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Energy market dynamics and institutional sustainability: How affect the Europe's circular economy

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ABSTRACT

This paper considers socioeconomic, environmental, institutional and demographic issues necessary for the circular economy (CE) transition, employing a sample of 27 European Union (EU) countries and the UK using panel data method. Environmental degradation, asymmetry and inequality in the recovery conditions from the COVID-19 pandemic, which have been particularly aggravated over the last three years (2019—2022), as well as the energy crisis in the Eurozone raise significant challenges for social cohesion and CE policies. This analysis aims to examine whether a change in the structure of the energy markets, densely populated areas, environmental performance, institutional quality, social protection and innovation affect the CE. The results reveal that circular activity is robustly and positively affected by factors such as institutional quality, resource productivity and entrepreneurship. As the level of social protection increases, the percentage of the population willing to adopt the CE principles increases, while EU countries consume more raw materials than they can actually recycle. An increase of 1% in the market share of the largest electricity production companies and the market share of companies supplying the largest volume of natural gas is linked to a reduction of 0.30% and 0.33%, respectively, in the circularity rate. This suggests that under imperfect competition in energy markets, there are signs of undermining the efforts of EU countries to collect waste for recovery.

1. Introduction

The global economic system, as characterized today by the rapid increase in consumerism, is no longer sustainable. Since the Industrial Revolution, the adoption and adherence to linear practices have resulted in the depletion of natural resources. In response to the sustainability challenges presented, Sustainable Development Strategies Frameworks were designed to delineate business planning processes, which included guiding the transition from a traditional linear production function to a circular one (Broman & Robèrt, 2017). To do so, the principles of circular economy (CE) are considered an appropriate tool which has recently risen to prominence in modern economies. The CE is a novel concept aimed at closing, narrowing and slowing material loops and achieving sustainability goals by enhancing economic, environmental and social outcomes. Circular models are considered appropriate to address contemporary environmental problems such as scarcity of resources, soil degradation, mismanagement of waste, the inability of the system to tackle the overconsumption of water resources and energy inefficiency (Su et al., 2013).

There is no widespread consensus on the content of the circular economy by academics who at first considered CE was similar to the recycling economy with waste that would be transformed into products which would then, through appropriate material transformation, be fully recycled. Although this is the approach taken by many schools of thought (e.g., cradle to cradle, performance economy and industrial ecology) and scientific fields (e.g., environmental economics, industrial economics and engineering), the

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delimitation of CE dimensions dates back to a symposium held in Oslo (1994) by the Norwegian Ministry for the Environment. UN environmental program highlighted that sustainable patterns of production and consumption were defined as “the use of goods and services that meet basic needs in order to improve quality of life and to minimize the over-exploitation of natural resources during the life cycle”. At a very early stage, the CE is considered an appropriate tool to foster economic growth (Busu & Trica, 2019) and sustainable waste management (Halkos & Aslanidis, 2023), although criticism is raised of becoming a hypothetic-normative utopia (Corvellec et al., 2022). Later, the application areas (micro-level, meso-level, and macro-level) are also defined based on a bottom-up approach. For this reason, participative governance is of paramount importance to reestablish and provide suitable labor conditions along with a lower throughput of raw materials (Moreau et al., 2017).

The 3Rs model (Reuse, Recycle and Reduce) was one of the first operational approaches of CE. Unlike the closely delimited recycling of waste, the focus of circular strategies has shifted from waste management to material life extension (Blomsma & Brennan, 2017; Den Hollander et al., 2017; Niero et al., 2021). The core of circular thinking as an eco-economy stresses the need to reduce resource use, comply with ecological criteria while protecting and facilitating the proper exploitation of natural resources to achieve sustainable growth (European Commission, 2012). Through reusing and new recycling formulas, the CE seeks to minimize the resources going into production processes through the necessary transformation (Stahel, 1997).

One of the fundamental pillars of CE is that end-of-life product waste streams need to be integrated in the industrial food supply chain as a material and energy flow (Veleva et al., 2015). The transformation and exploitation of waste as inflow to other areas is only achieved through processes which enable the closing of material and energy cycles, maximize waste exploitation and minimize the suboptimal use of critical and scarce materials moving towards a “zero waste” society (Ghisellini et al., 2016). Tools from industrial ecology and ecological economics (Bruel et al., 2019) have been incorporated in its conceptual and regulatory framework such as material flow analysis, cradle to cradle design (McDonough & Braungart, 2002) and performance economy, designed for waste reintegration during the production process (Murray et al., 2017; Pomázi & Szabó, 2021; Stahel, 2013). The first hierarchical principle towards achieving the 3R principles is to reduce waste generation by using resources efficiently. This can be achieved by designing products that use fewer materials, minimizing packaging and reducing energy consumption (Preston, 2012). The second principle is to reuse products and materials as much as possible by exploring new ways to utilize them, such as by repurposing or sharing, to extend their useful life. Its fundamental approach involves maximizing the useful life of every product, such as through sharing among multiple users, followed by refurbishing it for a new purpose, as in, for example, a second-hand market.

The next principle involves disassembling and repairing critical components to enable their extended useful life in the case that the entire product cannot be refurbished. The 3R model (known as the 4R model) has recently been extended by an additional principle—Repair—which emphasizes the importance of extending the useful life of products. Therefore, the third principle also includes ways to repair products, which can reduce waste, conserve resources and create job opportunities in repair and maintenance industries. Finally, recycling principles include materials that cannot be repaired or reused by breaking them down and turning them into new products. The applicability of CE principles in the economy has emerged over the past few years even through public procurement processes (Alhola et al., 2019) in response to decoupling economic growth from environmental degradation and suboptimal use of resources (Bocken et al., 2016; Geissdoerfer et al., 2017; Korhonen et al., 2018; Su et al., 2013). In the CE, reuse and recovery actions promise larger potential impacts than conventional recycling which is characterized by limited circularity, quality and value. In this way, both the demand for raw materials at the beginning of the production process (Fellner et al., 2017) and the volume of waste generated at the end of the production process can be reduced to an ‘end-to-end’ approach (Stahel, 1997). During the process of minimizing and counterbalancing the negative externalities, the most efficient capitalization of resources (Figge et al., 2022) and the drop of unnecessary demand and CE rebound effects (Font Vivanco et al., 2022; Zink & Geyer, 2017) lead to crucial issues either in terms of reduction or even in terms of waste hierarchy (Stahel, 2013). On this basis, the circular approach has often been used as “a general term that encompasses any 4R initiative involved in the process of production, and consumption” carried out in the single market incorporating inter alia “practices for the recycling of municipal waste” (Ghisellini et al., 2016; Schroeder et al., 2019). Adopting the 4R principles underlines the need for repeated circularity capable of promoting ecological stability and economic efficiency (Webster, 2013). It is worth noting that CE constitutes an approach for the promotion of the responsible use of resources (Moraga et al., 2019; Su et al., 2013) to achieve the goal of re-industrialization (EU, 2014).

In short, the CE has been established as a restorative and growth cycle (Morseletto, 2020) where natural capital can be maintained and enhanced, the attribution of resources can be optimized, and risks of the system can be minimized through policies and tools (Crespi et al., 2016). The CE model has been structured according to the resource-based approach, and therefore underlines at each level of declarations the importance of reducing raw material consumption and enhancing material productivity. New ideas, such as the sharing economy—the exploitation of natural capital through cooperative social stakeholders—have given rise and new orientation to lifecycle thinking (Korhonen et al., 2018). It is a development model that establishes a link between different ways of creating value and maintenance through recycling, reduction, reuse and recovery” while proposing a material transformation to enable separation and re-use after use (eco-design). Already since 2014, following the increasing interest of civil society and the need to develop a specific framework and a policy-relevant knowledge (Leipold et al., 2021), the CE has been established as a key determinant of achieving sustainability. An interesting finding is that material productivity is positively associated with increases even in wage rates (Flachenecker, 2018).

The lack of insights on the relationship between CE and energy market dynamics, institutional sustainability and demographic shifts is a significant gap in the existing literature since it fails to empirically explain the possible Bellagio process. According to Bellagio Declaration (2020), the whole process regarding monitoring the transition towards a CE need to holistically consider all relevant initiatives including the level of sustainability in economic, environmental and societal fields which make up the concept of institutional sustainability (Tantau et al., 2018) . To fill this gap, panel data estimation methodologies are applied to examine the relationship between circularity rate (as a proxy of CE) and energy markets' structure, material consumption, institutional quality, population density, resource productivity, social protection expenditures and entrepreneurial activity and whether are exhibiting short-term deviations from their long-run equilibrium for the period 2010–2021.

The remainder of the paper is organized as follows. Section 2 presents the literature review and the Research Questions (RQs) stemming from the theoretical dialogue; Section 3 presents the data and the methodology used in the empirical analysis. Section 4 presents the empirical results while Section 5 discusses the empirical findings of the paper and Section 6 concludes and outlines suggestions for further research. Table 1 provides a list of terminology related to the abbreviations used in this paper.

2. Literature review

Of late**,** CE has been considered a good tool to achieve sustainability goals. It is utilized to promote the principles of 'reduce, reuse, recycle, remanufacture and refurbish' at three levels of the economy - micro-, meso- and macro-levels. The first level includes the efforts made by firms to undertake initiatives and implement activities to avoid utilizing materials or extending the lifespan of materials used. The second level focuses on cooperation between firms which exchange materials and waste as raw materials with the most popular concepts being industrial symbiosis, industrial ecology and industrial metabolism. The third level relates to countries, cities and regions which adopt strategic plans to implement principles of CE to achieve waste reductions.

The majority of the literature has concentrated on examining CE at the company level, mainly by examining at firm level or among firms (first and second level). The third level is underexamined and only recently have some studies examined CE at a country level; here, an important index to measure the CE is the CMU, which is used by the European Union. A country's efforts to collect waste for recovery, which is of immense importance in Europe's concept of CE (Halkos & Aslanidis, 2023; McDowall et al., 2017), is reflected through the circularity material use rate (CMU). It is a represented index that is recommended from Eurostat in the Circular Economy Indicators database (https://ec.europa.eu/eurostat/databrowser/product/view/CEI_SRM030 accessed on May 23, 2023) and is defined as follows:

$$\mathrm{CMU} = \frac{\mathrm{U}}{\mathrm{M}}$$

where U denotes the quantity of waste recycled in domestic recovery plants which can serve as a substitute for primary raw materials, either directly or indirectly. M is the sum of the domestic material consumption (DMC) and the volume of waste treated (U). To understand the differences in CMU between European Union (EU) countries, it is necessary to first consider the effect exerted by the volume of waste treated (U) and domestic material consumption (DMC).

Fig. 1 is a graphical representation of the evolution of CMU along with the U and the magnitude of DMC providing evidence of the structural differences that arise from country to country in the EU panel. As can be seen, CMU tends to increase as U increases and at the same time, DMC decreases. In contrast, CMU decreases as U decreases and simultaneously, DMC increases. In most cases, the increase in CMU is mainly due to the proportionally larger decrease in DMC rather than to the proportionally larger increase in U. For example, in Belgium, France, Germany, Netherlands, Portugal and the United Kingdom, a relatively greater reduction in DMC leads to an improvement in CMU. Conversely, there are cases (Finland, Slovakia) where an increase in the volume of waste treated is accompanied by a decline in the levels of DMC, which, however, does not simultaneously imply an improvement in CMU but the opposite. This means that simply increasing the volume of waste treated may be insufficient to achieve higher levels of CE and that other factors, such as consumption patterns (Androniceanu et al., 2021), also need to be considered. It emphasizes the importance of understanding the complex relationships between different factors that affect circularity and the need for policies that take a comprehensive approach to promoting sustainability.

Within this discussion, an interesting research question arises.

RQ_1: Is there an association between domestic material consumption and circularity rate?

Resource productivity (RP) is included as a dependent variable in the empirical study of Robaina et al. (2020) which focuses on the investigation of CE determinants through a comparative analysis of the performance of EU countries for the period 2000–2016. The results show that a higher performance does not imply at the same time a higher growth rate of RP. In turn, Weisz et al. (2006) argue that in highly material-oriented economies, RP will be higher compared to the case of a country in which more tertiary sectors (services) participate in its productive structure. Elia et al. (2017) examine CE strategies by identifying indicators and methodological approaches for measuring environmental impact in industrial and service sectors (Kasztelan, 2020). Researchers conclude that resources' utilization is of immense importance to the effective implementation of the CE transition. Jiang (2011) attempts to estimate China's circular transition by focusing on Jiangsu, Heilongjiang, and Qinghai provinces. Although the levels of resource consumption are higher in Jiangsu, however, in combination with the social development index, they are associated with higher CE levels compared to Heilongjiang and Qinghai provinces. Moriguchi (2007) observes a decrease in RP over the years due to the increased imports for mineral structures. This is accompanied by a decrease in CMU. Pomázi & Szabó (2020) carry out a comparative analysis of the Visegrad countries' performance using indicators for DMC, RP and GDP. Researchers point out higher RP levels in Visegrad countries since the late 2000s. Robaina et al. (2020) noted that recycling rates are positively correlated with RP and especially for countries with high and medium resource efficiency growth rates. The higher the recycling, the higher the resource efficiency and the faster the economic growth with lower DMC. Finally, the empirical study by Pomázi and Szabó (2020) shows that the recycling rate in Hungary is slightly below the EU average as opposed to Czech Republic, Poland and Slovakia which are still deviating from the EU targets. The research question stemming from the theoretical dialogue is expressed as follows.

RQ_2: Is there an association between resource productivity and circularity rate?

RP and DMC are closely linked with the energy market's structure as energy is a critical input for the production and consumption of materials. At the same time, greenhouse gas emissions are mostly attributable to electricity production which is mainly generated from fossil fuels. As the International Energy Agency (2019) states, over 40% of all energy-related emissions stem from electricity generation. It is worth stressing that electricity and gas are homogeneous and divisible goods allocated according to a uniform price auction mechanism. Both purchasers and generators compete by simultaneous bid submissions to optimize their profits

Table 1
Terminology related to abbreviations.

Abbreviation	Terminology
CE	Circular economy
CMU	Circular material use rate
DMC	Domestic material consumption
U	Volume of waste treated
RP	Resource productivity
R&D	Research and development
POP	Population density

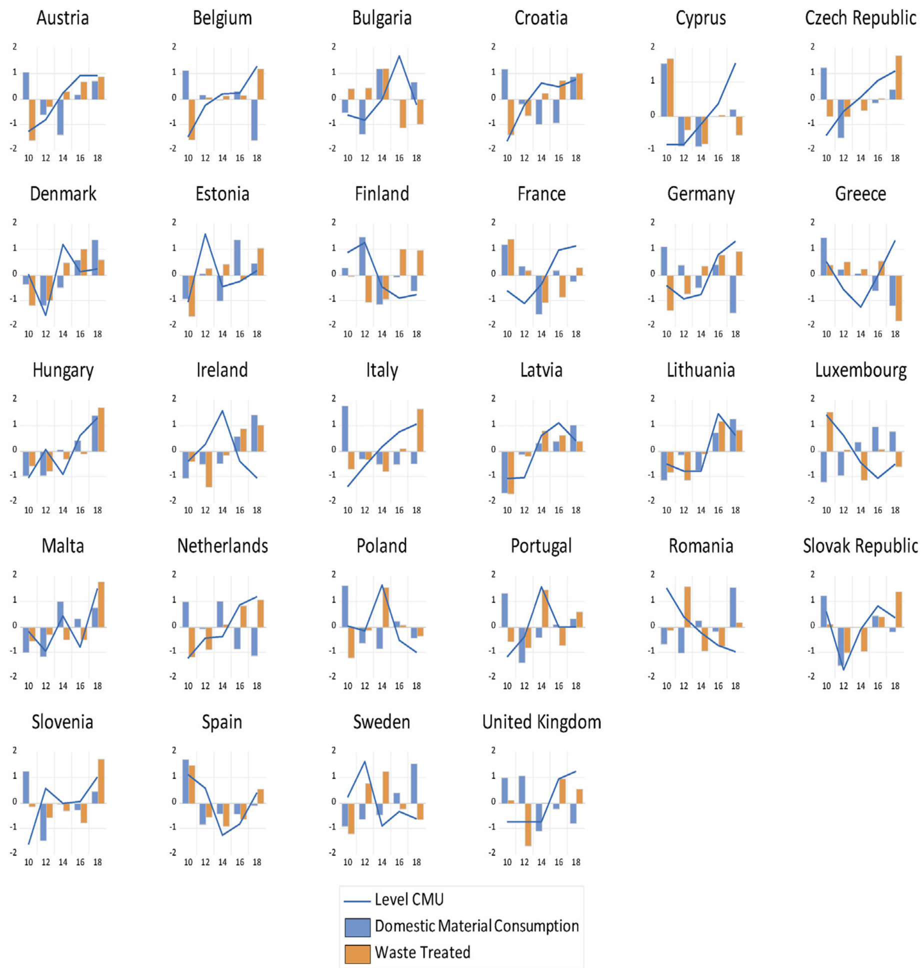

Fig. 1. CMU, volume of waste treated (U) and DMC in the EU (normalized data). (Note: Author calculations. CMU denotes circularity rate measured as the quantity of waste recycled in domestic recovery plants/the sum of the domestic material consumption (DMC) and the volume of waste treated (U) (source: Eurostat – Circular Economy Indicators).

while the price is cleared by the auctioneer. Focusing on the British electricity spot market, Green and Newbery (1992) detect a unilateral market power by assuming a non-cooperative game. In the case of a symmetric oligopoly, Klemperer and Meyer (1989) lay down the conditions for a univocal Nash equilibrium existence. To mitigate environmental threats, CE requires an energy transition in terms of accelerating decarbonization and a shift towards renewable energy sources and a low-carbon energy system. Dar et al. (2022) point out that natural gas consumption is negatively associated with CO_2 emissions and contributes to a lower carbon footprint.

However, there are practical barriers to CE implementation in economies, including linear decarbonization policies, cultural and regulatory obstacles, demographic challenges, environmental illiteracy and the structure of energy markets. These barriers are interconnected (Ghazanfari, 2023). When there is no threat of entries in energy markets, there is lack of competitive pressure and Bertrand-like competition which leads to an oligopolistic or even monopolistic behavior. A vertically integrated monopoly, as stated by Borowski (2020), is linked with the over-exploitation of fossil fuels. Eikeland (1998) notes that liberalized markets provide environmentally concerned actors with shared environmental responsibility. Lagendijk (2008) highlights the issue of an open internal electricity market to reduce the ecological footprint. The European Commission (2003) underlines the importance of a competitive energy market structure to enhance green transition and secure energy supply (Piebalgs, 2006). Kartal (2022) finds that the structure of the energy market might exacerbate environmental pressure leading to environmental degradation. Considering the related discussion, the following research question emerges.

RQ_3: Is there a relationship between the structure of the energy market and circularity rate?

Fig. 2 is a graphical representation of the evolution of the market share of the largest electricity production companies as a percentage of national production providing evidence of oligopolistic conditions that arise from country to country in the EU. As can be seen, the market share of the primary electricity generator varied among the EU Member States. In 2020, Cyprus recorded the highest share (100%) due to the dominance of a single electricity company in the national electricity production, followed by France (77.78%) and Croatia (75.71%). On the other hand, the largest electricity generator's market share was less than 20% in Italy (16%), Poland (17.37%), Luxembourg (17.90%), Sweden (19.10%) and Spain (19.84%). In comparison to 2013, the market share of the largest electricity generator in 2020 was lower in most EU countries, with a decline ranging from −40.45% in Luxemburg to −1.48% in Lithuania. However, the share remained stable in Cyprus and increased in Bulgaria, Czech Republic, Finland, Hungary, Poland, Romania and Sweden.

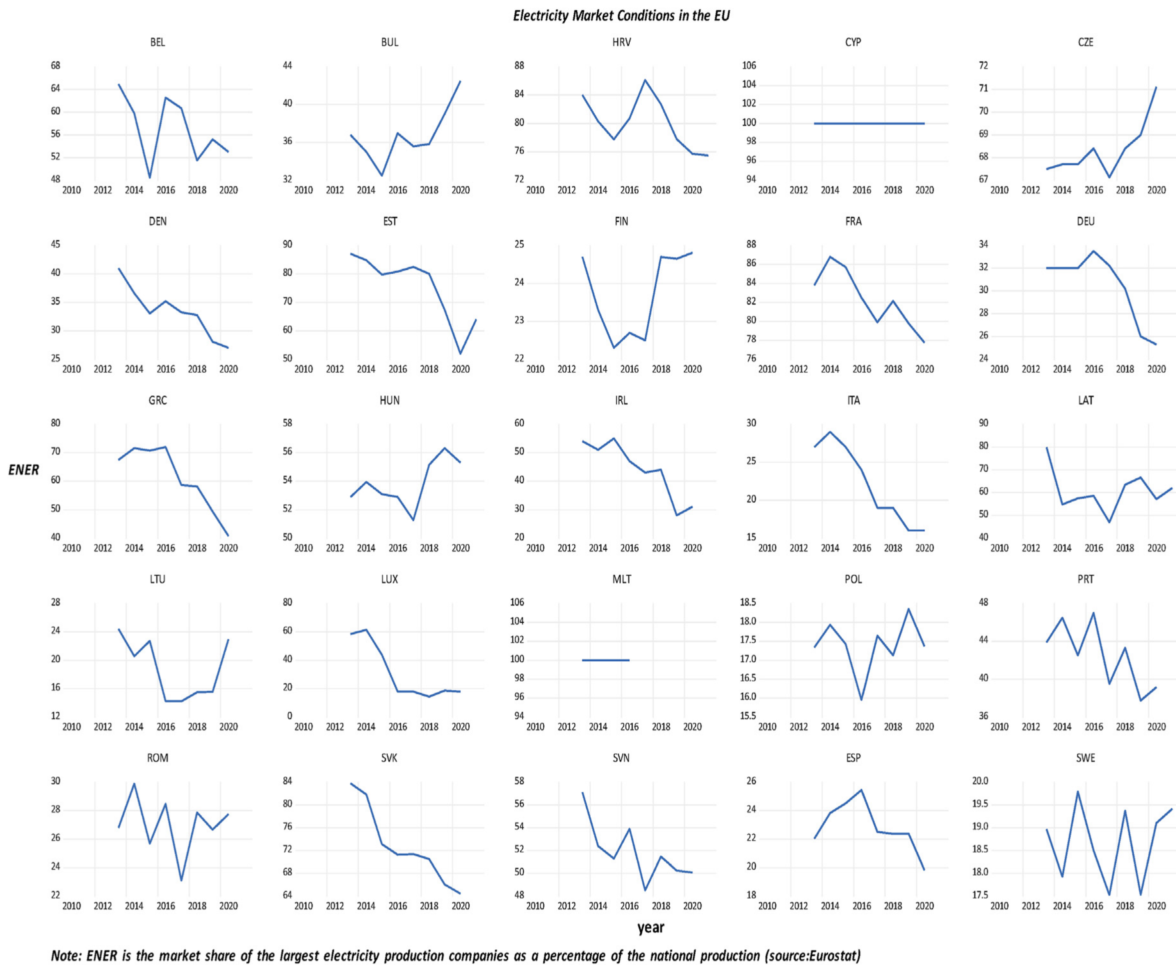

Fig. 2. Electricity market shares in the EU.

A competitive energy market can create opportunities for entrepreneurs and innovators to develop CE technologies. In this light, several researchers using a different dependent variable have analyzed the effect of entrepreneurship and innovation on CE indicators (Bianchi et al., 2021; Cullen & De Angelis, 2021; D'Adamo et al., 2021; Kostakis & Tsagarakis, 2022a; Kostakis & Tsagarakis, 2022b; Robaina et al., 2020). Specifically, Cullen and De Angelis (2021) underscore the importance of circular entrepreneurship as it tends to reduce waste generation. Expanding this consideration, D'Adamo et al. (2021) identify that the development of business initiatives can significantly reduce the waste generation. Kostakis and Tsagarakis (2022b) examine the effect of entrepreneurship using the CMU as a dependent variable. Researchers find that entrepreneurship is positively correlated with CMU. The empirical study of Robaina et al. (2020) concluded that R&D expenditures are negatively associated with RP and it appears to have a greater negative impact in countries with higher RP growth rates. In countries with low and medium RP growth rates, an increase in technological investments exerts a positive effect on RP. In the empirical study of Bianchi et al. (2021), employing dynamic panel data for 280 European regions at NUTS-2 level during the period 2006–2015, the results show, that R&D expenditures have a marginal effect on material productivity which, according to researchers, is due to the fact that R&D investments do not necessarily translate into local benefits because technological innovations are often developed in different areas from those where the plants are located. Kostakis and Tsagarakis (2022b) noted that for a 1% increase in R&D, there is an increase of 0.65% in CMU. Given the context of the discussion, the research question is formulated as follows.

RQ_4: Is there a positive association between entrepreneurial activity levels and circularity rate?

However, R&D investments need a safety net that reduces the risks associated with CE entrepreneurship and innovation. The importance of social equity is underscored by Jones (2009) concluding that a fair distribution of services and goods across society is of paramount significance to avert environmental threats. Geissdoerfer et al. (2017) argue that socially centered practices and policies, such as ensuring rights to CE activities and a human-centered design, can foster CE. Applying this new thinking while addressing the challenges of social equity, diversity and inclusiveness is a cornerstone to achieving a human-embedded CE (Lemille, 2017a; 2017b). Upadhyay et al. (2021) note that social policies could facilitate a CE-oriented value creation. Jones et al. (2010) point out that social protection policies are crucial to withstanding multiple shocks related to environmental degradation. The nexus between social protection and the attainment of environmental objectives is examined by Rodríguez et al. (2011) finding a positive relation. Focusing on the relationship between environmental degradation and poverty, Sachs and Reid (2006) argue that environmental protection requires a reduction in poverty although a few years before it has been considered as a resolved issue (Martinez-Alier, 2003). Anguelovski and Alier (2014) underline the need of a socially protected environment to achieve ecological sustainability. Based on the discussion, the following research question comes into focus.

RQ5: Is there a positive relationship between social protection expenditures and circularity rate?

A socially protected environment is closely linked with the quality of institutions. By promoting transparency, accountability and efficiency, high-quality institutions can help to ensure that social protection programs are well-designed, well-targeted and sustainable over the long term. For this reason, the effect of institutional quality on CE determinants has attracted increasing attention in recent years (Jones et al., 2010; Mrabet et al., 2021; Muhammad & Long, 2021; Sabir et al., 2020; Su et al., 2021; Suttibak & Nitivattananon, 2008; Tsai, 2008). Through policies and regulations, institutions can have an indirect or direct effect on the environment. Jones et al. (2010) stress that an equitable institutional environment is of paramount importance to deal with the environmental challenges. Sabir et al. (2020) examining the cases of Bangladesh, India, Pakistan and Sri Lanka state that a higher institutional stability decreases the pressure on the environment in contrast with the corruption. A buildup of higher institutional sustainability lessens political vulnerability and CO_2 emissions as recognized by Su et al. (2021) and Muhammad and Long (2021). Tsai (2008) underscore the importance of a higher social capital to sanction environment-conscious behavior, while Suttibak and Nitivattananon (2008) find that to increase recycling actions, legislative interventions are needed. Mrabet et al. (2021) considers political stability as key driver in addressing environmental threats. Sui et al. (2021) conclude that improved political stability creates spillover effects and is associated with higher environmental quality not only in a specific country but also in neighboring countries. The nexus between political stability and ecological footprint in South Asian nations (India, Bangladesh, Sri Lanka, Pakistan) is examined by Pata et al. (2022) finding a positive sign. With regard to the discussion, the following research question becomes apparent.

RQ6: Is there a positive correlation between the quality of institutions and circularity rate?

In countries with high political stability and institutional quality, there may be more opportunities for economic growth and social well-being, which can attract people to urban areas and increase population density. Conversely, in countries with low political stability and institutional quality, there may be fewer economic opportunities and lower quality of life, which can lead to migration and depopulation in certain areas, resulting in lower population density. However, the rapid increase of ecological deficits in combination with excessive social and individual demand has also contributed to economic deficits. Having considered the fact that the pressure on natural resources due to the expected increase in world population and future consumer demand could undermine the circular transition and is therefore a crucial determinant of CE, Robaina et al. (2020) examine population density (POP) as an independent variable to determine the effect exerted on RP. The results show that POP is positively correlated with RP. Researchers note that an increase in population concentrations results in increasing RP. Weisz et al. (2006) in turn, focusing on 15 EU countries for the period 1970 to 2001, conclude that population growth leads to lower resource consumption. The results show that high population density is negatively associated with DMC due to the fact that higher POP results in lower per capita availability of domestic goods, lower demand for construction materials, while at the same time net imports increase and outsourcing procedures are strengthened. In contrast, very low POP is negatively correlated with DMC as low population concentrations activate demand for some critical raw materials, increase per capita household consumption of raw materials, such as wood, while they are often associated with high per capita availability of resources and attract industries that specialize in material-intensive activities. In this regard, land availability is an important determinant of DMC (Bianchi et al., 2020). On the contrary, Fernández-Herrero and Duro (2019) exploring the relationship between socio-economic variables and material productivity, stress that POP could enhance RP due to higher resource pressures. In the research effort of Bianchi et al. (2020) which focused on investigating the linkages between socioeconomic factors and material productivity, the results show that POP is positively associated with the levels of material productivity while affecting the productivity through the economic structure of regional economies. Regions specializing in tertiary sectors increase material productivity through POP. Given this discourse, the following research question emerges.

RQ7: Is there a relationship between densely populated areas and circularity rate?

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3. Empirical methodology and data

3.1. Research framework

To address the aim of our study the following research plan has been designed. The suggested research has five basic steps (Fig. 3). Firstly, a set of seven research questions have been developed in the literature review. These questions emerge from the literature in order to build the critical foundation of the research suggested. This requires the identification of the potential relationships between: *domestic material consumption and circularity rate (RQ_1); resource productivity and circularity rates (RQ_2); energy market structure and circularity rate (RQ_3); entrepreneurial activity levels and circularity rates (RQ_4)*; *social protection expenditures and circularity rate* (RQ_5); *quality of institutions and circularity rate (RQ_6); densely populated areas and circularity rate (RQ_7).*

Secondly, an empirical model has been developed by utilizing six types of variables: domestic material consumption, resource productivity, energy market's structure, institutional quality index, population density, Total early-stage entrepreneurial activity and social protection expenditures. Thirdly, empirical results have been analyzed employing several econometric techniques and, fourth, a discussion regarding rejecting or supporting has been made.

3.2. Empirical model

Our empirical analysis consists of 27 EU countries and the UK from the period 2010 to 2021, subject to data availability. Focusing on CE determinants, the following six subsets of variables are included in the empirical model: proxies of environmental performance (Halkos & Petrou, 2019; McDowall et al., 2017; Robaina et al., 2020); the structure of the energy market (Borowski, 2020; Dar et al., 2022; Ghazanfari, 2023; Lagendijk, 2008); institutions (Jones et al., 2010; Muhammad & Long, 2021; Pata et al., 2022; Sabir et al., 2020); urbanization (Bianchi et al., 2020, 2021; Fernández-Herrero & Duro, 2019; Robaina et al., 2020); innovation, R&D and entrepreneurship (Cullen & De Angelis, 2021; D'Adamo et al., 2021; Kostakis & Tsagarakis, 2022a; Kostakis & Tsagarakis, 2022b); social

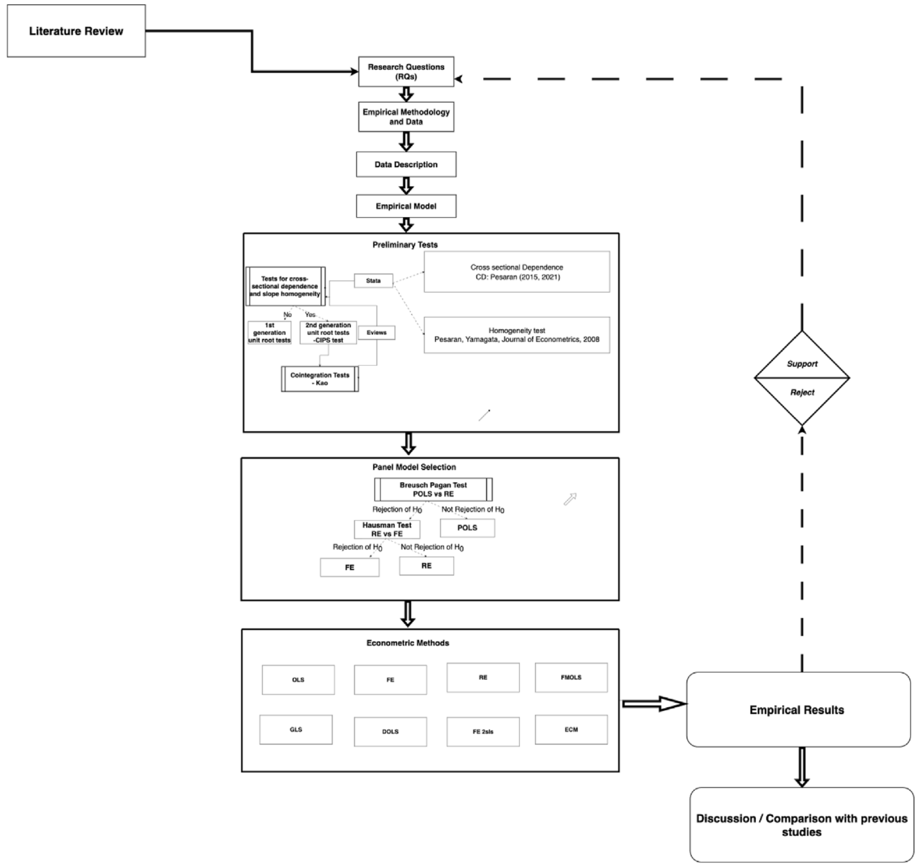

Fig. 3. Research framework.

protection (Anguelovski & Alier 2014; Jones et al., 2010; Rodríguez et al., 2011).

Transforming the variables into logarithmic form makes the variability in the data more homogenous. This, in turn, enables a more precise estimation of the coefficients and a deeper comprehension of the underlying relationship between the variables. Additionally, outliers within the data can skew the results and lead to inaccurate estimates of the coefficients. By applying logarithmic transformation, the impact of outliers can be reduced, and the data can be better fitted to the regression model. The use of double-log models in estimation implies that the coefficients are interpreted as constant elasticities. This interpretation is particularly useful in economic analysis, as it allows for a better understanding of the impact of changes in one variable on another. Following the need to meet the targets laid down in EU legislative acts, the CE monitoring framework and the theoretical underpinnings developed, our model is specified as follows:

$$\log(CMU)_{it} = \beta_0 + \beta_1 \log(DMC)_{it} + \beta_2 \log\,(ENER)_{it} + \beta_3 \log\,(GAS)_{it} + \beta_4 \log\,(IQI)_{it} + \beta_5 \log\,(POP)_{it} + \beta_6 \log\,(RP)_{it} + \beta_7 \log\,(SOC)_{it} + \beta_8 \log\,(TEA)_{it} + u_{it} \quad (1)$$

where CMU represents the circularity rate of country i at time t and βi denote coefficients to be estimated. DMC is the domestic material consumption, ENER is the market share of the largest electricity production companies as a percentage of the national production, GAS is the market share of the companies bringing the largest amount of the natural gas, IQI is the institutional quality index, POP is population density, RP is resource productivity, SOC is the per capita social protection expenditure (at constant 2010 prices), TEA is the total early-stage entrepreneurial activity while u_{it} represents the error term. As variables enter the regressions in logarithmic form, the coefficients are interpreted as constant elasticities.

3.3. Econometric methods

The extent, to which the variables of interest affect the behavior of CMU in the long-term, is estimated by employing different estimation procedures namely the OLS, the fixed effects (FE), the random effects (RE), the fully modified least squares (FMOLS) the generalized least squares (GLS), the dynamic least squares (DOLS) and FE 2sls estimation. Further tests such as White Period, Cross-Section SUR supported the robustness of the model. The coefficient estimates and their associated t statistics did not significantly change in any of the alternative runs. We have also tested the robustness of the model (Alhola et al., 2019) with FE to potential exclusion of either southern or northern countries. This check also supported that our results are generally robust.

The endogeneity of the variables is empirically investigated via error correction models (ECM). Specifically, three error correction models are employed to analyze the short and long-run dynamics of DMC, ENER, GAS, IQI, POP, RP, SOC and TEA on the behavior of CMU. The over-parameterized error correction model with FE includes the estimation of first differences (Δ) and lagged first differences of the variables (Adam, 1992), while the first difference (Δ) of the dependent variable (CMU) is included as an independent variable with a time lag (Hendry, 1980). Therefore, the over-parameterized ECM (ECM_01) is specified as follows:

$$\begin{aligned}\Delta\log(CMU)_t = {} & \beta_0 + \beta_1\,\Delta\log(DMC)_t + \beta_2\Delta\log(ENER)_t + \beta_3\Delta\log(GAS)_t \\ & + \beta_4\Delta\log(IQI)_t + \beta_5\Delta\log\,(POP)_t + \beta_6\Delta\log(RP)_t \\ & + \beta_7\Delta\log(SOC)_t + \beta_8\Delta\log(TEA)_t + \beta_9\Delta\log(CMU)_{t\text{-}1} \\ & + \beta_{10}\Delta\log(DMC)_{t\text{-}1} + \beta_{11}\Delta\log(ENER)_{t\text{-}1} \\ & + \beta_{12}\Delta\log(GAS)_{t\text{-}1} + \beta_{13}\Delta\log(IQI)_{t\text{-}1} + \beta_{14}\Delta\log(POP)_{t\text{-}1} \\ & + \beta_{15}\Delta\log(RP)_{t\text{-}1} + \beta_{16}\Delta\,\log(SOC)_{t\text{-}1} + \beta_{17}\Delta\log(TEA)_{t\text{-}1} \\ & + \beta_{18}(ECT)_{t\text{-}1} + u_t \end{aligned} \tag{2}$$

Following the empirical analysis, the variables and their lags that are not significant were eliminated while the first difference (Δ) of the dependent variable (*CMU*) is included as an independent variable with a time lag. Therefore, the parsimonious ECM with FE (ECM_02) is specified as follows:

$$\begin{aligned}\Delta\log(CMU)_t = {} & \beta_0 + \beta_1\,\Delta\log(DMC)_t + \beta_2\,\Delta\log(ENER)_t + \beta_3\,\Delta\log(IQI)_t \\ & + \beta_4\,\Delta\log(CMU)_{t\text{-}1} + \beta_5\,\Delta\log(POP)_{t\text{-}1} \\ & + \beta_6(ECT)_{t\text{-}1} + u_t \end{aligned} \tag{3}$$

Finally, both the variables and their lags that are not significant and the lagged first difference of the dependent variable (*CMU*) were eliminated. Therefore, the final parsimonious ECM_03 with FE is specified as follows:

$$\begin{aligned}\Delta\log(CMU)_t = {} & \beta_0 + \beta_1\,\Delta\log(DMC)_t + \beta_2\,\Delta\log(IQI)_t \\ & + \beta_3\,\Delta\log(POP)_t + \beta_4\,\Delta\log(ENER)_{t\text{-}1} \\ & + \beta_5\,\Delta\log(GAS)_{t\text{-}1} + \beta_6(ECT)_{t\text{-}1} + u_t \end{aligned} \tag{4}$$

3.4. Data

Variables are extracted from Eurostat, the OECD, World Bank, Global Entrepreneurship Monitor databases and include the following indicators: domestic material consumption (DMC) extracted from the Eurostat database is the annual quantity of raw materials directly used by an economy. It is expected to reduce the CMU. ENER and GAS as sourced from the Eurostat database reflect the impact of energy markets on CE. It is expected to influence the CMU. The IQI extracted from OECD in WGI database is the average of six variables (control of corruption, government effectiveness, political stability and absence of violence/terrorism, regulatory quality, rule of law, voice and accountability). The IQI has been estimated according to the methodology of Barbier and Burgess (2021) taking values from 0 (lowest institutional quality) to 5 (highest institutional quality). It is expected to increase the CMU. Population density (POP) is derived from the World Development Indicators database and is calculated from the ratio between total population and land area. It is expected to influence the CMU. Resource productivity (RP) is extracted from the Eurostat database and is used as a proxy for environmental performance. An increase in resource productivity is expected to increase the CMU. Social Protection expenditures (SOC) as sourced from Eurostat database reflect the interventions implemented from public or private bodies to relieve households and individuals. It is expected to increase the CMU. Total early-stage Entrepreneurial Activity (TEA), extracted from Global Entrepreneurship Monitor database, captures the percentage of population (18–64) that is “either a nascent entrepreneur or owner of a business”. An increase in Entrepreneurship is expected to increase CMU. Table 2 reports the summary statistics for the dependent and independent variables employed in this paper.

4. Empirical results

The existence of a statistical relationship among variables is carried out in five steps. The first step involves the Pesaran's CD test which is important to examine whether a cross-sectional dependence is existed in the panel. The results show that the null hypothesis of cross-sectional dependence is rejected (Table 3). To test slope homogeneity, test of Hashem Pesaran and Yamagata (2008) is employed. The results suggest that the null hypothesis is rejected (Table 3).

Having verified the cross-sectional dependency and heterogeneity of slope coefficients (Blomquist & Westerlund, 2013), the order of integration of the series is determined by performing standard unit root tests (ADF tests). The results suggest that all variables except the GAS and RP and SOC are integrated of order one (Table 4).

Accordingly, a panel co-integration analysis is performed using the Kao statistics to examine whether long-run equilibrium relationships emerge between the variables of interest for the sample countries. A co-integration relationship is detected among the variables of interest concluding that Eq. (1) finds statistical support in the panel (Table 5).

Having verified the same order of integration of the variables and considering the results of the Breusch-Pagan test which rejected the null hypothesis, the final conclusions should be drawn based on Eq. (2) with FE. Table 6 presents long-run coefficient estimates by applying OLS, FE, RE, FMOLS, GLS, DOLS, FE 2sls models which are re-estimated after removing non-significant variables. As can be observed, by taking CMU as a dependent variable, institutional quality (IQI) and environmental performance (RP) are estimated positively and statistically significant in all econometric specifications. These factors may be key instruments for enhancing CE within Europe. According to the re-estimation of Eq. (2), a strong negative effect is exerted on CMU by POP, DMC, GAS and ENER. As the EU energy markets are dominated by electricity and gas monopolies or oligopolies, significant barriers are arising towards CE adoption. DMC patterns are also important causes for lower circularity rates, as more households may be concentrated in a specific area with higher levels of consumption.

To carry out tests on the cointegrated vectors, a FMOLS estimator suggested by Phillips and Hansen (1990) and Hashem Pesaran and Yamagata (2008) is employed. According to Eq. (4), a

Table 2
Summary statistics.

Variable	Source	Obs	Mean	Std. Dev.	Min	Max
CMU	Eurostat	102	7.40	4.74	1.40	19.50
DMC	Eurostat	102	111.11	38.46	56.24	258.08
ENER	Eurostat	102	46.02	22.90	14.43	87.00
GAS	Eurostat	102	68.52	22.31	23.38	100.00
IQI	OECD	102	1.07	0.47	0.31	1.97
POP	World Bank	102	108.48	73.51	23.61	372.79
RP	Eurostat	102	1.35	0.68	0.38	3.40
SOC	Eurostat	102	5597.52	4625.64	1023.05	18580.21
TEA	Global Entrepreneurship Monitor	102	8.49	3.06	2.80	19.40

Table 3
Tests for cross-sectional dependence and slope homogeneity.

		Value	p-value
Cross-sectional dependence	Pesaran CD-test	3.95	0.00
Slope homogeneity	Delta test	Delta 1.27	
		Delta-adjusted (Δ_{adj}) 3.35	0.00

Table 4
Panel Unit root tests ADF - Fisher Chi-square.

Variable	Value	p-value
CMU	76.86	0.03
DMC	121.76	0.00
ENER	68.04	0.02
GAS	41.95	0.16
IQI	78.00	0.03
POP	223.50	0.00
RP	43.72	0.88
SOC	31.36	1.00
TEA	68.47	0.01

Table 5
Panel co-integration tests for heterogeneous panel.

Cointegration Statistics	Value
Kao Residual Cointegration Test ADF	−3.29[a]

[a] Represents p-value<0.001.

Table 7
ECM with fixed effects.

Variables	ECM_01	Sig	ECM_02	Sig	ECM_03	Sig
D(LDMC)	−0.61	a	−0.99	c	−1.16	c
D(LENER)	0.10		0.15	a		
D(LGAS)	−0.11					
D(LIQI)	0.21		0.72	c	0.44	b
D(LPOP)	−0.18				17.90	a
D(LRP)	−0.05					
D(LSOC)	−0.07					
D(LTEA)	−0.02					
D(LCMU(−1))	0.09		0.19	c		
D(LDMC(−1))	−0.12					
D(LENER(−1))	−0.19				−0.21	b
D(LGAS(−1))	0.40	b			0.33	c
D(LIQI(−1))	0.11					
D(LPOP(−1))	16.26	a	7.92	b		
D(LRP(−1))	−0.06					
D(LSOC(−1))	−0.86					
D(LTEA(−1))	0.04					
ECT(−1)	−0.44	b	−0.56	c	−0.39	c

[a] 10% level of significance.
[b] 5% level of significance.
[c] 1% level of significance.

1% increase in TEA and RP raises the CMU in Europe by 0.30% and 0.73% respectively. This in practical terms means that entrepreneurship and resources' utilization are crucial determinants and main drivers for the implementation of CE in EU countries. Technological advances together with decoupling between the use of natural resources may stimulate circular activity (Gan et al., 2013). Higher circularity rates are also robustly associated to strengthened institutional quality and higher levels of social protection. The nexus between SOC and CMU becomes stronger under the DOLS estimator (column 6). In the case of the GLS estimator (column 5), there is sufficient evidence to support the undermining of circular transition due to the control of electricity generation and natural gas imports by an oligopolistic system. As the DMC increases, EU countries are unable to provide the necessary means for the waste submitted to processing. In countries where there is an increase in the consumption of raw materials, the volume of waste collected for recovery far exceeds the potential of domestic economies to recycle them and then to recover. Respectively, in countries where a reduction of raw materials' consumption is achieved, there seems to be general inefficiency in the domestic mechanism and an inability to provide the necessary means for waste recycling and recovery. The panel FE 2sls (column 7) suggests, that there are signs of interaction between the oligopolistic structure of energy markets and environmental degradation. When there is no threat of entries, there is lack of competitive pressure and Bertrand-like competition which leads to oligopolistic pricing behavior and lower CE.

The short and long-term relationship between DMC, ENER, GAS, IQI, POP, RP, SOC, TEA and CMU are analyzed by employing ECM (Table 7). In all equations, the Error Correction Term (ECT), measuring the deviation in Europe's CMU from short-run to long-run equilibrium (Engle & Granger, 1987), is significant. The results of the over-parameterized ECM with FE (ECM_01) show that the speed of adjustment is about 44% while an effect of DMC, GAS and POP on CMU is estimated. Specifically, the magnitude of −0.61 of DMC implies that a 1% increase in DMC reduces the CMU in Europe by 0.61% on average, ceteris paribus. The magnitude of 16.26 of POP and 0.40 of GAS implies that a 1% increase in densely populated areas and in the market share of natural gas companies enhances the circular activity in Europe by 16.26% and 0.40% respectively. The results stand in contrast to long-term behavior and may be attributed to the fact that an increase in the number of consumers and not in the average number of individuals is responsible for the lower CMU levels. Consumption patterns and spatial distribution of

Table 6
Regression results. Dependent variable: circular material use rate (CMU).

Variables	OLS estimation	FE estimation	RE estimation	FMOLS estimation	GLS estimation	DOLS estimation	FE 2sls estimation
DMC		−0.78[c]	−0.68[c]		−0.73[c]		−0.68[a]
ENER		−0.19[b]	−0.13[a]		−0.27[c]		−0.30[b]
GAS	0.42[c]	−0.21[b]	−0.18[b]		−0.15[b]		−0.33[b]
IQI	0.83[c]			0.97[c]		0.50[c]	
POP	0.50[c]	−2.03[b]			−1.57[b]		
RP	0.42[b]		0.27[b]	0.73[c]	0.16[b]		
SOC	−0.43[c]			0.70[a]		1.19[c]	
TEA	−0.59[b]			0.30[b]		0.27[c]	
R^2	0.41	0.97	0.39	0.95	0.99	0.99	0.96
F-statistic	11.07[c]	139.34[c]	5.96[c]		688.14[c]		114.06[c]

[a] 10% level of significance.
[b] 5% level of significance.
[c] 1% level of significance.

population concentrations are also important causes for an increase or decrease of CMU, as more low-income households may be concentrated in an area which presents lower levels of consumption. For this reason, it should be examined not only the purely numerical figures but also the changes in the age structure of the population, the size of households and how they ultimately affect consumption.

The results of the parsimonious ECM with FE (ECM_02) indicate a positive effect exerted by higher institutional quality and environmental performance. As IQI increases by 1%, the CMU in Europe raises by 0.72% while a 1% increase in densely populated areas the year before tends to increase the CMU by 7.92% on average, ceteris paribus, implying elastic change. Incorporating in the field of empirical analysis the first difference of the dependent variable (CMU) as an independent variable with one time lag, the results suggest that a 1% increase in a country's effort to collect waste for recovery the year before raises the CMU the year after by 0.19%.

The coefficient of the final parsimonious ECM_03 is also correctly signed and significant at a 1% level and the value of −0.39 means that the speed of adjustment is about 39%. Results show that a higher level of DMC the year t and an anti-competitive behavior in electricity markets the year before raises the ecological footprint. The magnitude of 0.44 of IQI implies that a 1% increase in institutional quality increases the CMU by 0.44% while a 1% increase in POP raises the circular activity by 17.90%. However, even with a time lag, a 1% increase in GAS the year before tends to increase the CMU in Europe by 0.33% on average, ceteris paribus.

5. Discussion

Today, the majority of the current literature has concentrated on the company level and cooperation among firms to promote the principles of the CE (Nikolaou et al., 2021). At the macro-level, only a small number of studies have focused on the country level by utilizing macro-economic variables. This is a significant limitation for the field due to examine (at macro level) only progress on waste without examining economic and social aspects (Nikolaou & Tsagarakis, 2021). Table 8 summarizes the expected sign of the independent variables used in the empirical analysis according to previous relevant studies and presents our results regarding the short- and long-run correlations between the circularity rate, the structure of the energy markets, environmental performance, institutions, demographic growth, social protection and entrepreneurial activity in EU countries.

The results of the present study suggest that in both the short and long-run circularity rates decrease by an increase in domestic material consumption. This is a reasonable finding because when material consumption rises, there is a greater demand for raw materials, which can lead to an increase in the extraction of natural resources, resulting in more waste and pollution. As the demand for raw materials increases, the costs of production may rise, which could discourage circular practices such as recycling and reusing materials. Finally, an increase in domestic material consumption may lead to a shift away from circular business models, as companies may prioritize meeting the demand for new products instead of pursuing circular practices. All these factors can contribute to a decrease in circularity rates in both the short and long-run.

Table 8
Impact of the independent variables for 27 EU countries and the UK.

Variables	Expected Sign	Fixed Effects	FMOLS	GLS	DOLS	FE 2sls	ECM
DMC	–	–		–		–	–
ENER	+/–	–		–		–	–
GAS	+/–	–		–		–	+
IQI	+		+		+		+
POP	+/–	–		–			+
RP	+		+	+			
SOC	+		+		+		
TEA	+		+		+		

In most econometric specifications, environmental performance, institutional quality, social protection and entrepreneurship exert a positive and significant impact on circularity rates. Overall, an increase in resource productivity can contribute to a more sustainable and CE which is logical for several reasons. Firstly, when resource productivity increases, less raw materials are required to produce the same amount of goods, which can reduce the pressure on natural resources, resulting in less waste and pollution. Secondly, higher resource productivity can encourage the adoption of circular practices because it reduces the costs of production and makes it more economically viable to recycle and reuse materials. Thirdly, a focus on resource productivity can lead to the development of more innovative and sustainable technologies and business models, which can boost circularity rates in the long-run.

The results also show a long-run relationship between social protection expenditures and CE which is noteworthy for several reasons. Social protection measures such as healthcare, education, and income support can improve the overall well-being of individuals and increase their capacity to make sustainable choices, including the CE. At the same time, such measures can reduce income inequality and provide a safety net for vulnerable groups, which can lead to greater social cohesion and a greater willingness to support sustainable initiatives such as the CE. Social protection expenditures can also foster a culture of responsibility and care for others and the environment, which can increase the appeal of CE principles that prioritize social and environmental well-being. The results are in line with prior research conducted by Jones (2009), Geissdoerfer et al. (2017) employing bibliometric analysis and snowballing techniques, Upadhyay et al. (2021) adopting a narrative review approach, Sachs and Reid (2006) and Anguelovski and Alier (2014) using comparative research to investigate the utilization of valuation languages other than “green” economic growth.

The results show that an increase in institutional quality can create a more supportive environment for the adoption of CE practices in both the short and long-run. This means that improving institutional quality such as strengthening the rule of law, reducing corruption, and promoting transparency can create an enabling environment for CE practices to thrive thus providing a supportive legal and regulatory framework. It can foster a culture of responsibility and encourage individuals and businesses to adopt CE principles that prioritize social and environmental well-being. The findings are consistent with previous studies conducted by Jones et al. (2010), and Sabir et al. (2020) examining different samples such as the cases of Bangladesh, India, Pakistan, and Sri Lanka and Su et al. (2021) who direct their attention towards the Brazilian case as one of the world's largest CO_2 emitters. This positive sign is also in line with the research conducted by Muhammad and Long (2021) which examined the relationship between institutional factors and carbon emissions, as well as Tsai's (2008) study that focused on Taiwan. Earlier investigation by Suttibak and Nitivattananon (2008) on the factors influencing the performance of CE indicators, such as the solid waste recycling programs situated in different urban areas throughout Thailand, harmonizes with studies by Mrabet et al. (2021) who examined the causality between environmental quality and human development as well as the effects of political stability using a sample of 16 Middle Eastern and North African countries between 1990 and 2016, the empirical research conducted by Sui et al. (2021) investigating the spillover effects between developing and developed countries as well as the study by Pata et al. (2022) focusing on the cases of Pakistan, India, Sri Lanka, and Bangladesh. These findings are reasonable and noteworthy, as the proper functioning of institutions is known to strengthen citizen trust in policies and the institutions themselves. Nevertheless, these studies have presented discrepancies regarding CE indicators, examined time periods, utilized samples and the independent variables considered.

The long-run coefficient estimates show that higher entrepreneurial activity levels can contribute to a more dynamic and innovative CE. Entrepreneurs are often more innovative and flexible in their approach to business, which can lead to the development of new CE business models. They are more likely to identify and exploit opportunities in CE, such as developing new products and services based on the principles of reuse and recycling. Higher entrepreneurial activity levels can also foster a culture of innovation and experimentation, which can encourage more individuals and businesses to adopt CE. The favorable correlation aligns with the investigations conducted by Cullen and De Angelis (2021), who scrutinized circular entrepreneurship through the lens of the entrepreneurial process; D'Adamo et al. (2021), who concentrated on the municipality of Rome; and Kostakis and Tsagarakis (2022a), who explored the interconnection between entrepreneurship and circularity progress utilizing a panel dataset encompassing 18 EU countries from 2010 to 2019. Empirical evidence also indicates that there is a minor (Bianchi et al., 2021) or even negative (Robain et al., 2020) correlation between R&D expenditures and CE indicators. One such reason is that R&D investments do not always yield local benefits and may not be directed towards sustainable practices. Instead, R&D expenditures may focus on improving existing technologies that are not necessarily environmentally friendly. Furthermore, it depends on the industry and the type of innovation being developed. For instance, in industries characterized by high technological uncertainty, such as the renewable energy sector, R&D expenditures may be positively correlated with CE indicators. This is because in such industries, there is a greater need for innovation and experimentation to develop new technologies and processes that can facilitate the transition towards a circular economy. R&D efforts can help companies to identify new materials, processes, and business models that can reduce waste, increase resource efficiency, and promote circularity. However, in industries where innovation is less complex, such as waste management, R&D expenditures may not necessarily translate into improved CE performance (Giljum et al., 2010). This is because the waste management industry is already well-established and many of the technologies and processes used are mature and widely adopted. Therefore, additional R&D spending may not significantly improve CE performance in this industry. Other factors such as regulatory frameworks, market demand and consumer behavior can also play a significant role.

A change in densely populated areas leads to a different adjustment of circularity rates in the short and long-run. While demographic growth can have short-term benefits for the CE, in the long-term, it can create challenges that can negatively impact its implementation. In the short-term, with increasing densely populated areas, there is a greater concentration of resources and waste in a specific area, making it more cost-effective to implement circular practices such as recycling and reusing materials. This is because it is easier to collect and transport waste to recycling facilities and there is a greater demand for recycled materials in densely populated areas. However, in the long-run, with increasing population density, there is a greater demand for resources and energy, leading to more waste and pollution. This can result in a decrease in the availability of natural resources and an increase in the costs of production, which can discourage circular practices. Additionally, there may be greater competition for resources, leading to a shift away from CE business models and practices. A range of empirical studies have examined the relationship between population density and different CE indicators including Fernández-Herrero and Duro (2019) exploring the relationship between socio-economic variables and material productivity and Bianchi et al. (2021) which focused on investigating the links between socioeconomic factors and material productivity. These studies have consistently indicated that an increase in population results in an increase in material productivity. In addition, Robaina et al. (2020) provided evidence of a positive correlation between resource productivity and population, whereas Weisz et al. (86), who studied 15 EU countries from 1970 to 2001, identified a negative association between population and DMC.

The results also indicate a robust negative long-run relationship between increased market shares held by the largest electricity production companies and those supplying the largest volume of natural gas on circularity rates. This means that when the largest electricity production companies and natural gas suppliers have a higher market share, circularity rates are negatively impacted in the long run implying that a concentration of market power in energy industries may hinder the CE transition. Under imperfect competition in energy markets, there are signs of undermining the efforts of EU countries to collect waste for recovery. Imperfect competition in energy markets may hinder progress towards a higher level of CE because energy companies have greater market power, which can lead to higher prices for waste disposal and recovery services. This can reduce the incentive for waste collection and recycling, particularly for small or medium-sized waste management companies that may struggle to compete with larger firms. Energy companies may also prioritize the use of waste for energy generation, rather than for recycling or recovery, which can reduce the availability of materials for recycling and recovery. This can be detrimental to EU efforts to increase the use of recycled materials and reduce waste. Under imperfect competition, there may be less transparency and accountability in the energy markets, which can lead to inefficiencies and corruption in waste management and recovery. This can undermine EU efforts to promote sustainable waste management practices and reduce environmental harm. The results are consistent with several studies underscoring the importance of creating a competitive market environment. In particular, Green and Newbery (1992) examined the British spot electricity market as a symmetric duopoly. Klemperer and Meyer (1989) who attempted to demonstrate the existence of a Nash equilibrium in supply functions for a symmetric oligopoly. Borowski (2020) analyzed the electricity market from the perspective of energy sector entities and consumers. Accordingly, Eikeland (1998) investigated the Swedish 'green labeling program' as one of several new initiatives in various countries where electricity providers assure their clients of power from renewable energy sources and Lagendijk (2008) focused on the challenges of energy supply.

The afore-mentioned studies were conducted using different CE indicators, samples, timeframes and independent variables however supporting the notion of an inverse correlation between the structure of the oligopolistic energy markets and the CE. This means that in markets where a few large companies dominate, there is a lower likelihood of companies applying CE practices. This is because these companies may prioritize short-term profits over long-term sustainability and may have less incentive to invest in CE that could disrupt their existing business models. In contrast, markets with greater competition and more diverse actors, may be more conducive to the adoption of the CE as companies are forced to innovate and differentiate themselves to remain competitive (Horbach & Rammer, 2020). This can lead to increased investment in CE practices, as companies seek to differentiate themselves by offering sustainable and environmentally friendly products and services.

6. Conclusions

This study examines the relationship between circularity rate and energy markets' structure, material consumption, institutional quality, population density, resource productivity, social protection expenditures and entrepreneurial activity and whether are exhibiting short-term deviations from their long-run equilibrium for the period 2010–2021. The results highlight the need to replace the linear European model with a more sustainable and resilient model with lower levels of resource intensity in line with the principles of circular thinking. Circular rates tend to increase as the amount of waste recycled increases while at the same time domestic material consumption decreases. As the amount of waste recycled decreases and DMC increases, circular rates tend to decrease. This implies that countries consume more raw materials than they can actually recycle. However, the development of sustainable and competitive conditions for the circular model presupposes an institutional and social protection system capable of increasing the social welfare and establishing sound policies and regulations. This requires structural and radical changes in the current institutional rules, perceptions and attitudes. In countries with a broader and strengthened social protection system where citizens perceive the rulings of the judiciary as impartial, government regulatory interventions as effective and the level of trust in democratic institutions as adequate, circular rate tends to be higher. At the same time, entrepreneurship creates the preconditions for productivity improvements. Higher entrepreneurial activity levels are interrelated with higher circular rate. Circular transition will also be benefited from implementing major structural reforms in EU energy companies by eliminating the degree of vertical integration between electricity generation and gas supply companies, addressing the reputational risks and removing high barriers to entry. As market competition is protected in EU countries, not only the circular economy but also the social welfare will be increased through improved transparency of electricity and gas prices charged to consumers.

However, it is essential to exercise prudence when interpreting the empirical findings. This is because our analysis only focuses on a single CE indicator, the CMU, which does not encompass all aspects of circularity, such as sharing or repair. Moreover, the reliability of the findings may be influenced by various factors, such as the availability and quality of data, the accuracy of waste statistics, and the comparability of data across different countries and regions. Despite these limitations, the study's outcomes can still contribute to the discourse on the CE and provide crucial insights for developing and implementing more effective measures to advance the CE process in Europe.

Researchers can use the methodology and analytical techniques employed in the study as a basis for further research, while adapting them to the specific conditions of other non-EU regions. Considering the methodology employed in the empirical results, future research should aim to investigate the impact of several socioeconomic variables to circular economy indicators. Readerships can also learn from the limitations and challenges encountered in the study and take steps to address these in their own research. The study's results and conclusions can inform the development of research questions and hypotheses for future studies. For example, there are several regions around the world that face similar challenges to the EU's energy markets, including energy markets in North America which are dominated by a few large firms that limit competition and hinder the circular transition. The United States and Canada have implemented policies to promote renewable energy and reduce waste, but challenges remain in terms of regulatory frameworks and market structures. Also, many countries in Asia, including China and India, face significant environmental challenges related to air pollution and waste management while energy markets in these countries are dominated by state-owned companies. In Latin America, energy markets are characterized by high levels of government intervention while many countries are heavily reliant on fossil fuels making the CE transition more challenging. In Africa, energy markets are characterized by limited infrastructure and inadequate regulatory frameworks posing significant environmental challenges.

Author contributions

G. Hondroyiannis: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing, Visualization, Supervision, Project administration. E. Sardianou: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing, Visualization, Supervision, Project administration. V. Nikou: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing, Visualization, Supervision, Project administration. K. Evangelinos: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing, Visualization, Supervision, Project administration. I. Nikolaou: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing, Visualization, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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