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Circular Economy Innovation-Renewable Energy-Green Growth Nexus under Carbon Neutrality Targets: New Insights from Europe

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ABSTRACT

Climate change and global warming are the major problems irking the world community. Carbon emissions, released during economic activities, are considered the major drivers of environmental issues. Green growth is widely believed to be the panacea to environmental and economic problems because it helps separate carbon emissions and economic growth. Consequently, empirics have started to investigate the determinants of green growth. The circular economy practices help increase the lifespan of goods and services, which is vital in achieving environmental and economic goals. Nevertheless, the role of the circular economy in achieving green growth has never been estimated before. This gap in the current literature induces us to investigate the impact of circular economy innovation and renewable energy on green growth in Europe. The empirical analysis is conducted by employing 2SLS and GMM approaches. The findings observe a favorable influence of circular economy innovation and renewable energy on European green growth. In addition, logistic performance, ICT, government spending, financial development, and trade openness also promote green growth. These outcomes suggest policymakers should focus on the innovation of a circular economy and renewable energy to promote green growth.

Keywords: Circular Economy Innovation, Green Growth, Carbon Neutrality, Renewable Energy
JEL Classifications: Q27; Q01; Q56

1. INTRODUCTION

There are several theoretical approaches that can define sustainable development. Among them, the most renowned are circular economy (CE) and green growth (GG), which primarily highlight the discussion on the linkage between environment, growth, and society. Despite their significance in achieving the objectives of SDGs, it is still confusing to what extent these approaches covered the range of topics that fall under the domain of SDGs. In other words, to which extent these approaches are helpful in achieving the objectives of SDGs (Millar et al., 2019).

The idea of the circular economy refers to a novel economic paradigm that intends to switch from the renowned linear economic framework to a circular economic one. In order to implement the circular loops in economic terms, the circular economy intends to reconfigure goods, distribution networks, and consumption trends (Murray et al., 2017). Historically, to achieve higher economic performance, the conventional linear economic framework relies on the extraction of natural resources and their alteration into finished items by adopting industrial approaches and the dumping of trash in landfills. Due to the availability of scarce resources, traditional and popular economists have been struggling with vital inquiries regarding the factors of production, product selection, and end consumers. Particularly, in the short run, these issues are quite pertinent where the production capabilities are more vulnerable due to the fixed factors of production (e.g. land, labor, and capital). However, in the long run, this situation gets better because there is an improvement in the consumption of natural resources due to technological development, novel innovations, elevated organizational capacities, and the availability of new resources (Bell and Pavitt, 1995). Nevertheless, the Brundtland

raised questions over this formal economic notion in a report by highlighting the fact that natural resources are finite and may be depleted. This report provided some valuable suggestions to modern economies with regards to designing policies for the preservation of natural capital and fulfilling the demands of society, while guaranteeing the capacity of future generations to accomplish their requirements (WCED, 1987).

The need for the adoption of a new economic paradigm like circular economy is justified in the literature on the basis of acknowledgment that the economic valuation of natural capital is not the guaranteed standard for achieving the most optimum use of natural capital. Moreover, the principles and standards for determining a growth rate that takes into account the several ways to add value, such as reuse, recycling, and recovery have been influenced by the idea of strong sustainability (D'Amato et al., 2019). Within this context, the available empirical works are of the view that the circular economy plays a critical role in order to attain the objective of strong sustainability (Korhonen et al., 2018). In addition, the circular economy is widely recognized as an important contributor to achieving many other sustainability objectives such as "resource scarcity, waste mismanagement, soil protection, energy inefficiency, and ineffective water resource management" (Hondroyiannis et al., 2024). Such a transformation of the economy from the cost-benefit principle to the precautionary principle has given more significance to strong sustainability as compared to weak sustainability.

In the context of green growth, the circular economy is crucial in disconnecting the environmental impact from economic growth by utilizing a circular production process instead of a linear one, where waste is not a burden but a resource (Lieder and Rashid, 2016). There are three main highlights of the circular economy, such as separating economic growth from environmental harm, extending material lifecycles, and controlling production-related emissions (Ciliberto et al., 2021). As landfills require space, harm the ecosystem, and need a significant amount of investment, the circular economy approach particularly focuses on minimizing waste via optimized use of energy and other resources. Thus, circular economy approaches have become an ideal strategy for many European governments across the globe to decouple economic growth and environmental pollution (Ghisellini et al., 2016). Sustainable development simultaneously takes into account several dimensions, including economic, ecological, technical, and social. However, the economy has to face environmental pressure due to growth-related activities, leading to pollution and deterioration. The circular economy may prove vital in dealing with three main concerns related to sustainable development, such as emissions, trash, and energy usage (Dantas et al., 2021). Therefore, the circular economy is widely believed to be a primary contributor to green growth, which tackles environmental and economic objectives simultaneously. Nevertheless, the rise in environmental effects obstructing green growth is linked to the GDP.

Circular economy and green growth are increasingly becoming popular in the literature as a panacea for sustainable development. A growing body of literature has emphasized the role of both circular economy and green growth as determinants of environmental quality, but the contemporary literature in this regard lacks empirical evidence and theoretical frameworks that can clarify the complex nature of circular economy dynamics and their role in fostering green growth. More precisely, whether these two approaches are linked to each other or whether a circular economy helps achieve green growth needs an empirical investigation. Moreover, no past study has estimated the nexus between circular economy and green growth in the context of Europe, which is considered a leader in implementing circular economy practices and adopting a green growth model. Further, the results of the past studies are inconclusive due to the use of outdated estimation techniques. These points highlight that there is a significant gap in the circular economy and green growth literature, and this study tries to fill these gaps. Therefore, this study tries to investigate the role of circular economy innovation in promoting green growth.

In order to transform from conventional to green growth framework, renewable and clean energy adoption has become crucial. Several nations have invested significantly in the renewable energy sources as a crucial policy option to protect the ecosystem without sacrificing the economic objectives (Kaygusuz and Kaygusuz, 2002). Increasing the production of renewable energy sources like solar, wind, and hydropower is vital to reduce dependency on fossil fuels, which are a major source of carbon emissions as well as primary driver of economic activities (Nguyen and Kakinaka, 2019). There are several benefits of renewable energy sources, such as lowers carbon emissions, increases energy security, and encourages energy independence. Nevertheless, production and consumption of renewable is not up to its protentional in many countries because of massive upfront cost and advanced technology required for their generation, even if enthusiasm in adopting renewable energy sources is rising (Saidi and Omri, 2020).

This study has made some useful contributions to the current body of knowledge. First and foremost, to our knowledge, this is the first-ever empirical effort to scrutinize the impact of a circular economy and renewable energy on green growth. Thus, this analysis can prove vital in providing an empirical and theoretical base for future analysis. Moreover, the findings of the analysis have strong implications for green growth and sustainable development within the framework of a circular economy. Second, the said relationship has not been estimated previously in the context of Europe, which is crucial in understanding how European economies are incorporating circular economy innovation in their economies and their implications for green growth. Thirdly, the study employs advanced instrumental variables approaches to address endogeneity and normality issues. Lastly, the study findings provide practical suggestions to concerned European authorities, which are vital in achieving green growth by enhancing circular economy innovations and renewable energy.

2. THEORETICAL FRAMEWORK

Economics, traditionally referred to as social science, is based on managing limited resources to meet human requirements. Since the

resources available in the world are limited, thus we must manage these resources to make up for what we lack. Economic science scrutinizes how people, groups, and authorities are involved in decision-making regarding the distribution of these limited resources. In addition, economic science also plays a critical role in the allocation of limited resources and its role in manufacturing chain of products and services, from the collection of raw materials to distribution of products to end users (Lang and Marsden, 2018).

Since the start of the industrial revolution, the dominant economic notion in place is the idea of linear economy. Its fundamental idea is the dumping of goods after they have been used. According to linear economic idea, there is a linear cycle that drives every good from the extraction of raw materials, processing and converting them into final goods, selling and supplying them, consuming them, and then discarding them as waste (Rashid and Malik, 2023). In the linear economic model, there is no phenomenon of resuing or recovery of material used in the production process; hence, the materials used during all stages (extraction, production, usage, and disposal) of production become garbage that can't be reused (Sehnem et al., 2019). In this linear model, the natural capital throughout history has been demanded extensively without considering or anticipating the effects on the environment and without focusing on the reuse of materials once used. The waste produced during the production process and not being reused results in "sanitary landfills, incinerators, or even uncontrolled abandonment," causing more difficulties in separation and reuse (Abad-Segura et al., 2020).

Due to the limited availability of energy and natural resources, the linear economic model is considered unsustainable and inefficient, with detrimental impacts on both ecosystem and economic growth. In order to address the issues of linear economic model, in recent times, an alternative approach, known as the circular economy, has been unearthed, which is pivotal in making economy and life on earth more sustainable (Svensson and Funck, 2019). The primary pillars of circular economy are repair, recycling, reuse, and reduction. The waste or trash becomes a resource in a circular economy model (George et al., 2015), playing a vital role is decoupling economic growth and environmental harms. The economic idea of circular economy is related to green growth, whose primary goal is to lessen the amount of energy consumed as well as to maximize the lifespan of goods, materials, and resources used in the economy (Belmonte-Ureña et al., 2021). This model aligns with the idea of green growth as it is the opposite of the linear model and proposes a framework that relies on environmental, economic, and social factors. Therefore, we hypothesize that the circular economy plays a vital role in fostering green growth.

The energy transition theory explains the nexus between renewable energy and green growth. This theory posits that the shift from conventional clean energy reduces carbon emission intensity, significantly improving a nation's ecological performance. It further facilitates the creation of employment opportunities within the clean energy green energy sector, enhances energy efficiency, and reduces healthcare expenses associated with polluting energy sources. Increasing the local production of renewable resources enables governments to enhance energy security and reduce dependence on imported fuels. According to the research conducted by Chen et al. (2019), Khan et al. (2025), Behera (2025), the usage of renewable energy sources reduces reliance on fossil fuels and helps reduce carbon emissions and achieve economic objectives simultaneously. Thus, the transition to renewable energy sources helps decouple economic growth and CO_2 emissions.

3. ECONOMETRIC MODEL AND METHODS

This analysis aims to examine the influence of circular economy, renewable energy, and a wide variety of controlling factors on green growth. Studies such as Shi et al. (2024) and Georgeson and Maslin (2019), have provided the basic frameworks and case studies that have played a crucial role in explaining the ability of the circular economy practices to improve resource efficiency, diminish ecological effects, and stimulate affluence. These studies indicate that improvements in the circular economy may substantially decrease carbon footprints and mining activities while promoting more sustainable consumption and manufacturing practices. Recent studies, including Razzaq et al. (2023), Huang (2023), and Pang et al. (2024) have explored influencing factors of green growth. Building on these studies, we developed the following model for green growth:

$$GG_{it} = \kappa_0 + \kappa_1 CEI_{it} + \kappa_2 RE_{it} + \kappa_3 X_{it} + \alpha_i + e_{it} \quad (1)$$

In eq. (1), green growth (GG) is function of circular economy innovation (CEI), renewable energy (RE), control variables (X), and error term (et). In this framework, κ0 denotes the intercept, while αi captures country-specific effects. Several techniques have been proposed for estimating the models involving panel data. Some of the most famous techniques are POLS, FE, RE, 2SLS, and GMM. The most basic of all estimation techniques is POLS, which makes a pool of all observations that vary across time (T) and cross-sections (N). This method then estimates the data by considering them as a whole and without taking into account the time and cross-sectional segments of the panel data (Gujarati and Porter, 2009). However, this technique has a major shortcoming of not accounting for heterogeneity and endogneity that may exist within the cross-sectional units and thus give biased estimates. The FE and RE models are used as alternatives to POLS. FE should be used if the cross-sections are picked with surety, while if the cross-sections are picked randomly, RE is appropriate technique. Moreover, FE allows us to include the time-invariant variables in the analysis; however, the RE does not permit us to incorporate the time-invariant variables. The issue of endogeneity can't be accounted for with the application of these approaches.

In order to tackle the issue of endogeneity and unobserved heterogeneity, 2SLS may surpass the traditional panel data techniques stated above. Nevertheless, the consistent heterogeneous effects throughout time is the primary assumption the 2SLS relies on, thus addressing the endogeneity issue. Since 2SLS is an instrumental variable approach, this technique first incorporates the IV that is not linked to error terms and thus estimates the values of the regressors that are responsible for the endogeneity issue. In the second step we use these estimated values in our primary model to estimate their impact on the outcome variable. However, the selection of IV is quite a cumbersome task in the 2SLS technique (Woolridge, 2010). Therefore, we also apply the GMM technique, which is superior to other IV techniques because of its ability to include all right-hand side variables as endogenous variables (Du et al., 2012; Giovanis, 2013). There are two types of GMM, one is known as system GMM proposed by (Arellano and Bover 1995; Blundell and Bond 1998), and the other is known as difference GMM (Arellano and Bond 1991). Nevertheless, the unobserved heterogeneous time invariant effects related to the cross-sections are removed due to the inclusion of difference. In addition, the lag order of the variables is not always the appropriate instrumental variable, which may lead to the issue of being a weak instrument variable. The system GMM estimator was introduced to overcome this issue (Arellano and Bover, 1995). The system-GMM estimator has the ability to overcome the issues faced by dynamic panel data, which are not addressed by the other estimation approaches. One step-GMM approach is inefficient and may produce biased estimates because the Sargan Test in this approach doesn't account for the issue of heteroscedasticity (Bond et al., 2001). Therefore, we have adopted two step system GMM estimator in this analysis, which allows for the inclusion of dynamic variables to efficiently estimate the impact of the circular economy and renewable energy on green growth.

$$GG_{it} = \kappa_0+\lambda_1 GG_{it-1}+\kappa_1 CEI_{it}+\kappa_2 RE_{it}+\kappa_3 X_{it}+\alpha_i+e_{it} \quad (2)$$

We also use the quantile regression (QR) method introduced by Koenker and Bassett (1978). This technique helps us explore the response of varying levels of green growth to a change in circular economy innovation while controlling the heterogeneity among the selected nations. Moreover, it also controls outlier problems in the data and works well in the case of abnormal data distribution. Smoothed instrumental variable quantile regression (SIVQR), a procedure that combines quantile regression with the instrumental variable technique, is an additional econometric technique employed in this investigation. It integrates the IV technique with the QR technique; the IVQR technique proposed by Chernozhukov and Hansen (2005) is appropriate for tackling the endogeneity inside the quantile regression model. However, the IVQR method, with certain technical difficulties, includes just one endogenous regressor (Chernozhukov and Hansen, 2005). Thus, Kalpan (2022) proposed a SIVQR strategy to solve the issues with traditional IVQR estimators.

4. DATA AND DESCRIPTIVE ANALYSIS

The study's key objective is to explore the effect of circular economy innovation and renewable energy on green growth using 24 Eurpean economies from 2010 to 2022. Selection of economies is made based on data availability. The dependent variable is green growth. Following Ullah et al. (2023), adjusted net savings excluding particulate emissions damage as % of GNI is used as a proxy variable for green growth. The data series for green growth variable is gathered from the World Bank. Our focused variable is circular economy innovation (CEI), which is proxied by total number of patents related to recycling and secondary raw materials. Eurostat is the source of data collection for the circular economy innovation variable. Taşkın et al. (2020) described that renewable energy production reduces fossil fuel dependence, mitigates carbon emissions, and drives green innovation and investment in energy technologies that promote green growth. Renewable energy production is proxied by total energy production from nuclear, renewables, and other sources in quad btu. The data series for the REP variable is taken from the EIA.

Prior green growth literature used several control variables. For example, Li et al. (2021) reported a positive nexus between logistics performance and economic growth. The study states that efficient logistics systems enable smooth supply chain operations, reduce emissions from freight movements, and mitigate transportation costs, thus enhancing green growth. The logistics performance index is used as a proxy measure for this variable. Zheng et al. (2023) demonstrated that ICT development promotes green growth through the channels of green digital activities. ICT variable is measured through total users of internet as percent of total population. The third control variable is human capital, measured by gross percent of secondary school enrollment. Liu et al. (2023) reported a positive role of human capital in fostering green growth. Lin and Zhu (2019) reports that government spending enhances green growth by allocating funds for green infrastructure, environmental protection initiatives, and renewable energy projects. General government final consumption expenditures measure government spending (% of GDP). Cao et al. (2022) reported a positive role of financial development in enhancing green growth providing financial resources. Domestic credit to private sector by banks (% of GDP) is used as proxy measure of financial development. Hille et al. (2019) claimed that the inflow of FDI into green technology and renewable energy sectors drives green growth. FDI variable is measured in terms of net inflows of FDI as percent of GDP. Following Huang (2023), trade openness is included as a control variable, revealing that trade openness enhances market access for green technologies and products that promote green growth. Total trade as percent of GDP is used as a proxy variable for trade openness. Natural resource (NR) contributes to renewable energy development and green growth. Natural resource rents are measured as percent of GDP. World Bank is the source of data collection for LP, ICT, HC, GS, FD, FDI, Trade, and NR. Table 1 provides a detailed description of the variables.

The descriptive statistics are shown in Table 2. It can be seen that mean scores for all variables are observed positive. The mean scores are reported as: 2.189 for GG, 1.894 for CEI, 3.542 for LP, 4.370 for ICT, 4.699 for HC, 0.667 REP, 20.16 for GS, 4.344 for FD, 1.194 for FDI, 4.754 for TRADE, and 0.591 for NR. The standard deviations scores for GG, CEI, LP, ICT, HC, REP, GS, FD, FDI, TRADE, and NR are reported as 0.651, 1.385, 0.455, 0.166, 0.148, 1.109, 3.247, 0.590, 1.278, 0.430, and 0.725, respectively. The skewness test findings show that GG, CEI, LP, ICT, and FDI exhibit negative skewness, whereas HC, REP, GS, FD, trade, and NR exhibit positive skewness.

Table 3 reports the correlation matrix. The correlation matrix results report that the correlation association between CEI-GG is positive, depicting the positive influence of circular economy innovation on

Table 1: Variables description

Variables	Symbol	Definitions	Sources
Green growth	GG	Adjusted net savings, excluding particulate emission damage (% of GNI)	World bank
Circular economy innovation	CEI	Total number of patents related to recycling and secondary raw materials	EUROSTAT
Renewable energy production	REP	Total energy production from nuclear, renewables, and other (quad Btu)	EIA
Logistics performance	LP	Logistics performance index	World bank
Information and communications technology	ICT	Individuals using the Internet (% of population)	World bank
Human capital	HC	School enrollment, secondary (% gross)	World bank
Government spending	GS	General government final consumption expenditure (% of GDP)	World bank
Financial development	FD	Domestic credit to private sector by banks (% of GDP)	World bank
Foreign direct investment	FDI	FDI, net inflows (% of GDP)	World bank
Trade openness	TRADE	Trade (% of GDP)	World bank
Natural resources	NR	Total natural resources rents (% of GDP)	World bank

Table 2: Descriptive statistics

Variables	Mean	Min	Max	Median	SD	Skewness	Kurtosis
GG	2.189	−2.266	3.262	2.319	0.651	−2.290	13.21
CEI	1.894	−2.526	4.859	1.917	1.385	−0.285	2.812
REP	0.667	0.002	5.334	0.244	1.109	2.869	11.14
LP	3.542	1.776	4.344	3.646	0.455	−0.827	3.856
ICT	4.370	3.687	4.594	4.404	0.166	−1.266	4.789
HC	4.699	3.985	5.100	4.664	0.148	0.383	5.077
GS	20.16	11.38	27.36	19.66	3.247	0.045	2.691
FD	4.344	3.204	6.262	4.377	0.590	0.838	4.466
FDI	1.194	−6.394	5.456	1.176	1.278	−0.585	8.217
TRADE	4.754	3.951	5.974	4.772	0.430	0.395	2.984
NR	0.591	0.003	5.714	0.336	0.725	2.739	14.33

Table 3: Correlation matrix

Variables	GG	CEI	LP	ICT	HC	REP	GS	FD	FDI	TRADE	NR
GG	1										
CEI	0.155	1									
LP	0.398	0.623	1								
ICT	0.549	0.130	0.456	1							
HC	0.207	0.135	0.306	0.385	1						
REP	0.087	0.558	0.395	0.125	−0.007	1					
GS	0.157	0.348	0.468	0.396	0.322	0.378	1				
FD	0.043	0.194	0.434	0.166	0.194	0.235	0.575	1			
FDI	0.252	−0.199	0.051	0.299	0.098	−0.287	−0.160	−0.101	1		
TRADE	0.347	−0.519	−0.213	0.329	−0.080	−0.537	−0.357	−0.295	0.593	1	
NR	−0.114	−0.022	−0.298	−0.337	−0.106	−0.274	−0.082	−0.201	−0.096	−0.086	1

green growth. Correlation coefficients for LP-GG, ICT-GG, HC-GG, REP-GG, GS-GG, FD-GG, FDI-GG, and Trade-GG are positive, confirming the positive impact of all these control variables on green growth. Conversely, the correlation between NR-GG is found negative, confirming that natural resource is negatively correlated with green growth. Shrestha (2020) argued that correlation testing enables researchers to detect the existence of multicollinearity among variables of interest. Table 4 shows that no variables are perfectly correlated, allowing us to estimate the model.

Our study also used VIF test to detect the multicollinearity issue among variables of concern. Table 4 shows the results of VIF and 1/VIF. According to the rule of thumb, a VIF value >10 and 1/VIF value below 0.1 indicates the existence of multicollinearity. The highest VIF score in our model is documented for Trade variable i.e. 3.61 and lowest VIF score is reported for HC i.e., 1.4. In summary, none of the VIF scores in our model is >10 and none of the 1/VIF scores is below 0.1, which confirms the absence of multicollinearity among explanatory variables in our model. Moreover, the mean VIF score in our model is 2.23, confirming that the extent of multicollinearity in the model is quite low.

Table 4: VIF results

Variables	VIF	1/VIF
TRADE	3.61	0.277
LP	2.71	0.369
CEI	2.65	0.377
ICT	2.59	0.386
GS	2.33	0.430
REP	2.18	0.458
FD	1.78	0.561
FDI	1.66	0.602
NR	1.42	0.705
HC	1.40	0.716
Mean VIF	2.23	

5. EMPIRICAL RESULTS AND DISCUSSION

This study presents the basic results using fixed and random effect models in Table 5. To ensure consistency, 2SLS and GMM methods were also applied. In Table 5, The FE and RE models results show that the effect of CEI on GG is insignificant. Contrary to this, the 2SLS and GMM results reveal that the effect of CEI on GG is positive and significant with coefficient estimates 0.027 and 0.024, respectively. These findings reveal that a 1% increase in the CEI is linked with the 0.027% and 0.024% increase in the GG. This shows that circular economy innovation effectively stimulates green growth in the selected sample of European economies.

In support of our finding, Belmonte-Ureña et al. (2021) demonstrate that there exists a close linkage between circular economy and green growth. The justification is that circular economy practices play a significant role in driving environmental sustainability and resource efficiency. A study by Apostu et al. (2023) highlighted the importance of recycling rates in fostering green growth. The results inferred that circular economy strategies, such as remanufacturing, recycling, and material reuse, not only control the depletion of natural resources but also mitigate environmental degradation and waste generation, thus promoting green growth. Moreover, our findings align with Yu et al. (2023). These studies report that the adoption of circular economy strategies opens new avenues for development, stimulates innovation, and improves economic competitiveness. A study by Busu and Trica (2019) explored the circular economy performance in the case of UK, Germany, Netherlands, and Nordic nations, and concluded that circular economy leads to increased job creation and industrial productivity, thus stimulating growth. The results also suggest that circular economy practices reduce production cost, enhancing industrial competitiveness and productivity. Our findings are consistent with Belmonte-Ureña et al. (2021), who highlighted that circular economic model is sustainable, feasible, and value-added strategy for the green growth. Acircular economy can boost renewable energy production, a key driver of green growth. Similar findings are reported by Shobande et al. (2024) for Europe. While, REP has an insignificant role in GG in all models.

Table 5: Green growth estimates (FE, RE, 2SLS, GMM)

Variables	FE	RE	2SLS	GMM
	(1)	(2)	(3)	(4)
L.GG				0.184**
				(0.079)
CEI	0.024	0.020	0.027**	0.024*
	(0.028)	(0.026)	(0.013)	(0.014)
REP	0.167	0.120	0.300	0.251
	(0.268)	(0.093)	(0.288)	(0.194)
LP	0.127	0.235**	0.202*	0.184*
	(0.110)	(0.103)	(0.112)	(0.097)
ICT	1.843***	1.612***	3.831***	0.864*
	(0.461)	(0.336)	(0.960)	(0.464)
HC	0.134	0.305	0.026	0.298
	(0.313)	(0.251)	(0.333)	(0.322)
GS	0.142***	0.078***	0.219***	0.130***
	(0.032)	(0.024)	(0.046)	(0.030)
FD	0.127	0.098	0.787**	0.557**
	(0.216)	(0.142)	(0.357)	(0.237)
FDI	0.019	0.011	0.011	0.019
	(0.026)	(0.026)	(0.028)	(0.020)
Trade	0.167	0.336	1.185*	0.804*
	(0.457)	(0.245)	(0.642)	(0.418)
NR	0.014	0.049	0.115	0.002
	(0.058)	(0.053)	(0.074)	(0.042)
Constant	2.838	7.713***	8.169*	11.14*
	(3.423)	(2.209)	(4.234)	(3.884)
Observations	206	206	206	139
Number of countries	24	24	24	23

***P<0.01, **P<0.05, *P<0.1

The result of the control variables reveals that LP enhances the GG. The coefficients obtained from the RE, 2SLS, and GMM models are positive and significant with coefficient values 0.235, 0.202, and 0.184, respectively. These findings show that a 1% improvement in LP is associated with a 0.235%, 0.202%, and 0.184% increase in the GG. This implies that logistics performance contributes positively to determining the European economies' green growth. This outcome is consistent with the findings of Sikder et al. (2024), who denoted the positive impact of logistics performance on economic growth. Regarding the ICT variable, the results of the FE, RE, 2SLS, and GMM models reveal that ICT positively and significantly affects GG. The coefficient estimates of ICT are 1.834, 1.612, 3.831, and 0.864, respectively. This infers that a 1% rise in ICT is associated with a 1.834%, 1.612%, 3.831%, and 0.864% increase in the GG. This finding is in accordance with the finding of Zheng et al. (2023), who reported that ICT improves green growth through reducing pollution emissions.

The GS result indicates that government spending positively and significantly affects green growth. The FE, RE, 2SLS, and GMM coefficient estimates of GS depict that a 1% rise in GS results in a 0.142%, 0.078%, 0.219%, and 0.130% increase in the GG. This result aligns with the findings of Zhang et al. (2021). The FE and RE models results indicate that the effect of FD and TRADE on GG is statistically insignificant. Whereas, the 2SLS and GMM models results suggest that the impact of FD and TRADE on GG is significant and positive. This shows that a 1% rise in the FD is linked with the 0.787% and 0.557% increase in the GG. The TRADE estimates depict that a 1% rise in the trade results in a 1.185% and 0.804% increase in the GG. Xu (2022) reported a similar positive impact of trade openness on green growth. The results of the FE, RE, 2SLS, and GMM models reveal that the effect of HC, FDI, and NR on GG is statistically insignificant in our study.

We use QR and SIVQR techniques for robustness analysis. In Table 6, the QR and SIVQR result shows at low, medium, and high quantiles (0.25, 0.50, 0.75). The CEI positively influences GG at low, medium, and high quantiles (0.25, 0.50, 0.75) and the QR coefficients are 0.126, 0.016, and 0.031, while SIVQR coefficients are 0.296, 0.182, and 0.235. REP positively and significantly impacts GG at medium and high quantiles (0.50, 0.75) in SIVQR model. LP and ICT significantly and positively affect GG at low, medium, and high quantiles (0.25, 0.50, 0.75) in QR model, while LP and ICT are found significantly positive at medium and high quantiles (0.50, 0.75) in SIVQR model. HC exerts a significant and positive impact on GG only at a high quantile (0.75) in QR

Table 6: Estimates of green growth (QR and SIVQR)

Variables	QR			SIVQR		
	(0.25)	(0.50)	(0.75)	(0.25)	(0.50)	(0.75)
CEI	0.126**	0.016*	0.031**	0.296**	0.182*	0.235**
	(0.053)	(0.009)	(0.015)	(0.121)	(0.105)	(0.100)
REP	0.056	0.048	0.032	0.014	0.101***	0.113*
	(0.056)	(0.033)	(0.039)	(0.229)	(0.036)	(0.061)
LP	0.531***	0.532***	0.508***	0.057	0.742**	0.983***
	(0.183)	(0.108)	(0.130)	(1.461)	(0.378)	(0.242)
ICT	1.192***	1.328***	0.623**	0.849	0.955***	1.004***
	(0.435)	(0.256)	(0.309)	(2.222)	(0.364)	(0.327)
HC	0.139	0.234	0.592**	0.384	0.429	0.329
	(0.387)	(0.228)	(0.275)	(1.332)	(0.746)	(1.030)
GS	0.015	0.029**	0.016	0.002	0.022	0.038**
	(0.021)	(0.012)	(0.015)	(0.104)	(0.021)	(0.018)
FD	−0.026	0.113	0.111	0.117	0.029	0.061
	(0.118)	(0.069)	(0.083)	(0.408)	(0.124)	(0.086)
FDI	0.034	0.065**	0.059*	0.034	0.042	0.035
	(0.046)	(0.027)	(0.032)	(0.177)	(0.031)	(0.031)
Trade	0.754***	0.492***	0.513***	0.983	0.464*	0.283*
	(0.199)	(0.117)	(0.141)	(1.395)	(0.249)	(0.163)
NR	0.083	0.105**	0.105**	0.0277	0.158***	0.192***
	(0.071)	(0.042)	(0.050)	(0.511)	(0.055)	(0.068)
Constant	9.234***	8.808***	7.460***	9.541	8.390**	7.682*
	(2.035)	(1.196)	(1.443)	(8.931)	(3.425)	(4.531)
Observations	206	206	206	206	206	206
Number of countries	24	24	24	24	24	24

***P<0.01, **P<0.05, *P<0.1

model. GS variables report a significant and positive impact on GG at the medium quantile (0.50) in QR and at high quantile (0.75) in SIVQR. Impact of FD on GG is found statistically insignificant at all quantiles in both QR and SIVQR models. FDI positively impacts GG at all quantiles in QR and SIVQR models. While only the medium and higher quantiles coefficients are statistically significant in QR model. Trade positively impacts GG at all quantiles in QR and SIVQR models; while all coefficients are statistically significant except the lower quantiles coefficient in SIVQR model. NR reports a significant and positive impact on GG at medium and high quantiles (0.50, 0.75) in both QR and SIVQR models.

6. CONCLUSION AND POLICY RECOMMENDATIONS

In recent years, urgent challenges of resource scarcity, climate change and environmental degradation have raised the importance of circular economy strategies. The circular economy, including material reuse, recycling, energy recovery, and waste reduction, presents a better alternative to the traditional linear economic model. The circular economy initiatives support the sustainability of the consumption of natural resources. Moreover, green growth, aiming to enhance environmental sustainability, social equity, and economic prosperity, is recognized as a fundamental aspect of development strategies. Despite the growing importance of green growth initiative, there remains a significant gap regarding the empirical nexus between circular economy strategies, renewable energy, and green growth, particularly in the European region. Therefore, the present study addresses this gap by exploring the impact of circular economy and renewable energy on green growth in Europe from 2010 to 2022. By employing 2SLS, GMM, and quantile regression methodology, the study reports the following outcomes: The findings confirm a favorable impact of circular economy and renewable energy on green growth. In addition, logistic performance, ICT, government spending, financial development, and trade openness also prove vital determinants of green growth. All these factors influence green growth favorably, confirming that these factors help decouple economic growth and environmental impacts.

Our findings point towards the following policy recommendations. Firstly, there should be more determined efforts to restore green innovation policies prioritizing eco-friendly technologies' growth. This approach will reduce waste generation and stimulate sustainable green growth. Secondly, policymakers should incentivize consumers and producers to enhance waste recycling capabilities through a combination of subsidies, taxes, and incentives. Additionally, the regression analysis indicates the enhancing impact of the circular economy on green growth. Thus, European governments and policymakers should prioritize technology development by incentivizing adopting and creating eco-friendly technologies. Such policies should be formulated to encourage waste recycling capacity by utilizing financial incentives for waste generation to drive green growth. Thirdly, policymakers should formulate policies promoting circular economy practices, including product design for recyclability and durability and encouraging circular supply chains. Fourthly, public awareness campaigns should be initiated that inform stakeholders about the potential benefits of the circular economy. Furthermore, governments should encourage circular investment and finance through mechanisms like tax incentives, preferential loans, and green bonds for circular economy initiatives, activating private sector resources for circular economy projects. Fifthly, it is suggested that circular economy policies that include economic policy, R&D, employment, industrial policy, consumption, agriculture, water, and development in less developed areas will make economies less unprotected and more competitive, thus contributing to overall green growth. Lastly, governments should implement policies that promote waste prevention, enhance the consumption of recycled materials, and substitute resources in production processes. Given the positive connection between renewable energy and green growth, we suggest that policymakers proactively promote creating and implementing eco-friendly energy technologies to achieve green economic objectives. Implementing targeted tax incentives, R&D funding, and public-private cooperation focusing on enhancing green energy production may be successful.

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