ИКОНОМИЧЕСКИ ИЗСЛЕДВАНИЯ
ECONOMIC STUDIES

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Volume 32(3), 2023

CIRCULAR USE OF MATERIALS: DRIVERS OF THE CIRCULARITY RATE IN THE EUROPEAN UNION[2]

In the transition to a greener economy, countries need suitable indicators to follow progress on sustainability. One such metric, the 'circularity rate', indicates the share of recovered resources used in the economy which substitute for primary raw materials. The current paper analyses 27 European Union member countries to study the effects of selected waste management and resource efficiency indicators as well as several socio-economic determinants on the circularity rate. Results indicate that four factors emerge as equally important – GDP per capita, research and development expenditure, resource productivity and environmental tax revenues, where past values of R&D expenditure and resource productivity are especially useful in predicting the circularity rate. The research findings also emphasise the importance of adequate environmental taxation policy and its role in driving circularity. Finally, suggestions for future research on the topic are made to expand the model and allow for comparisons with other countries on their path to a circular economy.
Keywords: Circularity rate; Circular economy; Resource efficiency; Recyclable materials; Environmental taxation
JEL: H23; O13; Q53; Q56

1. Introduction

Unsustainable production and consumption practices throughout the years have continuously supported the unhealthy exploitation of environmental, social, and economic resources. Overpopulation, overconsumption, deforestation and desertification extend society's demand on nature beyond planetary limits. A system which puts quantity over quality causes natural resource depletion, waste and pollution (Bocken, Short, 2021). This practice requires huge energy inputs and leads to ecosystem disruptions. Together with diminishing resources, it lowers the resource productivity of many industries and increases long-term costs for both humankind and the environment (Villena, 2018).

The circular economy aims at breaking this pattern with its restorative and regenerative nature (Ellen MacArthur Foundation, 2022). It is a system that minimises the input of energy

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[2] This paper should be cited as: *Pantcheva, R. (2023). Circular Use of Materials: Drivers of the Circularity Rate in the European Union. – Economic Studies (Ikonomicheski Izsledvania), 32(3), pp. 148-161.*

and materials as well as waste and pollution through practices such as eco-design, repair, reuse and recycling. The circular economy is often viewed as a necessary condition for sustainable development, which in turn balances social, economic, and environmental interests at present without compromising the welfare of future generations (Geissdoerfer et al., 2017). The wide scope and lack of a precise definition of the circular concept make it difficult to assess using a single indicator. Saidani et al. (2019) review 55 circular economy indicators, while Parchomenko et al. (2019) propose a taxonomy of 63 metrics, divided into resource-efficiency, product-centric, material-stocks and material-flows clusters. The majority of indicators appear to be associated with the preservation of materials (Moraga et al., 2019). This dimension, however, fails to account for energy, land and water management, environmental impacts, product lifecycle, institutional and social factors (Llorente-González, Vence, 2019). Material-related metrics are more easily comprehensible, but they may actually reduce material consumption at the cost of social, economic, and environmental welfare (Corona et al., 2019). One of the reasons is that resource-efficiency metrics target the reduction of used resources but are not directly aimed at the circulation of products and materials (Bocken et al., 2006).

Waste recycling and recovery goals promote waste reduction, but they only partially recover materials and energy (Morseletto, 2020). The recycling rate, for example, indicates the share of recycled waste in the total amount of solid municipal waste. It acts as a promise that a certain fraction of the generated waste will be transformed into a secondary resource. However, it does not guarantee the actual recovery and preservation of the original quality (Moraga et al., 2019). To enhance the circular transition, recycling and material substitution targets should be combined to ensure the share of renewable or secondary materials in products (Fellner, Lederer, 2020). Moreover, although waste recovery is indeed a pillar of the circular economy, secondary materials are of little use without a well-developed market for recycled raw materials (Sagan, Sobotka, 2021). These materials need a proper collection and distribution infrastructure to be safely delivered to the demand side without posing an additional threat of contamination (Tansel, 2020).

The circular economy monitoring framework developed by the European Commission covers four categories: production and consumption, waste management, secondary raw materials, and competitiveness and innovation (Eurostat, 2022a). In an attempt to create a single macroeconomic circular indicator, Eurostat has developed the *circular materials use rate*, known as the *circularity rate*. It measures the share of domestically recovered materials, including biomass, metal ores, non-metallic minerals and fossil energy materials, which are re-fed into the economy. The circularity rate is used as an approximate measure for circular economy in a few previous studies (Giannakitsidou et al., 2020; Kumar et al., 2021; Neves, Marques, 2022).

This research paper conducts an econometric analysis of 27 European countries from 2010 to 2019. Its main purpose is to identify important factors that promote the circularity rate among a set of macro-level indicators related to socio-economic and sustainable development. Understanding circularity drivers is beneficial to society, businesses and policymakers on their path to a circular economy. Below, five initial hypotheses are formulated.

H1: GDP per capita as an approximation for economic development has a significant positive impact on the circularity rate.

H2: Research and development expenditure as an approximation for innovation has a significant positive impact on the circularity rate.

The first two hypotheses are used to confirm previous research findings (Kostakis, Tsagarakis, 2021, 2022) by expanding the set of countries included in the analysis. Hypotheses 3-5 are developed based on reviewed literature and tested for the purposes of the current study.

H3: Resource productivity has a significant positive impact on the circularity rate.

Resource productivity enhances resource efficiency by reducing the input of primary raw materials for the same production level and thus increases the circularity rate (Lehmann et al., 2022).

H4: The environmental tax revenues influence the circularity rate positively.

According to Tchorzewska et al. (2022), low ecotaxation does not prove effective unless in combination with public financing. However, with increasing levels, it acts as a positive stimulus for green investment, respectively, as a circularity enabler. Another study on environmental taxes finds that a linear tax is preferred to a constant or a zero tax, and promotes sustainable product design that prevents wastes, reduces the environmental impact and brings additional social benefits (Cai et al., 2022). Delving more deeply into the matter, Kim et al. (2017) show that if the tax is imposed on the resources supplier instead of the manufacturer, an increasing tax burden may not stimulate innovation and that better results are obtained under a cost-sharing model. However, excessive tax levels do not prove beneficial in either case, which should be a key assumption in optimising taxation policies.

H5: Government effectiveness is positively correlated with the circularity rate.

A stable and effective government is vital for the creation of a healthy business environment, sound environmental policies and social involvement to facilitate the transition to a circular economy (Cramer, 2022).

2. Data and Methods

Most research on circular economy indicators focuses on the recycling rate as a simple, understandable and easy-to-communicate metric. Recycling rates do influence circularity, but there are additional factors, such as renewable energy, sustainable production and product life extension, that further improve it (Eurostat, 2022b). There are few previous studies on the circularity rate in particular. Kostakis and Tsagarakis (2021) outline the positive impact of GDP per capita, R&D expenditure, the fertility rate, higher education, environmental taxes and urbanisation. In a later study, they confirm the role of economic growth and innovation. They also discover a positive influence of entrepreneurship and social development (Kostakis, Tsagarakis, 2022). Neves and Marques (2022) suggest that the age distribution of the population may also play an important part in the circular economy as older people usually display change-averse behaviour and are less likely to quit the 'take-make-waste' approach.

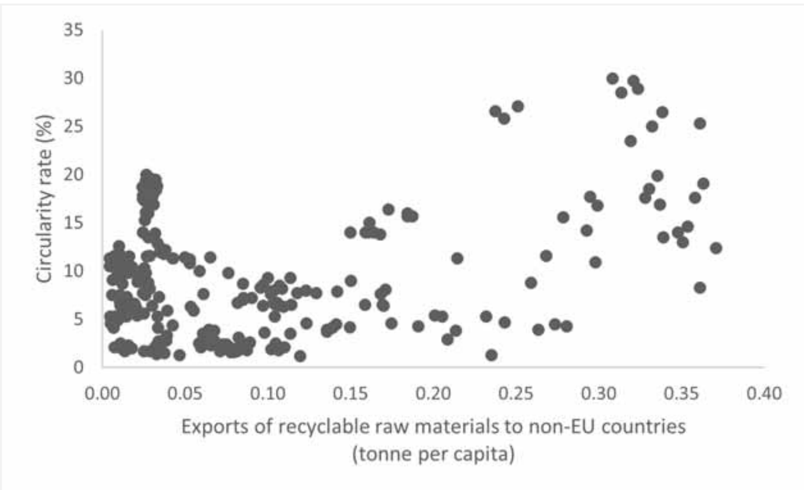
The circularity rate is calculated using the following equation:

$$CMU = \frac{U}{DMC + U} = \frac{(Rw - IMPw + EXPw)}{DMC + (Rw - IMPw + EXPw)} \quad (1)$$

In equation (1), *CMU* stands for circular materials use. Domestic material consumption (*DMC*) is used as an approximation for raw material consumption in the economy. *U* is the amount of re-fed materials, which is approximated by the amount of recyclable waste sent to domestic recovery plants. For this purpose, domestically recycled waste — R_W (excluding energy recovery and backfilling) is corrected by IMP_W (amount of imported waste for recovery in domestic plants) and EXP_W (amount of waste exported for recovery outside the country) (Eurostat, 2018). Therefore, the substitution of primary raw materials with secondary raw materials saves the extraction of primary resources as long as the total amount of materials used by the economy remains unchanged.

Richer countries usually generate less biowaste and more packaging waste, while the situation in low-income countries is the exact opposite (Kaza et al., 2018). Some countries that produce recyclable waste, however, cannot deal with it and export it for recycling abroad. Trade in recyclables manages wastes and supports the supply of raw materials. Yet, the impact on material circularity is questionable since recyclable wastes are unusable until they undergo recovery procedures (Llorente-González, Vence, 2019).

Figure 1. Circularity rate in EU-27 as a function of exports of recyclable raw materials to non-EU countries (2010-2019)

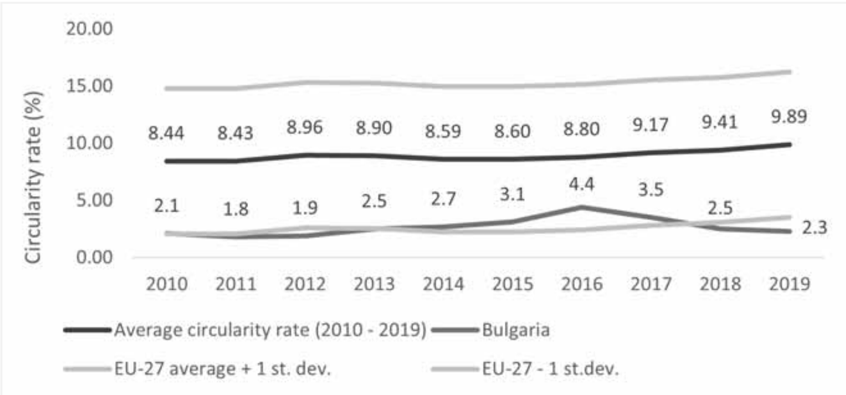


Source: Eurostat, 2022a.

Although the export of recyclable raw materials is beneficial to limiting primary resources extraction and promoting circularity, as seen in Figure 1, there are some adverse effects to consider. Developing countries, which are usually recipients of such wastes, often burn or landfill them instead of recycling them, which is a step back from the circular economy. Still, exports to non-European countries are significantly increasing over the years (Eurostat, 2022a). With this regard, one of the primary EU waste goals should be to deal with European waste domestically and not via exports to low-income countries (European Commission, 2010).

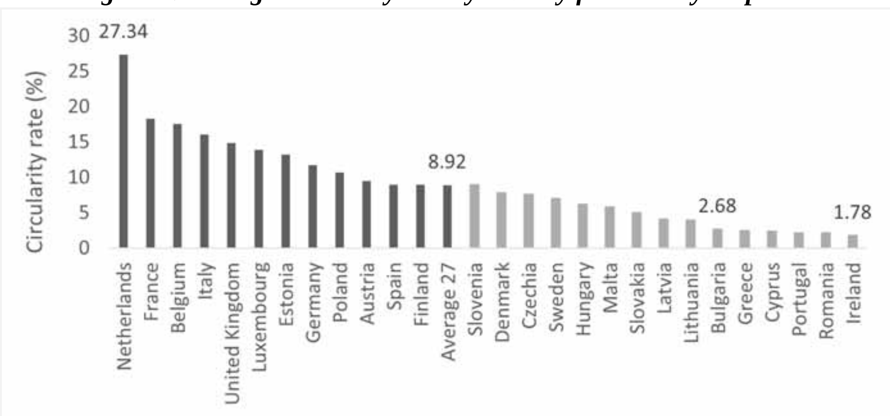
The current analysis begins with a review of basic tendencies among 27 European Union countries in recent years (Figure 2 and Figure 3). All member states are included except for Croatia, which joined in 2013 and data from previous years are scarce. The average circularity rate increases over the period by approximately 17% and displays steady growth, especially since 2015. As seen in Figure 3, the average circularity rate over the 10-year period is approximately 8.9%. The Netherlands leads the way, followed by France and Belgium, while Ireland, Romania and Portugal score the lowest. Bulgaria consistently displays a low circularity rate throughout the years. The years 2015 and 2016 mark a slight improvement, but 2018 sets a downward tendency.

Figure 2. Average circularity rate for the 27-EU countries by year (2010-2019)



Source: Eurostat, 2022a.

Figure 3. Average circularity rate by country for the 10-year period



Source: Eurostat, 2022a.

The year 2015 marked an important step up in the European Union climate policy. It was when the Paris agreement was signed, aimed at limiting global warming below 2 degrees Celsius. The same year the European Commission adopted the initial circular economy action plan, paving the road to a transition from linear to circular economy. It proposed certain actions to change production and consumption practices, close the loop, limit waste and pollution and bring about economic, social, and environmental benefits.

This study adds to existing knowledge by testing a new set of factors that potentially affect the circular materials use rate. Table 1 presents the independent variables which cover aspects, such as waste management, resource efficiency and socio-economic development.

Table 1. Description of used variables

Independent variable	Unit of measure	Description
Energy productivity	PPS per kgoe (kilograms of oil equivalent)	The indicator is the result from the division of GDP by the gross available energy for a specific calendar year.
Environmental tax revenues	Percentage	The indicator is measured as the share of environmental tax revenues in GDP.
Gross domestic product	PPS per capita	GDP per capita is the ratio of GDP to the average population in a specific year. It measures the value of the total output of goods and services produced by an economy and the purchasing power standards expression allows for comparisons among countries.
Greenhouse gas emissions (GHGE) intensity of energy consumption	Index	The indicator is calculated as the ratio between energy-related greenhouse gas emissions and gross inland consumption of energy. It expresses how many tonnes of CO_2 equivalents of energy-related greenhouse gases are emitted in a certain economy per unit of energy consumed.
Government effectiveness	Index	The index reflects perceptions of the government's performance.
Recycling rates of: – glass packaging – metallic packaging – paper and cardboard packaging – plastic packaging – wooden packaging	Percentage	The indicators are defined as the share of recycled packaging waste in all generated packaging waste.
Research and development expenditure	Percentage	The indicator shows gross domestic expenditure on research and development (R&D) in business, government, higher education and private non-profit organisations, expressed as percentage of GDP.
Resource Productivity	PPS per kg	The indicator reflects the GDP generated per unit of resources used by the economy.
Trade in recyclable raw materials: – imports from EU countries (imports-intra) – imports from non-EU countries (imports-extra) – exports to non-EU countries (exports-extra)	Tonnes per capita	The indicators are calculated as the ratio of traded amounts to the average population in a specific year. Quantities include plastic, paper and cardboard, precious metal, iron and steel, copper, aluminum and nickel that are shipped between the EU members states and across the EU borders.
Municipal waste generation	Kg per capita	Municipal waste is mostly produced by households, commerce, offices and public institutions.
Share of children and young people	Percentage	The indicator reveals the share of people below 18 years of age in the total population.

Source: Eurostat, 2022a; GOV.UK, 2022; The World Bank, 2022.

Most of the variables are sourced from Eurostat (2022a). The only exceptions are the *recycling rates of packaging waste* of the United Kingdom (GOV.UK, 2022) and *research and development expenditure* (The World Bank, 2022).

The *energy* and *resource productivity* indicators relate to decoupling economic growth from energy consumption and the use of natural resources, respectively. *GDP* accounts for economic development, while R&D is an approximation of innovation. The *trade-in recyclable raw materials* (TRRM) is part of the 'secondary raw materials category', which follows progress on the reuse of materials, prevention of primary resources extraction and security of raw materials supply.

3. Results

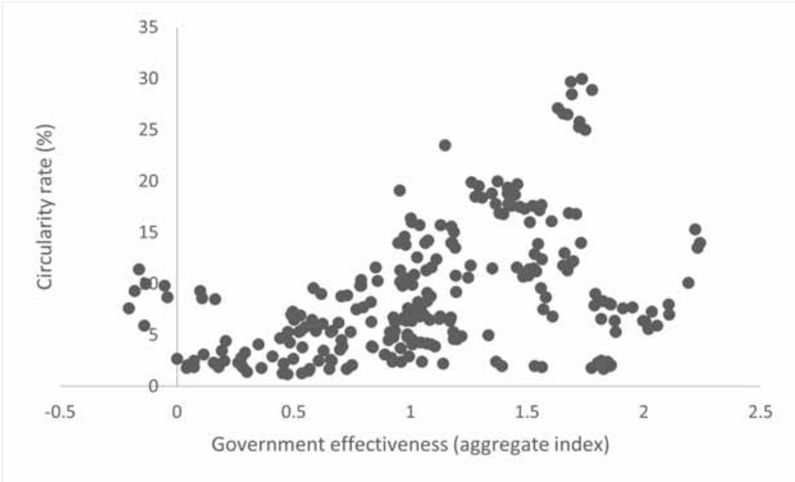
First, correlations among the variables are reviewed to gain a general understanding of their relationships. The correlation analysis suggests no potential multicollinearity issues. The strongest positive correlations are between the *circularity rate* and *resource productivity*, *research and development expenditure*, *government effectiveness*, the *recycling rates of glass and metallic packaging*, *GDP per capita* and *TRRM (exports-extra)*. *Government effectiveness* displays a moderate positive correlation of 43% with the circularity rate, which supports H5 as seen on Figure 4. However, this variable does not find a place in the final model and neither does the *recycling rate of glass and metallic packaging* or *TRRM (exports-extra)*.

All variables are log-transformed to achieve close to normal data distribution and improve data quality. To determine the order of integration, unit root tests on the variables of interest are performed. The results show that most variables are non-stationary, but the unit root is overcome after the first difference, which means the data are integrated of first order. The KAO panel cointegration test indicates that the series have a long-run equilibrium which rejects the possibility of spurious relationships. Therefore, a Granger causality test is performed to examine potentially significant factors. Table 2 presents the two significant outcomes of the Granger causality tests using the first differences of the log-transformed variables.

The null hypothesis of the test is that the specific variable does not Granger cause the *circularity rate*. For both *research and development expenditure* and *resource productivity,* the null hypothesis can be rejected at 1% significance level. This means that past values of *research and development expenditure* and *resource productivity* can help predict the dependent variable.

Considering the information so far and following a forward selection procedure, an initial panel regression model is constructed. Table 3 presents the regression output results. Model A shows the specifics of a mixed OLS panel regression model. It indicates that *R&D*, *resource productivity* and *environmental tax revenues* explain the variations in the European circularity rate well. Results show that innovation, which is approximated by *research and development expenditure*, promotes circularity, as stated in previous studies. However, despite the significant coefficient of *GDP per capita*, it enters the model with a negative sign, contradicting earlier expectations.

Figure 4. Circularity rate in EU-27 as a function of government effectiveness (2010-2019)



Source: Eurostat, 2022a.

Table 2. Granger causality test in first differences

Independent variable	F-statistic	P-value
Δ R&D expenditure	5.476	0.005
Δ Resource productivity	8.381	0.000

Number of observations: 189. Number of lags: 2. Δ signifies 'difference'.

Table 3. Regression models

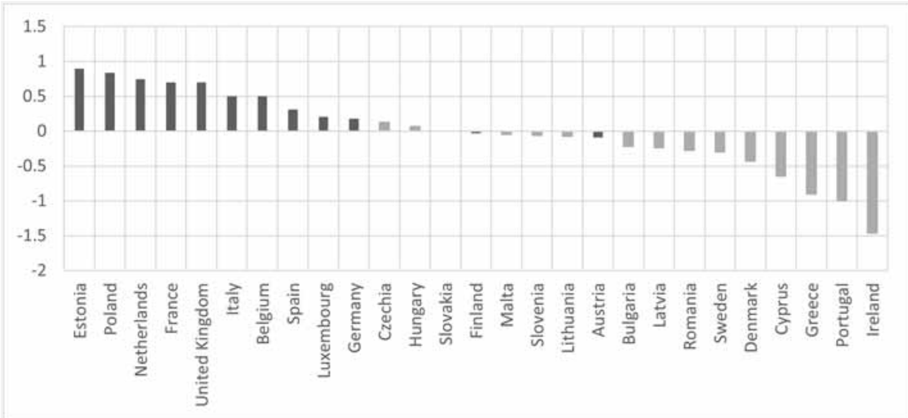
Coefficient	Initial model	Corrected model
GDP per capita	-0.349*** (0.138)	0.336** (0.146)
R&D expenditure	0.722*** (0.069)	0.388*** (0.076)
Resource productivity	0.877*** (0.096)	0.358*** (0.097)
Environmental tax revenues	0.177 (0.136)	0.460*** (0.146)
Intercept	4.606*** (1.389)	-2.241 (1.521)
R	0.723	0.968
R-squared	0.522	0.937
Adjusted R-squared	0.515	0.929
No. observations	270	270
Periods included	10	10

All variables are log-transformed. Standard errors are reported in parentheses.
****, ** and * indicate significance at the 1%, 5% and 10% level, respectively.*

The same model is then run with cross-section and period-fixed effects. The redundant fixed effects test rejects the period fixed effects, which leaves only the cross-section fixed effects. The cross-section dependence test points to the possible presence of cross-sectional dependence. To correct for that, the model is estimated using White cross-section (period cluster) method that is robust to cross-sectional correlation and heteroskedasticity. The output from the final estimation is presented in Table 3 under Model B. It corrects the negative sign and confirms the significance of the other variables. Here, all four factors emerge as equally influential, with a slightly larger positive effect of *environmental tax revenues*.

Model B also introduces a fixed constant term which indicates a country-specific level of the circularity rate, depending on individual characteristics which are defined outside the model.

Figure 5. Country-specific fixed effects



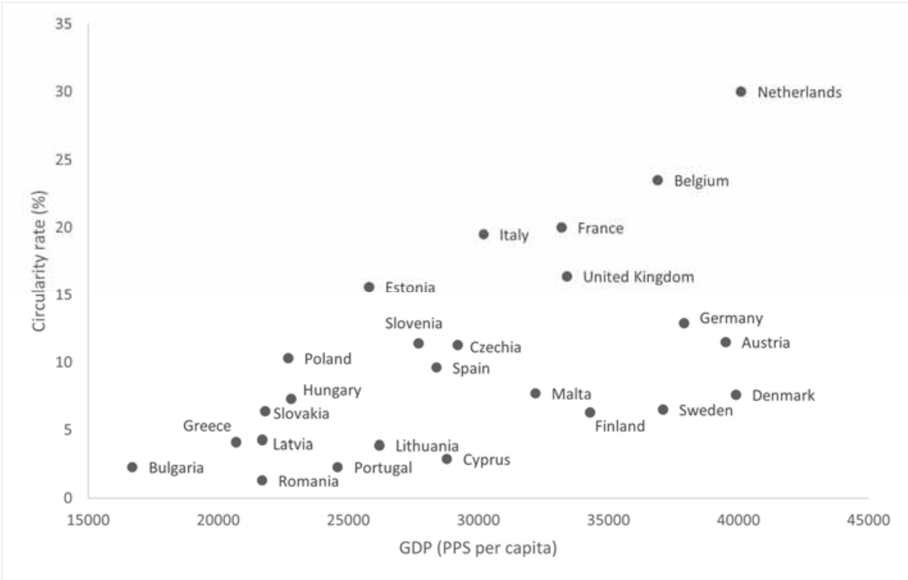
As seen from Figure 5, Austria and Finland, which are otherwise countries with above-average circularity rate, here demonstrate a negative country-specific constant. A possible explanation of this phenomenon is that both countries demonstrate below-average resource productivity and exports of recyclable raw materials for the studied period. They also generate more solid municipal waste than the EU average.

4. Discussion

Economic growth across most European Union countries is still fueled by the input of natural resources and capital, which strains planetary limits. Developed countries are not yet decoupled from the use of primary raw materials, but they are gradually shifting from heavy industry to services. Higher GDP means better living standards, healthier business climate and new job opportunities. This enhances a more productive use of assets, while higher tax revenues and private investment can be directed to improve resource productivity, waste prevention, collection, and recycling technologies, thus promoting circularity. Model B shows that a 1% rise in the GDP of a country can potentially increase its circularity by 0.34%. Figure 6 displays the relationship between the circularity rate and GDP per capita in 2019.

Luxembourg and Ireland are removed as outliers. The above-average circularity section is predominantly occupied by Western, Central and Northern European countries, with the addition of Italy and Spain, which are also among the most competitive European economies. It can be seen that most countries which have joined the European Union at a later stage reside primarily in the lowermost region of the scatterplot. This is an indication that countries, especially less economically developed ones, which have started implementing green European policies more recently, still struggle to make considerable progress with respect to the circular economy.

Figure 6. Circularity rate in the EU as a function of GDP per capita in 2019



Source: Eurostat, 2022a.

Research and development is a source of knowledge for the creation of new products, services and technologies or the improvement of existing ones. R&D is closely linked to innovation and not only provides a competitive edge to businesses but also plays a key role in reducing materials and energy consumption as well as the environmental footprint. Innovation in product design and recycling as a result of research and development improves the material recovery process (Sagan, Sobotka, 2021). The estimated models also suggest that R&D is a significant determinant of circularity. For example, Model B indicates that 1% increase in research and development expenditure can increase circularity by up to 0.39%.

Sustainability requires a permanent reduction of inputs and wastes. Another driver of circularity is the resource productivity. As suggested by the final model, it is as important as economic development and R&D investment. Improved resource productivity means that the economy becomes even more competitive as it manages resources and pollution efficiently and limits environmental risks. Producing more with less decouples economic growth from the use of exhaustible resources and reduces raw materials consumption. This is a key prerequisite for promoting the circular economy because higher circular use of materials does not necessarily indicate sustainability. As the overall input of materials increases on a global scale, the circularity rate cannot prove useful in tracking progress towards circularity if the use of secondary and primary raw materials increases at a similar pace.

Environmental damage can be limited to some extent with the use of environmental taxes. They are directly linked to the 'polluter-pays-principle' and are intended to tax production and consumption practices that threaten environmental health. Such taxes can be related to energy and materials, transport or pollution. Green policies regarding environmental taxation provide incentives to increase efficiency and switch to renewable resources and environmentally friendly technologies by putting a price on the generation of negative externalities. Moreover, revenues from environmental taxes can be used to subsidise the recycling and recovery industry, thus enhancing the circularity rate (Freire-González et al., 2022). In fact, while the four factors appear equally influential, the share of environmental tax revenues in GDP stands out as having a somewhat higher impact on circularity. According to Model B, a positive change of 1% has the potential to raise the level of circularity by 0.46%. This positive effect can have two possible explanations. First, higher revenues can result from larger environmental taxes imposed on producers and consumers who cause negative externalities. This can stimulate them to reduce the use of primary raw materials and improve resource recovery. Second, the additional income can be distributed towards environmental restoration, the increase of resource productivity and waste prevention, or towards the improvement of recycling and recovery processes. It should be noted, though, that higher environmental tax revenues can signal that rates are too low and more environmentally damaging products and services are produced, which offsets the positive effects of sustainable investment.

The empirical findings of this study should be considered in light of some limitations. First, the little prior research on the topic of circularity rate made it difficult to assess a larger set of potentially influential factors to form a deeper understanding of its role in tracking circular progress. Second, data availability limited the scope of the study in two ways: time range and a number of countries. Information about the circularity rate and several other indicators for most countries was limited to the period 2010 – 2019. Data was also scarce for non-EU members, which further influenced the sample size and did not allow for comparisons among EU and non-EU countries. These limitations, however, present an opportunity for further research that can account for the effect of the Covid-19 pandemic and the economic crisis, as well as the revisited targets and financial incentives related to the European Green Deal. Moreover, if data availability allows, this study can be carried out for other European countries, Asian countries, or the USA in order to make comparisons.

5. Conclusion

Unlike other material sustainability indicators, the circularity rate is representative of the actual recirculation of materials. Recycling and recovery, for example, stimulate the reduction of waste, but materials are only partially recovered. Therefore, material recovery and resource efficiency are key determinants of circular progress. In order to effectively distribute secondary raw materials among all potential stakeholders, an efficient secondary materials market is needed. A proper distribution network for secondary materials and the introduction of material substitution targets have the potential to significantly enhance the circular performance of countries.

The exports and imports of recyclable raw materials as building components of the circularity rate have an important role in balancing the world supply and saving primary resource extraction. Increasing exports from the European Union to non-EU countries indeed prove beneficial to EU member states. However, what happens to the recyclable materials, especially in developing countries, lacks transparency. Considering the possible incineration or landfill disposal of such materials, exports should be internalised in the EU in order to prevent pollution in low-income countries.

The study results support all five initial hypotheses. Economic development has a key role in promoting circularity through a stable business environment, higher private and public green investment and better waste management services. More R&D expenditure demonstrates a similar positive effect along with higher resource productivity, which allows economies to produce the same level of output by reducing inputs. Additionally, government effectiveness may not have a direct impact on the circularity rate according to the research model, but it is indeed positively correlated with circularity and indirectly increases the efficiency of policies that promote green investment and innovation.

This study adds to existing knowledge by showing that past levels of R&D expenditure and resource productivity help predict the circularity rate and results also reveal the importance of environmental taxation. The environmental tax revenues influence the circular use of materials positively and this factor emerges as having a somewhat higher impact than the rest.

As the current study outlines key circularity drivers, the results may prove beneficial to producers, consumers and policymakers as well as other researchers. Public and private investment in R&D is linked to improved resource productivity which enhances economic competitiveness and economic growth. Producer and consumer decisions often create negative externalities. In this respect, policymakers should optimise ecotaxation to avoid low or excessive rates. These should increase progressively, matching the degree of environmental impact. It should also be noted that environmental taxation alone cannot control environmental impacts and promote circularity. Governments should push for an increase in environmental awareness, a healthier business environment to promote sustainable growth, and stricter regulation of polluting activities.

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