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Circular Economy in Action: Examining the Decoupling of Economic Growth and Material Use across EU Countries

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ABSTRACT:
The circular economy (CE) is a transformative approach that not only preserves and reuses resources but also redefines how economic growth can be achieved in a more sustainable manner. The aim of the paper is to assess whether economic growth in EU countries can be decoupled from resource use through CE practices. Using data from Eurostat spanning 2010-2022, we analyze key indicators such as Raw material consumption (RMC), Gross domestic product (GDP) and Circular material use rate (MUR). We apply correlation analysis and decoupling analysis to assess the efficacy of CE practices in achieving sustainable economic growth. The results indicate significant variability among EU countries in their ability to decouple economic growth from resource consumption. Some countries demonstrated strong absolute decoupling, indicating successful CE integration, while others faced challenges with expansive negative decoupling. The study underscores the necessity for tailored strategies to enhance CE implementation across diverse economic contexts within the EU.

Keywords: decoupling, circular economy, raw material, circular material, GDP, EU countries

1. Introduction

The circular economy (CE) concept is much discussed in the European Union (EU), but only limited progress has been accomplished so far regarding its implementation (Kirchherr et al. 2018). Contemporary European society has ambitious but clear medium- and long-term goals, including action plans, for moving towards sustainability. The circular economy embodies a contemporary approach centred on sustainability and waste reduction, gradually integrating into production and consumption practices (Huttmanová et al. 2024) Moving away from traditional production and consumption models is one way to create a sustainable future. However, efforts to intensify environmental protection, conserve natural resources, and mitigate the impacts of climate change often conflict with the goal of increasing economic growth. Considering more efficient ways to use resources in transformative processes that ensure sustainable or green economic growth is now essential. One way to green economic performance is by applying the concept of the circular economy. The circular

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economy is currently seen as a new, modern approach to creating sustainability and an opportunity to modify the factors of economic development. On the other hand, it is also a return to more rational resource management, conservation, and their multiple uses. The circular economy is a regenerative system that seeks to redefine traditional linear models by emphasising the importance of maintaining the use of products, materials and resources for as long as possible (Shevchenko et al. 2021; Geissdoerfer et al. 2017) define circular economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. The most popular vision of circular economy - the technocratic one, which aims to decouple the economy from resource use through circular technologies was presented by Ziegler et al. (2023) in Simamindra & Rajaonarivo (2024).

Promotion and implementation of sustainable production and consumption practices have become a priority to obtain social, economic, and environmental benefits. Circular economy is based on an integrative approach which requires the analysis of all the relevant factors that may determine changes in the classical linear model of economic growth (Androniceanu, Kinnunen, Georgescu 2021). Economic growth and environmental performance must go hand in hand. The environment is based on economic activity and growth, providing the main resources we need in the production process and absorbing unwanted by-products (waste and pollution). Circular economy and environmental assets contribute to economic growth and social activity, helping to regulate flood risks and local climate and maintaining the supply of clean water and other resources. Correspondingly, economic growth contributes to the investment and dynamism needed to deploy and develop new technology, which is foundational to both managing environmental assets and productivity growth (Busu & Trica 2019). Resource decoupling refers to the ability to generate economic growth without a corresponding increase in resource consumption, which also presented Kjaer et al. (2019) that resource decoupling only occurs when the resource use declines, irrespective of the growth rate of the economic driver. Decoupling is commonly applied in several key areas: energy consumption (Chovancová & Vavrek 2020), waste generation (Alcay et al. 2021), material consumption (Serrano & Valbuena 2021) etc. This concept is critical in achieving sustainable development, where economic activities do not deplete natural resources or cause environmental harm. However, "CE is emerging as an economic strategy rather than a purely environmental strategy" (Yuan et al. 2006 in Homrich et al. 2018), requiring a "complete reform of the whole system of human activity, which includes both production processes and consumption activities" (Yuan et al. 2006 in Homrich et al. 2018).

Chen & Pao (2022) analyzed the causal relationship between CE and economic growth using data from EU-25 countries from 2010 to 2018. Their model results confirmed that in terms of short-run causality, an increase in material recycling led to a decrease in waste generation, an increase in waste generation led to an increase in CE-related investment, and economic growth led to circular economy growth, but not vice versa. This implies that encouraging CE-related innovation investments and promoting material recycling to stimulate the secondary raw material market can help achieve zero waste goals.

2. Material and Methods

To evaluate the potential for decoupling economic growth from resource use through circular economy practices in EU countries, we employed a multi-faceted methodological approach. First, we present descriptive statistics and correlation analysis. Descriptive statistics provide a foundational understanding of the data, including measures of central tendency and variability. Following, we proceed with correlation analysis. The correlation coefficients help us assess whether increases in economic performance are associated with changes in raw material consumption and the use of circular materials. Finally we perform decoupling analysis described in this subchapter.

Our analysis spans the period from 2010 to 2022 and utilizes data from the Eurostat database. The key indicators analysed include raw material consumption (RMC), gross domestic product (GDP) per capita, and circular material use rate (MUR).

2.1 Decoupling Analysis

The circular economy aims to keep resources in use for as long as possible through recycling, remanufacturing, and other practices. By extending the lifecycle of materials, the circular economy can help achieve resource decoupling. In general, we recognize two types of decoupling: absolute decoupling, which occurs when the economy grows, and resource use decreases in absolute terms; and relative decoupling, which occurs when the economy grows, but the rate of resource use growth is slower than the rate of economic growth.

The research problem whether is it possible to identify a decoupling between economic growth and resource use in EU countries has been transformed into research questions:

1. To what extent have EU countries achieved resource decoupling, through circular economy practices? / To what extent have EU countries achieved resource decoupling, through circular economy practices?
2. Are there differences in resource decoupling among EU countries (with varying levels of circular economy implementation)?

The main objective of this paper is to investigate whether economic growth can be decoupled from resource use through circular economy practices. We used indicators available in the Eurostat database for the period 2010-2022: Raw material consumption (RMC) of the EU – also referred to as material footprint – represents the total amount of extracted raw materials needed to produce the goods and services consumed by residents of the EU; GDP per capita and Circular material use rate (MUR). The following methods were used in the evaluation process: Descriptive Statistics (Examine trends in GDP and material consumption over time, identify patterns of resource use relative to economic growth); Correlation analysis and Separate Decoupling Analysis. Decoupling Factor (DF) was calculated using the formula:

DF for GDP per capita and RMC:

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$$DF_{GDP-RMC} = \frac{\frac{\Delta RMC}{RMC}}{\frac{\Delta GDP\ per\ capita}{GDP\ per\ capita}}$$

DF for GDP per capita and Circular material use rate:

$$DF_{GDP-MUR} = \frac{\frac{\Delta MUR}{MUR}}{\frac{\Delta GDP\ per\ capita}{GDP\ per\ capita}}$$

The classification of decoupling stages, as detailed in Table 1, provides a framework for evaluating the extent to which economic growth and resource use are decoupled in the context of circular economy practices.

Table 1 Decoupling classification

DF	Decoupling stage	The rate of change description
< 0	Absolute (strong)	negative for EI* and positive for EG**
0 < DF < 1	Relative (weak)	growth is lower for EI than for EG
> 1	Recessive	decrease is higher for EI than for EG
< 0	Strong negative	positive for EI and negative for EG
0 < DF < 1	Weak negative	decrease is lower for EI than for EG
> 1	Expansive negative	growth is higher for EI than for EG
= 1	Critical	equal for EI and EG

*EI – environmental impact/pressure (EI); **EG – economic growth
Modified from: Xu et al. 2017; Chovancová et al. 2023

3. Results
3.1 Descriptive Statistics and Correlation Analysis

We began our analysis with descriptive statistics to examine trends in GDP and material consumption over time, identifying patterns of resource use relative to economic growth. Descriptive statistics are presented in table 2.

Table 2 Descriptive statistics results

Variable	Obs.	Mean	Std.Dev.	Min.	Max.
GDP	270	26567.37	17269.91	5390	86540
RMC	270	18.28075	8.101124	6.77	54.707
MUR	270	8.827778	6.342669	.6	29

Source: own research

Following this, we conducted a correlation analysis to explore the relationships between GDP, RMC, and MUR. Table 3 captures the results of correlation analysis.

Table 3 Correlation analysis results

Variable	GDP	RMC	MUR
GDP	1,0000	-	-
RMC	0.2613	1,0000	-
MUR	0.2343	-0.2929	1,0000

Source: own research

The results of the correlation analysis indicate a positive correlation between GDP and RMC (r = 0.2613), suggesting that economic growth is accompanied by increased consumption of raw materials. A positive correlation was also observed between GDP and MUR, with a coefficient of r = 0.2343. This indicates that higher GDP levels are associated with greater use of circular materials. Overall, we can conclude that achieving higher GDP is linked to increased consumption of both raw and circular materials.

A negative correlation was noted between the consumption of raw materials and circular materials. This implies that higher consumption of raw materials is associated with lower utilization of circular materials. This may suggest that countries with high raw material consumption engage less in recycling and other circular practices.

3.2 Results of decoupling analysis

Building on the insights gained from the descriptive statistics and correlation analysis, we proceeded with a decoupling analysis to determine the extent to which economic growth in EU countries could be decoupled from resource use. In the first phase we assessed the decoupling stages in EU countries, using indicators Raw material consumption (RMC) a Gross Domestic Product (GDP) using formula (1). Results are presented in table 4.

Table 4 Decoupling factor GDP-RMC and country rate

Country	**ΔGDP**	**ΔRMC**	**DF GDP-RMC**	**Decoupling stage**
LUX	0,04	-0,21	-4,92	Absolute (strong) decoupling
NLD	0,15	-0,23	-1,59	Absolute (strong) decoupling
FIN	0,08	-0,12	-1,42	Absolute (strong) decoupling
DEU	0,08	-0,10	-1,19	Absolute (strong) decoupling
FRA	0,06	-0,06	-0,90	Absolute (strong) decoupling
GRC	0,12	-0,10	-0,80	Absolute (strong) decoupling
MLT	0,39	-0,10	-0,25	Absolute (strong) decoupling
AUT	0,05	-0,01	-0,24	Absolute (strong) decoupling
IRL	1,09	0,00	0,00	Relative (weak) decoupling
SVK	0,23	0,03	0,12	Relative (weak) decoupling
EST	0,30	0,06	0,19	Relative (weak) decoupling
HRV	0,40	0,15	0,37	Relative (weak) decoupling
POL	0,46	0,18	0,38	Relative (weak) decoupling
EU 27	0,15	0,06	0,39	Relative (weak) decoupling
CYP	0,34	0,24	0,69	Relative (weak) decoupling
SWE	0,12	0,08	0,69	Relative (weak) decoupling

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SVN	0,27	0,22	0,79	Relative (weak) decoupling
ESP	0,14	0,11	0,79	Relative (weak) decoupling
LTU	0,40	0,33	0,84	Relative (weak) decoupling
PRT	0,20	0,18	0,87	Relative (weak) decoupling
LVA	0,32	0,31	0,94	Relative (weak) decoupling
CZE	0,22	0,24	1,10	Expansive negative decoupling
BGR	0,42	0,52	1,23	Expansive negative decoupling
ITA	0,10	0,13	1,27	Expansive negative decoupling
HUN	0,39	0,50	1,29	Expansive negative decoupling
ROU	0,46	0,69	1,50	Expansive negative decoupling
BEL	0,11	0,22	2,09	Expansive negative decoupling
DNK	0,16	0,42	2,59	Expansive negative decoupling

Source: own research

The results indicate that during the evaluated period, economic growth increased alongside a reduction in raw material consumption, most notably in Luxembourg (DF - 4.92). The Netherlands, Finland, and Denmark also showed positive results in decoupling economic growth from raw material consumption. France, Greece, Malta, and Austria were similarly categorized with strong decoupling. These findings suggest that for these countries, achieving higher economic growth is crucial, although this progress may negatively impact environmental quality.

On the other hand, a group of countries, including the Czech Republic, Bulgaria, Italy, Hungary, and Romania, particularly Belgium and Denmark, experienced moderate economic growth associated with greater pressure on environmental quality and raw material consumption. A relatively large group of countries (13) achieved weak decoupling, where economic growth was accompanied by a slower increase in raw material consumption. This means that the rate of environmental impact growth was lower than that of economic growth. At the EU average level, relative (weak) decoupling was also achieved.

The results in Table 4 (and Figure 1) highlight the varying degrees of progress in implementing sustainable practices into the economic performance of different countries. For example, in the case of Ireland, GDP changes significantly impacted overall results, while RMC remained unchanged during the evaluated period. Conversely, the most significant change in RMC was observed in Romania. Considering the decoupling factor, we conclude that there are differences among EU countries in decoupling economic growth from raw material consumption.

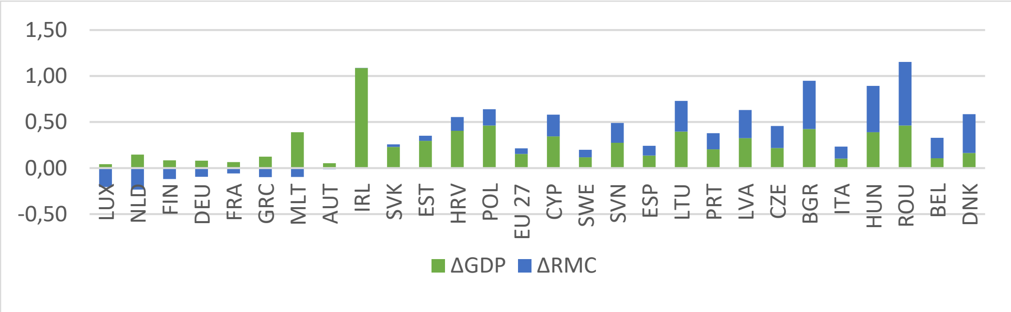

Figure 1 Decoupling factor GDP-RMC and country rate, EU countries
Source: own research

We further evaluated the decoupling stages in EU countries using the indicators Circular Material Use Rate (MUR) and Gross Domestic Product (GDP), using formula (2). The results are presented in Table 5 and Figure 2.

Table 5 Decoupling factor GDP-MUR and country rate

Country	ΔGDP	ΔMUR	DF GDP-MUR	Decoupling stage
LUX	0,04	-0,66	-15,71	Absolute (strong) decoupling
FIN	0,08	-0,92	-11,04	Absolute (strong) decoupling
ESP	0,14	-0,20	-1,49	Absolute (strong) decoupling
SWE	0,12	-0,15	-1,30	Absolute (strong) decoupling
ROU	0,46	-0,44	-0,95	Absolute (strong) decoupling
POL	0,46	-0,31	-0,67	Absolute (strong) decoupling
DNK	0,16	-0,04	-0,24	Absolute (strong) decoupling
SVN	0,27	0,01	0,04	Relative (weak) decoupling
IRL	1,09	0,06	0,05	Relative (weak) decoupling
EU 27	0,15	0,03	0,17	Relative (weak) decoupling
NLD	0,15	0,03	0,18	Relative (weak) decoupling
PRT	0,20	0,04	0,20	Relative (weak) decoupling
EST	0,30	0,08	0,27	Relative (weak) decoupling
HUN	0,39	0,30	0,76	Relative (weak) decoupling
LTU	0,40	0,32	0,81	Relative (weak) decoupling
CYP	0,34	0,33	0,97	Relative (weak) decoupling
HRV	0,40	0,49	1,20	Expansive negative decoupling
LVA	0,32	0,42	1,30	Expansive negative decoupling
ITA	0,10	0,17	1,64	Expansive negative decoupling
FRA	0,06	0,12	1,89	Expansive negative decoupling
DEU	0,08	0,17	2,13	Expansive negative decoupling
BGR	0,42	0,92	2,17	Expansive negative decoupling
BEL	0,11	0,28	2,60	Expansive negative decoupling
CZE	0,22	0,78	3,57	Expansive negative decoupling
MLT	0,39	1,40	3,58	Expansive negative decoupling
SVK	0,23	0,98	4,25	Expansive negative decoupling
GRC	0,12	0,82	6,65	Expansive negative decoupling
AUT	0,05	0,50	9,52	Expansive negative decoupling

Source: own research

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Based on the evaluation results in Table 5, we conclude that EU countries are divided into three relatively distinct groups based on their decoupling stage. The largest group (12 countries) achieved expansive negative decoupling, which includes Slovakia. For these countries, economic performance improvements were achieved at the expense of increased environmental pressure. In contrast, Luxembourg, Finland, and five other countries (Spain, Sweden, Romania, Poland, and Denmark) showed negative changes in environmental impact and positive changes in economic growth. These countries succeeded in making progress in economic growth while simultaneously reducing the consumption of circular resources.

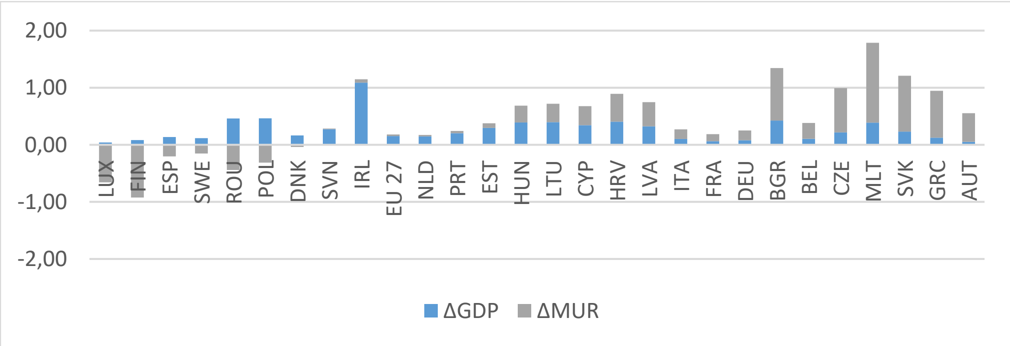

Figure 2 Decoupling factor GDP-MUR and country rate
Source: own research

4. Discussion

The results of the analysis highlighted the disparities in the implementation and progress of circular economy practices across EU member states. These results comply with those of Fura et al. (2020) who suggest that economic structures and development significantly impacts the success of material decoupling across EU countries, suggesting that highly developed nations are leaders in CE implementation. Another important factor is environmental policy coherence within the EU. According to Ahlström & Sjåfjell (2022) ensuring that policies are aligned and coherent across EU member states can facilitate the transition to a circular economy. Although decoupling analysis unveil this variability among countries, it does not examine factors behind performance of EU countries in the context of circular economy. Further analysis is required to bring more light to circular economy dynamics within EU in order to develop targeted policies and strategies that can help harmonize CE efforts among EU countries.

It should be noted that although decoupling method is widely promoted within the sustainability framework, it is not a panacea for addressing the deeper, systemic issues of overconsumption, environmental degradation, and the unsustainable nature of current economic growth models. For instance, Voulvoulis (2022) suggests that the transition to a circular economy requires not only decoupling economic growth from resource consumption but also systemic changes in production, consumption, and waste management practices.

5. Conclusion

This study analyses the potential of decoupling economic growth from resource use through circular economy (CE) practices across EU countries. Our findings indicate significant variability in the success of these practices among different nations. Our decoupling analysis identified several countries, such as Luxembourg and Finland, that have achieved strong absolute decoupling. These nations have successfully increased their economic growth while reducing raw material consumption and environmental impact, demonstrating effective integration of CE practices. Conversely, other countries, including Czechia, Bulgaria, and Belgium, exhibited expansive negative decoupling, where economic growth resulted in increased environmental pressure and resource consumption. The evaluation of decoupling stages using MUR and GDP further highlighted the varied progress among EU countries. While a group of nations showed commendable achievements in balancing economic growth with environmental sustainability, others struggled to mitigate the environmental impacts of their economic activities. Notably, the largest group of countries achieved expansive negative decoupling, indicating the need for improved CE strategies to balance economic and environmental goals.

Currently, the concept of the circular economy appears to be one of the effective ways to implement sustainable practices into production processes. However, it is evident that current economic growth is based on the utilization of basic resources. The question remains whether European society can maintain its level of economic growth while simultaneously reducing the resources needed to achieve it. Our results show that it is possible, and that countries with higher economic growth have managed to reduce resource consumption and achieve absolute decoupling. In the EU's efforts to pursue the sustainability goals, EU countries retain their own specificities in the way they could achieve them. This is also reflected in our results, and there is also considerable heterogeneity among European countries in their economic performance. Such variability demands a nuanced approach, requiring tailored strategies rather than blanket solutions, but individual countries can inspire each other and share "best practice" in approaches and methods of achieving sustainability goals as well as in the process of establishing environmental strategies. Another area of our interest will be to monitor whether these procedures, practices, and methods aimed at achieving absolute decoupling are transferable and applicable across European countries, and to what extent European countries can gradually build economic growth and development based on circular resources.

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