall material use, %	

The first step of the research was to exclude the countries with outlier values in any of the indicators. Thereafter, the second part focused on ecological and material flow measures. Firstly, it used the footprint data to define the basic characteristics of the member states' environmental impact and made a classification accordingly. Then, it applied the Pearson correlation (Equation (1)) to discover the relations between the indicators.

$$r = \frac{N \sum xy - (\sum x)(\sum y)}{\sqrt{[N \sum x^2 - (\sum x)^2] [N \sum y^2 - (\sum y)^2]}} \quad (1)$$

where:

N = number of pairs of scores

$\sum xy$ = sum of the products of paired scores

$\sum x$ = sum of x scores

$\sum y$ = sum of y scores

$\sum x^2$ = sum of squared x scores

$\sum y^2$ = sum of squared y scores

Although it is a quite simple analytical method, it demonstrated whether the initial expectations of circularity appear or not. For instance, do countries with less material use (Domestic Material Consumption, DMC) and higher resource productivity truly generate less waste than others? Furthermore, do cycle mechanisms really result in more efficient resource usage? This part of

the research aimed at answering these fundamental questions. Then, the third step reconciled the results of the ecological classification and the statistical analysis of circular patterns. This comparison indicated how the circular performance of EU member states comes along with their environmental conditions. At last, the fourth and fifth parts of the research introduced a new methodology to measure circularity. It enables the users to define how much of a circular transition a country needs to reach a sustainable level of resource utilization. Based on this description, Figure 1 illustrates the design of the research, and the next chapter presents the results of the first three steps.

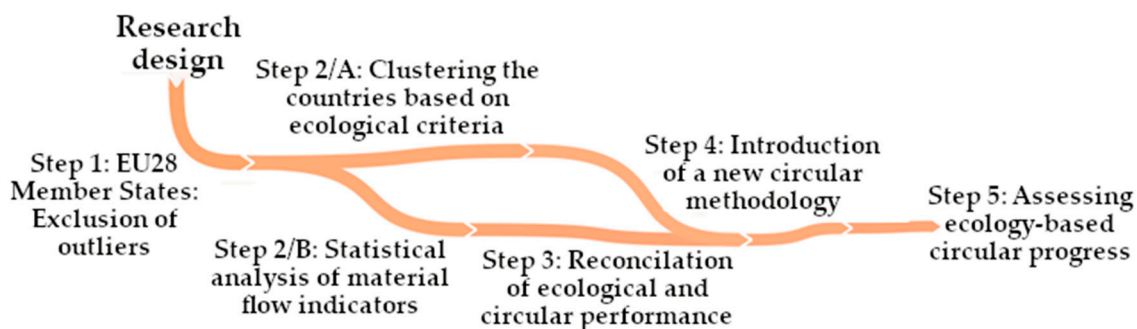


Figure 1. The design of the research.

3. Results

The analysis started by filtering countries with outlier values. It resulted in the exclusion of six EU member states, namely, Bulgaria, Estonia, Finland, Latvia, Luxembourg, and Sweden. Bulgaria and Estonia were excluded because of the extreme magnitude of their waste generation. Finland, Latvia, and Sweden possess rather high levels of biocapacity. Luxembourg has an enormous amount of per capita EF consumption, which makes it not only a European but also a worldwide leader. The distinct nature of the outlier indicators did not make possible to group these countries in a single cluster, and their excessive values would distort the correlation analysis. Thus, the following results represent the conditions of the rest of the 22 EU nations. For the sake of easier visualization, the paper uses country acronyms in the figures. The elaboration on the applied acronyms can be found in Appendix A. As a second step, these countries were distributed into clusters based on their environmental impact (Figure 2).

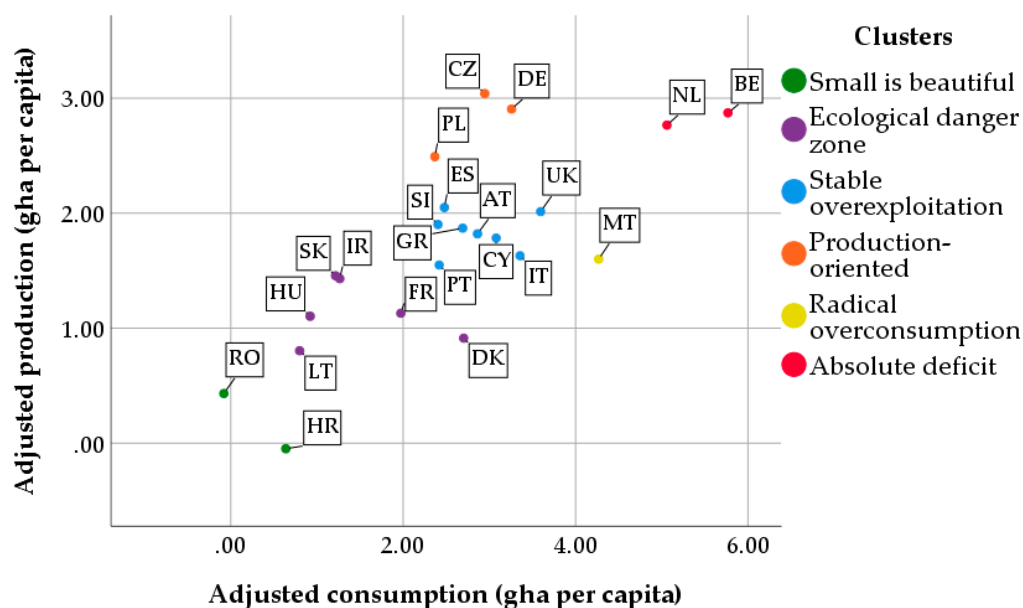


Figure 2. Results of the cluster analysis based on adjusted EF indicators.

The basis of this division was not only the countries' ecological footprint but also an adjusted version of it. Since most member states overexploit their resources, both of their EF measures (production and consumption) surpass their biocapacity. Hence, the EF indicators were adjusted by the withdrawal of biocapacity. This value indicates the level of overexploitation in terms of production and consumption. The clusters were classified through the centroid method that measures the distances from central values. By the logic of the figure, the zero point of the graph marks a state where the amount of utilized resources is in balance with the biocapacity. Moving towards the top-right corner, the graph shows the level of overexploitation. According to the data, there is no country which would be below its ecological limits. Only Romania (in consumption) and Croatia (in production) have at least one aspect that performs properly. Together they form the group of the most sustainable nations. Their opposite is the cluster of the Netherlands and Belgium that harness many times more resources than the available amount. The nations in between are categorized on the basis of the extent of their overuse and its characteristics (e.g., production or consumption orientation). This resource intensity ranking will be relevant after the elaboration on the results of the statistical analysis.

Concerning the correlations between the material flow indicators, the following description focused on the ones which are essential in the scope of the study. The first remarkable result was the relationship between DMC and the generated waste of the countries ($r: -0.57; p < 0.01$). Figure 3 illustrates that the countries consuming the most materials are in fact the ones generating the least amount of waste. Moreover, this controversial ratio is highly unequal in the case of Italy, the Netherlands, and Belgium.

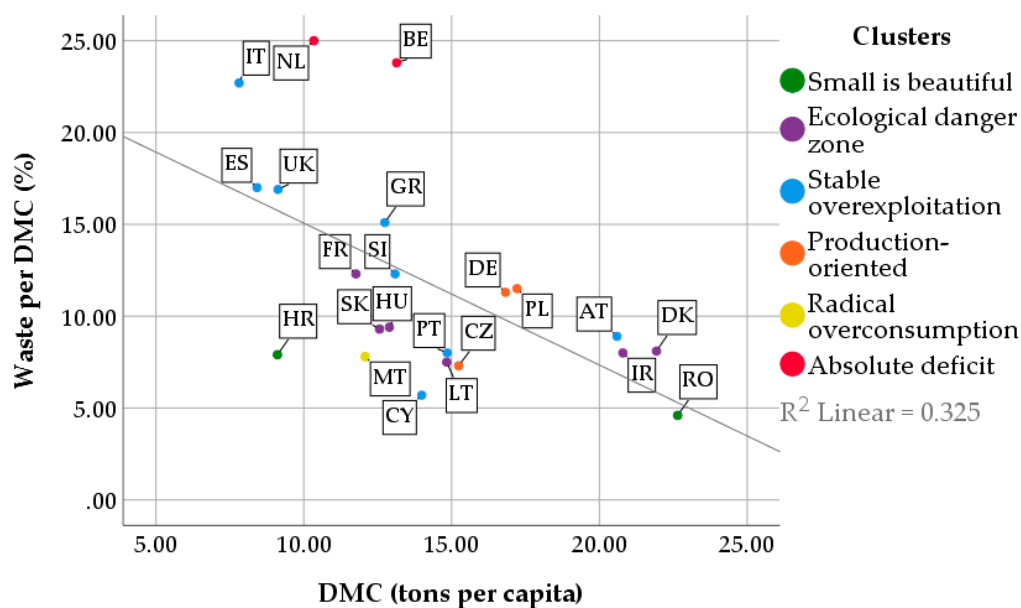


Figure 3. The correlation between domestic material consumption and waste generation.

Another surprising correlation is the one between resource productivity and waste generation ($r: 0.82; p < 0.01$). The illustration of the connection (Figure 4) implies that the more productive a country is, the more waste it generates. The two endpoints of the contour line look similar as on the previous figure. Although Romania uses its resources the least efficiently, it generates a minimal amount of waste. In contrast, the most productive member states (Belgium, the Netherlands, Italy, UK, Spain) end up with the highest waste generation. The only difference is that the countries between these two extremes are not that dispersed, they are rather concentrated. The correlation, though, is even stronger than in the previous case. These two phenomena appear to be quite controversial, since they say that less material consumption and efficient resource utilization lead to more waste. However, this mechanism should not be necessarily considered as a sign of rebound. This logic, in fact, is obvious even in a circular economy, because it implies thinking in opposition to the linear economy. As a result of recycling waste, domestic material consumption—which covers only primary materials—can be

decreased, since productivity is calculated on the basis of DMC, whose lower amount increases its performance. Thus, before drawing a general conclusion, the circular mechanisms (recycling and circular material use rate) must also be reviewed.

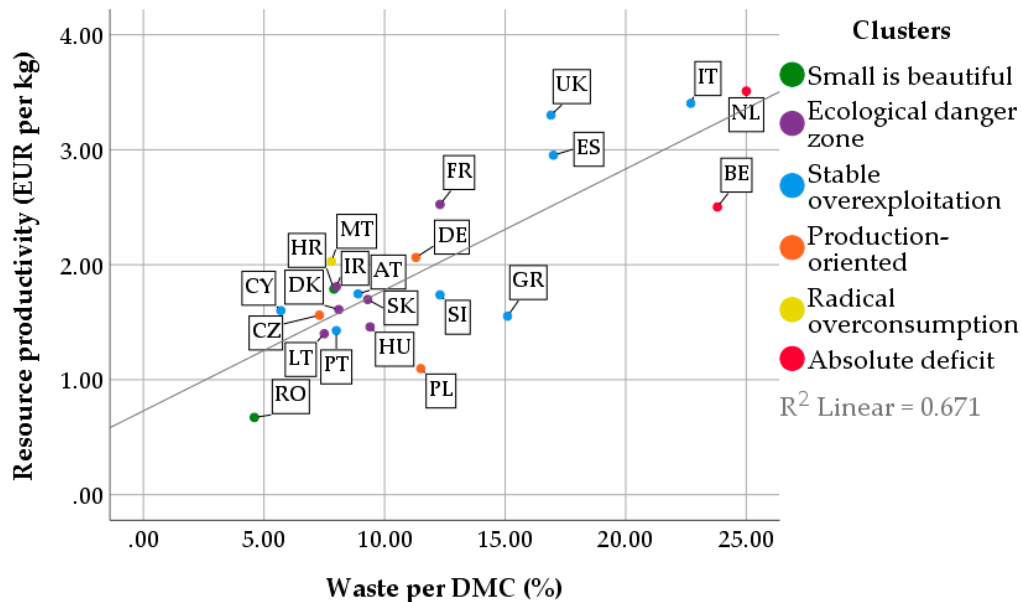


Figure 4. The correlation between resource productivity and waste generation.

Concerning the recycling and the circular material use rate (CMU), it is important to clarify the methodological difference between the two measures. The former does not provide an entire picture of circularity because it is limited to the share of recycling from the total amount of waste (excluding major mineral wastes). However, the CMU compares the same magnitude of recycling to the overall material use (both primary and secondary) of an economy (Equation (2)).

$$CMU = \frac{U}{M} = \frac{Rw - Rw_{imp} + Rw_{exp}}{DMC + (Rw - Rw_{imp} + Rw_{exp})} \quad (2)$$

where:

CMU: Circular material use rate,

U: circular use of material,

M: overall material use,

Rw: amount of recyclable waste,

Rw_{imp}: amount of imported recyclable waste,

Rw_{exp}: amount of exported recyclable waste,

DMC: Domestic Material Consumption.

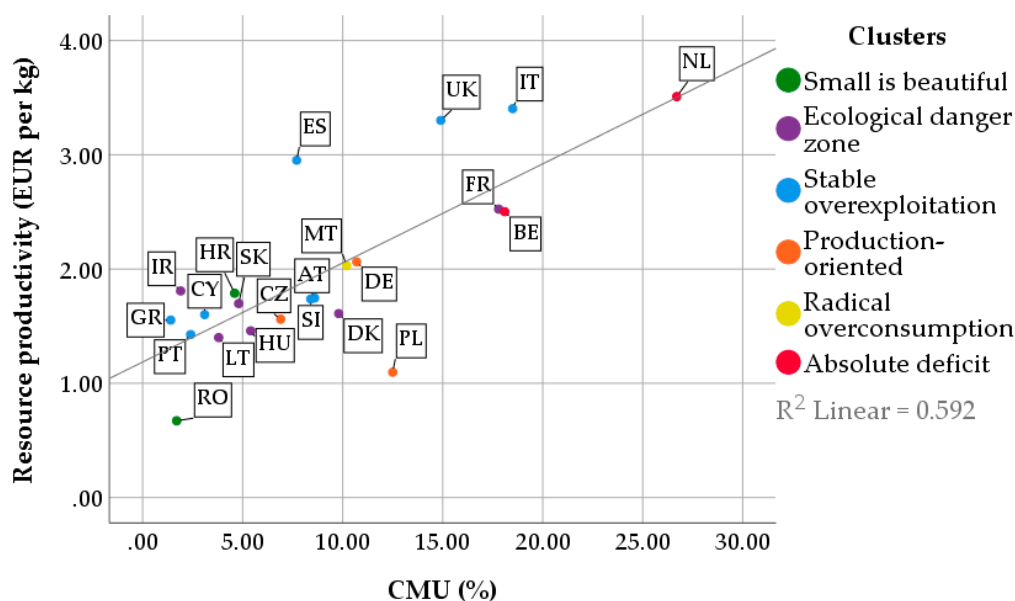
After the methodological elaboration, Table 2 presents the correlation values between these measures and the previously applied material flow indicators. While the circular material use shows a rather strong and highly significant relation to resource productivity and waste amount, the recycling rate lacks the same intensity or does not indicate connection at all. This pattern implies that the CMU is a more accurate indicator in terms of circularity and answers the sub-questions of the research. The current part of the analysis aimed at finding if countries with less material use and enhanced efficiency generate less waste than the ones with opposite attributes. Moreover, it was investigated if there is a connection between cycle mechanisms and resource productivity. According to the results, the first assumption turned out to be wrong. Nevertheless, the outcomes also showed that this is not a controversy. It is not productivity which decreases the magnitude of waste but, conversely, the amount of waste can raise the efficiency through recirculation.

Table 2. Correlation between the cycle mechanisms and the major material flow indicators. CMU: circular material use rate.

Variables		DMC/Capita	Resource Productivity	Waste/DMC
Recycling rate	Pearson Correlation	−0.091	0.409	0.461 *
	Sig. (2-tailed)	0.688	0.059	0.031
	N	22	22	22
CMU	Pearson Correlation	−0.391	0.769 **	0.787 **
	Sig. (2-tailed)	0.072	0.000	0.000
	N	22	22	22

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

After these findings, the only question that remains open is the one asked in the introduction: are the current European measures adequate to support policies of circular transitions? According to the results, it seems that efficiency endeavors have a narrow focus on the input side of the system. Thus, they tend to reduce primary material utilization as much as possible. However, this logic not only forgets the case of the waste but also it promotes its generation. Although the CMU indicates the effectiveness of recycling activities, it also favors countries producing the most waste. This is the point where the matter of the ecological classification becomes relevant. By looking at the correlation between resource productivity and circular material use (Figure 5), one would observe that these factors are associated. Nonetheless, the ecological indications put this picture in a completely new perspective: they show that the member states preferred by these metrics are in fact the ones presenting the worst ecological conditions.

**Figure 5.** The correlation between resource productivity and circular material use.

These findings imply the importance of including ecological criteria in measuring circular performance. Therefore, the following sub-section introduces a novel indicator which extends the scope of the CMU mechanism with such aspects.

3.1. Measuring Circular Transitions Through Ecological Criteria

The upcoming circular methodology is based on the CMU indicator of Eurostat [80]. That mechanism focuses on the efficiency of recirculating resources into production. Thus, it considers the ratio of secondary raw materials (U) to all the DMC (M) used in an economy. The present study

did not question the use of that tool, because the state of material circulation is an important measure. The aim was rather to highlight its deficiencies from an ecological and policy-making viewpoint. The previous results showed that the matter of waste generation is not handled appropriately by the CMU. Moreover, the consideration of ecological limitations is entirely missing from its logic. Although the latter aspect is not an essential requirement for circular methods [81], there is a possibility for its involvement. Equation (3) presents a mechanism that integrates ecological patterns into the calculation of circular material use. While the CMU shows the current level of secondary raw material use, this so-called “Ecological Circulation Index” indicates how high this level should be to stay in balance with the biocapacity (BC). The model associates the ecological footprint of a country with its primary raw material consumption (DMC). Thus, it assumes that the DMC must be substituted with the same amount of recycled materials as the ecological footprint exceeds the biological capacity. The BC/EF segment demonstrates the extent of resource deficit or surplus. The operation in the outer parentheses results in the deviation between the material consumption and the balanced level (where $EF = BC$). In the case of resource deficit ($EF > BC$), the method increases the amount of secondary raw material use (U) by the extent of the shortage. Even though resource surplus ($EF < BC$) is not common among the analyzed countries, the equation can be applied for that instance too. It would mean that a member state could even raise its material use because there are available resources.

$$ECI = \frac{U + \left(DMC - \left(\frac{BC}{EF} \times DMC \right) \right)}{M} \quad (3)$$

where:

ECI: Ecological Circulation Index,
 U: Circular use of material,
 DMC: Domestic Material Consumption,
 BC: Biocapacity,
 EF: Ecological Footprint,
 M: Overall material use.

Because of its size, the table of the countries’ ECI values is located in Appendix A. Since the ECI shows an expected level, and the CMU demonstrates a current state, there is room to compare the two indicators. The table also presents the measure of “Circular deficit” which stands for a lacking performance regarding circular transition. The key observation of this comparison is another controversial pattern in the material flow. One can observe that the better a country performs in circular material use, the more it falls behind the ideal level. Moreover, the ones that appear modest at first sight are, in fact, not that far from a sustainable operation.

The statistical evidence in Figure 6 also supports this statement. It illustrates the correlation between the CMU and the ECI indicators. The correlation coefficient shows a relatively large ($r: 0.56$) and highly significant ($p < 0.01$) positive relationship between them. The first observation is that member states from the same clusters are closer to each other than in the case of any other relations. The groups with the slightest environmental impact can be clearly differentiated (except for France), so as the other extreme. Another key finding is the state of the Mediterranean countries. The circular deficit is above 60% in all of these member states. Furthermore, Cyprus and Malta have extremely poor values and present the widest transition gaps (90% and 78%). However, these countries are only exceptions. The CMU and ECI values indicate a controversial relationship by for the other member states. Normally, one would assume that modestly performing actors need the most efforts to develop, and the leaders are the ones to follow. The outcomes of the research show the opposite, though. Thus, these findings answered the research question concerning the adequacy of methodologies measuring circular transition. The argument has proved that the lead indicator of the EU has major deficiencies. Its logic leads to inaccurate observations regarding the efficiency of circular material flows. Hence, it is

recommended to reconsider its application. The section after the illustration discusses these results in more detail and elaborates on their practical adaptation.

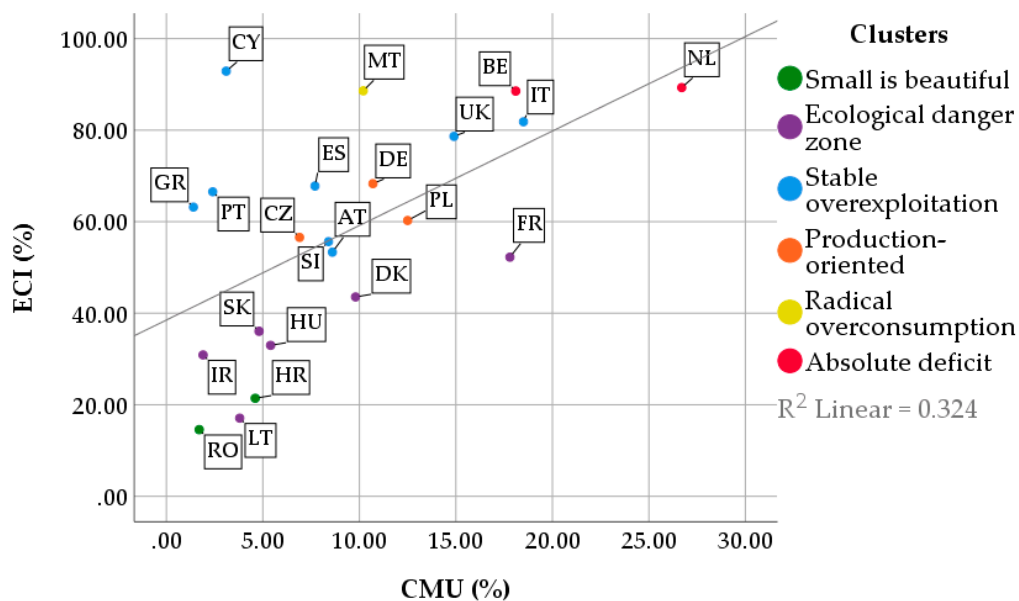


Figure 6. Correlation of the CMU and ecological circulation index (ECI) values.

4. Discussion

The present paper aimed at finding evidence for controversies in currently applied circular measures. The analysis focused on the material flow indicators of the Eurostat database because of their major role in policy-making. The starting point of the study was to discover the need to investigate rebound trends in circular development. Although the connection between these two fields is rarely researched, recent literature has shown some interesting endeavors. Csutora [54,55] was the first to recognize a phenomenon in household consumptions similar to the rebound mechanism. She found that there is no difference in the environmental impact of conscious and non-conscious consumers. The reason—as she describes—is that people tend to buy more eco-friendly products and services as a consequence of the perception that they do less harm to the environment. Eventually, this attitude results in less environmental savings from eco-friendly products than expected. Then, Zink and colleagues [57,82] used similar arguments to highlight common misconceptions regarding circular activities (e.g., recycling, refurbishment, reuse). Zink and Geyer [63] directly connected the concept of rebound and the CE to emphasize that these misbeliefs would lead to paradoxical effects. They stated that assuming a 1:1 displacement of primary raw materials by secondary ones is a false idea because of technological limitations and consumer behavior. Thus, there are clear signs in the literature indicating that efficiency improvements would lead to controversial outcomes not only in the field of energy use but also in material flows. The other aspect in realizing the research gap was the prioritization of circular actions. When establishing the (novel) theoretical basis of the CE, the Ellen MacArthur Foundation defined the main preferences of circularity. Although circulation is mostly associated with recycling, it is of higher importance to prevent the generation of waste [15,24]. Besides closing material loops, one can lengthen them with the extension of product lifespan [83] or simply narrow them by refusing consumption [84]. According to these principles, Cramer [62] created a hierarchical order of 10 different circular activities. That ranking features recycling as the second least efficient action in terms of CE. On the basis of these examples, it seems that the literature clearly sets the priorities of circularity. However, studies report that many initiatives miss the right conceptualization and associate it with the treatment of waste [2,8].

The current paper used this pattern of misinterpretation to connect the rebound effect with circularity. The research relied on the assumption that measuring circular efficiency in line with such

unfavorable actions as recycling would lead to major deadweight losses. The initial results indicated the credibility of this statement by showing the controversial relationship between the basic material flow indicators of the EU. The main lesson was that the current measurement system has a narrow focus on input indicators (material consumption, resource productivity) and neglects the issue of waste generation. As a matter of fact, the circular index of the EU even encourages high amounts of waste because it only considers recycling performance, which can be induced by that aspect. Discovering this contradiction led to the design of a new circular method that involves the ecological criteria of the measured system. Though this pattern rarely appears in most of the circular evaluations, the ecological limitation is as significant as the effectiveness of a certain activity [85]. Petit-Boix and Leipold [86] directly emphasized the definition of environmental impacts before deciding on circular strategies. The application of the Ecological Circulation Index showed an interesting phenomenon among the EU member states. Albeit recycling is in the focus of the current circular thinking, the recognition of its effectiveness is quite deceptive. Instead of looking at its present state, the ECI indicates the level of recycling which keeps the primary raw material consumption of a country in balance with its biocapacity. By this perspective, the poorly performing countries do not seem so disadvantageous because they have less intense resource exploitation in comparison with others. Moreover, the member states considered as leading circular innovators are in fact well below expectations. Naturally, these results do not mean to encourage the increase of recycling efficiency because that activity must not be the major aim of circularity. The added value of this study is rather to challenge the way European decision-making perceives the CE. The concept can only triumph if it is applied as a novel way to manage resources and not as a new alternative to pursuit economic growth.

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

Appendix A

Table A1. Circular characteristics based on ecological measures.

Member States	CMU (%)	ECI (%)	Circular Deficit (%)
Austria (AT)	9.10	53.33	44.23
Belgium (BE)	18.10	88.54	70.44
Croatia (HR)	4.60	21.42	16.82
Cyprus (CY)	3.10	92.89	89.79
Czech Republic (CZ)	6.90	56.56	49.66
Denmark (DK)	9.00	43.55	34.55
France (FR)	17.80	52.25	34.45
Germany (DE)	10.70	68.30	57.60
Greece (GR)	1.40	63.18	61.78
Hungary (HU)	5.40	32.98	27.58
Ireland (IE)	1.90	30.87	28.97
Italy (IT)	16.80	81.83	65.03
Lithuania (LT)	3.80	17.07	13.27
Malta (MT)	10.20	88.60	78.40
Netherlands (NL)	26.70	89.29	62.59
Poland (PL)	12.50	60.25	47.75
Portugal (PT)	2.50	66.53	64.03
Romania (RO)	1.70	14.56	12.86
Spain (ES)	7.70	67.79	60.09
Slovakia (SK)	4.80	36.05	31.25
Slovenia (SI)	8.40	55.64	47.24
United Kingdom (UK)	15.00	78.64	63.64

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