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Towards a circular economy: Implications for emission reduction and environmental sustainability

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Abstract

Governments and policymakers worldwide have been setting targets to achieve an ambitious net-zero emission target by 2050 to tackle the pressing issue of climate change. However, achieving the net-zero emission target by 2050 depends on the factors determining the transition from traditional fossil fuel energy sources to renewables. In connection with this, policymakers have emphasised the need to transition from a linear to a circular economy. In this paper, we investigate the effectiveness of the progress towards a circular economy in reducing CO_2 emissions and promoting environmental sustainability. To do so, we use annual historical data for a panel of 29 European countries from 2000 to 2020. Using an identification strategy that adopts heteroscedastic-based instrumental variables and addresses endogeneity issues, we find that progress towards a circular economy significantly improves environmental quality via reducing CO_2 emissions. Our findings suggest that business strategies promoting recycling and circular economy practices play an important role in environmental sustainability by reducing emissions.

KEYWORDS

business strategy, carbon dioxide emissions, circular economy, climate change, environmental policy, net-zero emissions, recycling, sustainable development

1 | INTRODUCTION

Over the past few decades, many countries have committed to achieving net-Zero emissions before 2050. However, greenhouse gas (GHG) emissions have increased dramatically, and global warming has emerged as a major policy concern around the world (Alam et al., 2021; Chakraborty & Maity, 2020; Diffenbaugh & Burke, 2019; Hoegh-Guldberg et al., 2019; Pittock, 2017; Trenberth & Fasullo, 2013). Materials management activities have contributed to a significant share of GHG emissions directly or indirectly in OECD countries. Total GHG emissions are projected to reach 75 Gt CO_2-eq by 2060, of which materials management would constitute about two thirds (50 Gt CO_2-eq) of the projected total emissions (OECD, 2020). Along these lines, the Ellen MacArthur Foundation (2021) report suggests that about 45% of the total current emissions are associated with making products that require less energy and resource use, which is in line with the basic principle of a circular economy. Moreover, it is well established that businesses play a crucial role in

Abbreviations: ARDL, Autoregressive-Distributed Lag model; CE, circular economy; CEI, circular economy indicators; CO2, carbon dioxide; COP26, 26th Session of the Conference of the Parties; EKC, Environmental Kuznets Curve; EKC, Environmental Kuznets Curve; EU, European Union; FMOLS, fully modified ordinary least square; GHG, greenhouse gas; IPAT, impact of population, affluence and technology; IV, instrumental variable; OECD, Organisation for Economic Co-operation and Development; IPCC, Intergovernmental Panel on Climate Change; GMM, generalized method of moments; SDG, Sustainable Development Goals.

safeguarding the environment (Erdiaw-Kwasie et al., 2017; Triguero et al., 2022; Welford, 2016). As a result, promoting business strategies aimed at promoting and driving circular economy practices at the firm level is gaining growing relevance in the policy and research circles, particularly around climate change issues (Agrawal et al., 2021; Antonioli et al., 2022; Barreiro-Gen & Lozano, 2020; Falk & Hagsten, 2020; Kennedy & Linnenluecke, 2022; Suchek et al., 2021). Perhaps we should answer a more fundamental question: To what extent circular economy indicators can influence carbon emissions?

In a circular economy (CE), the main objective is to maximise the value of products, materials and natural resources (renewable and non-renewable energy, water, wood, metals, etc.); use waste as a resource; and minimise waste generation (Bressanelli et al., 2019; Moktadir et al., 2020; Morseletto, 2020; Ünal & Shao, 2019; Urbinati et al., 2017). By promoting a circular economy, net Zero can provide substantial economic benefits at the global, national and household levels (Gregorio et al., 2018; Lyeonov et al., 2019; Wang & Brown, 2014). It is possible to reduce greenhouse gas emissions by improving material flow efficiency and extending the useful life of products and materials (Çimen, 2021; Munaro et al., 2020; Ness & Xing, 2017). Based on Ness and Xing (2017), circular economy strategies drive changes in corporate operations, product and service offerings, and supply chains, all of which reduce waste and pollution. Also, circular economy intermediaries may increase the rate of packaging and partnership innovations (Jabbour et al., 2020; Ormazabal et al., 2018) and advance reusability (Ferasso et al., 2020; Lazarevic & Valve, 2017; Salmenperä et al., 2021; Zhijun & Nailing, 2007). Additionally, Preston (2012), Mhatre et al. (2021) and Joensuu et al. (2020) claim that a circular economy can help countries make use of new, environmentally friendly technologies to minimise the use of virgin materials, design for recovery and use low-carbon materials. In this way, pollution can be significantly reduced.

According to the Circularity Gap Report (2021), transitioning to a circular economy could reduce greenhouse gases by 39% and ease pressure on virgin materials by 28%. Some scholars have observed that cyclical systems consume resources and cause waste and emissions because of the energy required to operate (Corvellec et al., 2021; Haas et al., 2015; Korhonen et al., 2018; Skene, 2018). A circular economy, thus, seems to have an ambiguous effect on carbon emissions: positive, negative and no significant impact. Perhaps the controversy over the circular economy results is due to the complex mechanisms through which it influences carbon emissions. In the studies cited above, the direct effects of the circular economy on carbon emissions were evaluated using circular economy indicators as explanatory variables. A circular economy can also indirectly reduce carbon emissions (Genovese et al., 2017; Skene, 2018).

There are at least three ways that a progress towards a circular economy with effective business strategies and practices can reduce greenhouse gas (GHG) emissions. First, by eliminating waste and pollution, a circular economy can reduce the GHG emissions that emanate from the production of the materials that go to waste. Second, a circular economy can reduce GHG emissions by retaining the embodied energy in products and materials by recycling them instead of producing new primary products and materials that produce GHG emissions. Third, a circular economy enables storing and retaining carbon in the soil, which helps improve soil and environmental quality. In line with this, the Ellen MacArthur Foundation (2021) report indicates that the circular economy can play a crucial role in achieving the net-zero emission target with an estimated GHG reduction of 9.3 billion tonnes by keeping materials in use, designing out waste and regenerating farmland. This reduction in GHG emissions is estimated to be equivalent to the current global emissions from all forms of transport (Ellen MacArthur Foundation, 2021).

Governments, international bodies, industry groups and the public continue to focus on net-zero emissions. The United Nations climate summit in Glasgow in November 2021, called COP26, highlighted its importance at length. Due to carbon emissions being one of the leading causes of global warming, there has been a vast literature examining the causes and alternative strategies for mitigating carbon emissions (Abbasi & Riaz, 2016; Charfeddine & Kahia, 2019; Zaidi et al., 2019; Zhu et al., 2016). In addition, economic growth, population growth and trade have been examined in literature as antecedents to environmental quality (Begum et al., 2015; Hailemariam et al., 2020; Ivanovski & Marinucci, 2021; Nasreen et al., 2017; Panayotou, 2016; Shahbaz et al., 2013). These studies have focused on reducing energy-related CO_2 emissions through energy efficiency and renewable energy. However, buying carbon offsets and cutting operational carbon is not enough to reach Net-Zero (Kreibich & Hermwille, 2021; McLaren et al., 2019). It will only reduce emissions by half, which is not enough to reduce global warming and reach the net zero target.

To sum up, much of the existing literature on emissions and climate change has focused on the role of energy consumption and energy intensity along with some other macro variables. However, studies focused on the role of circular economy have been largely ignored. Some evidence shows that the largest share of carbon footprints in many countries come from scope 3 emissions, making circular strategies seem especially relevant (Lin et al., 2013; Onat et al., 2014; Pattara et al., 2012). It is imperative to understand the circular economy's effectiveness in promoting environmental sustainability so that policymakers can create favourable conditions for carbon emission reductions.

This paper aims to fill this gap in the literature by investigating the impact of progress towards circular economy (measured by the recycling rates of municipal waste, recycling of biowaste and packaging waste) on carbon emissions using recently innovated panel data techniques. To do so, we use 20 years of annual historical data for European countries from 2000 to 2020 and employ an instrumental variable approach to pin down the causal effect of the transition to a circular economy on CO_2 emissions. Our findings reveal that progress towards a circular economy significantly reduces emissions. Specifically, our instrumental variable estimates reveal that a 1% increase in the recycling rate of municipality waste leads to approximately a 0.06% reduction in CO_2 emissions.

Compared to previous studies, this study contributes to the extant literature in three significant ways. To begin with, this study offers rigorous empirical evidence as to how circular economy and CO_2 emissions are interconnected. In the empirical analysis, the study contributes to the limited literature on the nexus between the circular economy and carbon emissions by illustrating the disaggregated measures of the circular economy using more extended historical panel data. Methodologically, our modelling framework follows a sound identification strategy based on an instrumental variable approach that enables us to pin down the causal effect of the circular economy on CO_2 emissions.

The remainder of this study is structured as follows. Section 2 presents the literature review related to the key concepts of the paper. The next section discusses the data and methodology employed in this paper. Section 4 presents the empirical results and discussions. Finally, Section 5 concludes.

2 | BRIEF LITERATURE REVIEW

2.1 | Circular economy and CO_2 emissions

The number of research studies evaluating carbon emissions and addressing them is extensive, and variations in programmes, models, scopes and conclusions stem mainly from the variables used. One of the first studies to examine the link between human activities and carbon emissions was conducted by Ehrlich and Holdren (1971), who developed a model based on the IPAT, which examines key drivers of anthropogenic environmental impacts. Three basic factors contribute to the success of this model: population (P), affluence (A) and technology (T). IPAT model was improved by Dietz and Rosa (1997) and Zhu and Peng (2012). In spite of this, it is still inconclusive to attribute the sole cause of carbon emissions to the population even if affluence and technology are constant.

Various studies have explored the effects of energy consumption on carbon emissions, income-based accounting, and production-based accounting methods (Li et al., 2018; Martínez-Zarzoso & Maruotti, 2011; Wu et al., 2016). For example, Davis and Caldeira (2010) have questioned the adequacy of the production-based perspective for its tendency to result in carbon leakages, which pose serious policy efficiency difficulties. Recent studies have explained a rise in carbon-cutting programmes such as carbon taxes and emission trading systems (Davis & Caldeira, 2010). A major limitation of carbon pricing is the difficulty in measuring how much carbon is produced, the lack of standardisation in measuring emissions, and the likelihood that companies will purchase carbon offsets instead of reducing their emissions (Ellerman et al., 2003; Green, 2021; Klenert et al., 2018). Considering these findings, more recent studies suggest the need for innovative approaches and solutions that can drive net-zero transition across all carbon scopes (Krishnan et al., 2022; Mensah et al., 2018).

A more debated academic question about indirect carbon emissions among countries also underlines this popular discussion. To begin with, understanding the differences between direct emission and indirect emission is important in addressing this concern. A direct GHG emission (scope 1) is created directly from the production of goods (factory fumes, for example), regardless of whether the source is owned or controlled by the reporting entity. Indirect GHG emissions (scopes 2 and 3), on the other hand, are produced by activities of a reporting entity but occur at sources owned or controlled by a different party (e.g., emissions from purchased electricity, steam and heating/cooling; emissions caused by vendors within the supply chain). The performance of countries around the world has improved considerably in recent years, both direct emissions (scope 1) (Fontaras et al., 2017; Nejat et al., 2015; Reitz et al., 2020; Yin et al., 2015) and indirect emissions (scope 2) (Ang & Su, 2016; Blumsack & Fernandez, 2012; Cho et al., 2014; Petchers, 2020; Romm, 2014). However, recently released studies have indicated that energy efficiency alone will not reach net-zero targets (Deng et al., 2014; Wei et al., 2021). In addition to business travel, procurement, waste and water, other determinants of scope 3 carbon emissions have been discussed (Braam et al., 2016; Harangozo & Szigeti, 2017; Klein-Banai & Theis, 2013; Ozawa-Meida et al., 2013) but have not been thoroughly studied.

A few but growing number of studies have examined the relationship between circular economy and carbon emissions. Most of these studies have used panel data, typically spanning a period of just over 10 years, to study a sample of firms, sub-national regions or countries (Magazzino et al., 2021; Pauliuk, 2018; Pauliuk et al., 2012; Robaina et al., 2020). For example, in their study, Pauliuk et al. (2012) examine the effects of dynamic material flow on production, recycling and iron ore consumption during 2001–2010 in the Chinese steel cycle. Magazzino et al. (2021) examined the causal relationship between MSW generation and income level, urbanisation and GHG emissions from waste disposal in Denmark.

Similarly, a study by Robaina et al. (2020) estimates the efficiency of 26 European countries using a Multidirectional Efficiency Analysis, considering the generation of waste, recovery and recycling of plastic based on the generation of waste and recovery of plastic from recycling. In a meta-analysis examining changes in gross domestic product, job creation, and CO_2 emissions, Aguilar-Hernandez et al. (2021) examine more than 300 circular economy scenarios. These studies find that CO_2 emissions and circular economy indicators are related. Unfortunately, many of these studies focus on relatively short periods, meaning they cannot capture changes in carbon dioxide emissions over time. In addition, addressing the endogeneity issue remains a challenge in the existing empirical studies.

There are two opposing viewpoints regarding the impact of a circular economy on CO_2 emissions. According to one strand of literature, a circular economy reduces CO_2 emissions, so the quality of the environment is improved (di Maio & Rem, 2015; Geissdoerfer et al., 2018; MacArthur, 2013). As a result, countries with strong circular policies make significant investments that lower CO_2 emissions. Pao and Chen (2021) have studied the relationship between circular economy and CO2 emissions in the European Union (EU) (2021). The researchers observed that for every 1% increase in the recycling rate of municipal waste (RMW), average CO_2 emissions decreased by 0.5%. In another study, Schwarz et al. (2021) examined the environmental impacts of recycling and the most efficient methods of recycling specific plastic polymers. According to their study model, recycling the 15 most requested polymers in Europe reduces plastics' CO_2 emissions by 73% or 200 Mtonnes CO_2 equivalent.

According to Laurijssen et al. (2010), increased recycling makes biomass more available and reduces life-cycle energy consumption and carbon dioxide emissions. A recent study by Cudjoe et al. (2021) examined how recycling steel, nonferrous metals, plastic and paper wastes would benefit energy (electricity) and the environment (greenhouse gases and air pollutants). Study results showed that solid waste recycling prevented 4765.9 billion kg of carbon dioxide emissions and 22.502 billion kg of methane emissions using the model equations method. Similarly, in a study of cointegration among MSW recycling, economic growth, carbon emissions and energy efficiency, Razzaq et al. (2021) employed bootstrapping autoregressive distributed lag models using quarterly data from 1990 to 2017. Based on the study results, 1% more MSW recycling can contribute positively to economic growth and reduce carbon emissions by 0.317% (0.157%) and 0.209% (0.087%) in the long run (short-run).

Alternatively, the second strand of literature argues that a circular economy has no significant effect on CO_2 emissions. For example, the trade relationship between China and Nigeria is used by Li et al. (2020) to investigate how a circular economy may reduce energy intensity in countries with a high mining and extractive sector. Using Fisher's ideal index decomposition and Bayesian VAR models to analyse data from 1991 to 2014, the study found that energy efficiency in mining and extractive-related sectors has not been translated into CO_2 emission reductions in both countries. In addition, Meys et al. (2020) conclude that chemical recycling technology will not reduce fossil resource consumption or greenhouse gas emissions, given that their minimal environmental impacts are already higher than those of current benchmark waste treatment methods. Similarly, Cudjoe et al. (2021) studied steel, plastics and paper recycling in China and found that recycling these three materials negatively impacted the environment in terms of emissions. Finally, through panel cointegration and causality analysis, Bayar et al. (2021) discuss how municipal waste recycling and renewable energy affect the environmental sustainability in EU member states from 2004 to 2017. Based on their causality analysis, recycling rate, renewable energy and carbon dioxide emissions had no significant interaction.

In sum, two main segments of inconsistency characterise the evidence in the limited empirical literature. Based on the first group of empirical studies, circular economy indicators appear to reduce CO_2 emissions, while another strand of literature finds no evidence of the nexus between circular economy and CO_2 emissions. A common challenge in the existing literature is the short-span data on circular economy indicators and the lack of an appropriate identification strategy to overcome the issue of endogeneity. To fill this gap in the literature, this study uses relatively long panel data of European countries over the period 2000–2020 and employs an instrumental variable identification strategy to effectively pin down the causal effect of circular economies on CO_2 emissions.

3 | METHODOLOGY AND DATA

3.1 | Methodology

To investigate the effect that the progress towards a circular economy has on per capita carbon emissions, we follow the literature (e.g., Churchill et al., 2018) and adopt an empirical model based on the popular theoretical foundation of the Environmental Kuznets Curve (EKC) hypothesis of the form:

$$CO2_{it} = \alpha_i + \beta_1 CEI_{it} + \theta_1 Y_{it} + \theta_2 Y_{it}^2 + X_{it}'\gamma + \mu_t + \varepsilon_{it}, \tag{1}$$

where $CO2_{it}$ is an indicator is per capita carbon emissions for country i at year t and CEI_{it} denotes circular economy indicators, including recycling rates of municipal waste, biowaste and packaging waste. Y_{it} is GDP per capita, and Y_{it}^2 denotes its squared term. Following the literature (see, e.g., Ivanovski & Hailemariam, 2022), we control for a vector of control variables denoted by X_{it}, including urbanisation (% of the total population), trade (imports plus exports as % of GDP), globalisation index and freedom house's polity 2 measure of democracy. α_i denotes country fixed effects that capture time-invariant cross-country differences and μ_t are time fixed effects that capture common global shocks such as business cycles and oil price shocks. ε_{it} denotes the idiosyncratic error term that includes other relevant omitted factors.

An important econometric issue in estimating β_1 in Equation 1 is the potential bias due to endogeneity. To address this issue, we use the instrumental variable (IV) estimation approach using heteroscedastic-based instruments following the approach proposed in Lewbel (2012). This approach has been commonly employed in the empirical literature as a proper identification strategy where the zero conditional mean assumption is potentially violated (e.g., Churchill & Smyth, 2017; Dzhumashev & Hailemariam, 2021). The validity of the estimates in an IV approach relies on the plausibility of three key assumptions: (i) The instrumental variable must satisfy the condition of orthogonality; (ii) there should be a significant correlation between the instrumental variable and the endogenous variable and (iii) the exclusion restriction assumption must be satisfied so that the instrument affects the outcome variable only via its effect on the endogenous variable.

Practically, it is challenging to find external instrumental variables that simultaneously satisfy all three conditions. The innovative IV approach proposed in Lewbel (2012) offers an elegant way of constructing synthetic instrumental variables to identify structural parameters without valid external instruments. Identification is achieved using heteroscedastic-based instruments where the regressors are uncorrelated with the product of the heteroskedastic errors.

3.2 | Data

Our outcome variable is per capita carbon emissions and constitute the largest greenhouse gas share. According to the Intergovernmental

TABLE 1 Summary statistics

Variable	Mean	Std. Dev.	Min	Max	Obs.
Annual per capita CO2 emissions (mt)	7.36	3.47	2.93	25.67	545
Recycling rate of municipal waste (%)	28.95	17.70	0.00	64.30	560
Recycling of biowaste (kilogrammes per capita)	53.03	53.86	0.00	253.00	576
Recycling rate of packaging waste	56.93	12.94	5.90	85.30	443
Trade openness	114.21	65.12	42.35	408.36	603
Urbanization	72.62	13.20	50.75	98.08	603
Democracy	2.39	4.27	−3.85	10.00	507
Globalization	23.08	36.45	−34.94	88.03	545
Real GDP per capita	34,774	25,157	3,985	111,968	603

[Correction added on 17 August 2022, after first online publication: The data in Variable column in Table 1 have been updated in this version.]

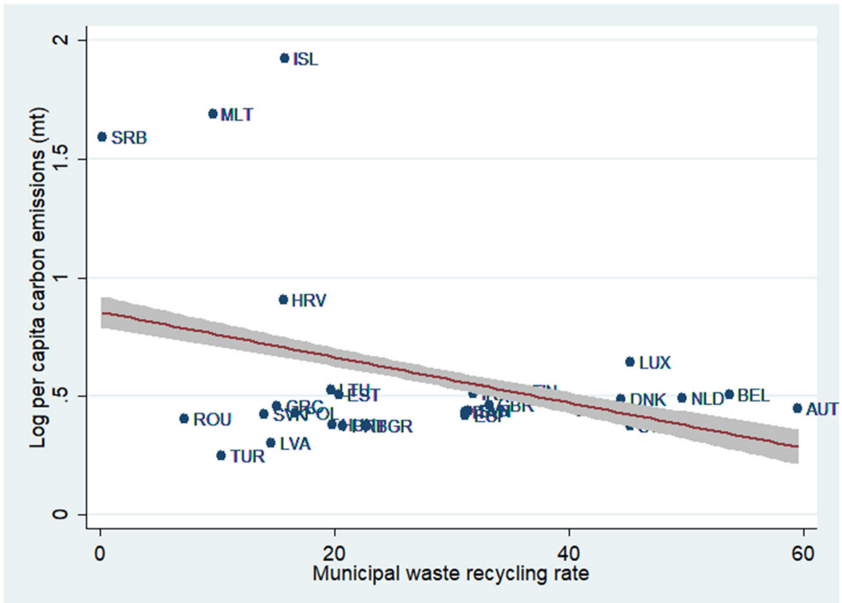

FIGURE 1 Cross-country correlation between average per capita CO2 emissions and municipal waste recycling rate

Panel on Climate Change (IPCC), CO_2 emissions from the combustion of fossil fuels and industrial processes constitute about 78% of the total greenhouse gas emissions between 1970 and 2010. Emissions from fossil fuels alone contributed to 69% of global greenhouse gas emissions in 2010.[1] It is common in the literature to use the level of per capita CO_2 emissions as a measure of environmental degradation (e.g., Churchill et al., 2019, 2021; Ivanovski & Hailemariam, 2022). Data on per capita carbon emissions are sourced from The Emissions Database for Global Atmospheric Research (EDGAR). We also use greenhouse gas emissions in our robustness check. Data on circular economy indicators (CEI), including municipal waste recycling, biowaste and packaging waste indicators, for 29 European countries are sourced from Eurostat.[2]

Our choice of sample countries is based on availability of historical data on circular economy with consistent definitions to foster comparability across countries. The European Commission developed four thematic areas consisting of ten CEIs to monitor the progress towards a circular economy in a consistent manner. While our sample is based on European countries, the results of this study have external validity in other advanced economies.

In this paper, we use two indicators: recycling rates (the share of recycled waste) and specific waste streams (packaging waste and biowaste), for which time series data for a panel of European countries is available for the period from 2000 to 2020. Data for all the control variables are sourced from the Quality of Governance database of the University of Groningen. Table 1 presents the summary statistics of the key variables. As shown in Table 1, the mean value of CO_2 per capita indicates that an average global citizen emits about 7.4 metric tonnes (mt) of carbon dioxide annually, with a standard deviation of 3.5 mt. Looking at the CEIs, on average, the EU countries recycle about 29% of municipal waste. However, there are significant variations in the recycling rate across the national economies, with a standard deviation of 17.7%. This variation is greater for specific recycling of biowaste. In addition, the table indicates significant variations across the sample countries for the other variables.

[1] https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter5.pdf
[2] See Table A1 for the list of the 29 European countries included in our sample.

TABLE 2 Pooled OLS estimates

	(1)	(2)	(3)
Recycling rate of municipal waste	−0.023** (0.009)		
Recycling of biowaste		−0.038*** (0.009)	
Recycling rate of packaging waste			−0.247*** (0.041)
Real GDP per capita	4.548*** (0.564)	6.713*** (0.856)	5.062*** (0.931)
Real GDP per capita squared	−0.217*** (0.029)	−0.320*** (0.043)	−0.241*** (0.046)
Trade openness	−0.334*** (0.064)	−0.392*** (0.065)	−0.270*** (0.072)
Urbanisation	−1.656*** (0.268)	−0.991*** (0.225)	−1.235*** (0.325)
Democracy	0.015 (0.021)	−0.017 (0.012)	0.061** (0.024)
Globalisation	−0.009** (0.004)	−0.010** (0.005)	−0.006 (0.005)
Observations	468	455	401
R-squared	0.942	0.945	0.949

Note: The dependent variable is per capita CO2 emission. Robust standard errors in parenthesis.
**Statistically significant at 5% significance level.
***Statistically significant at 1% significance level.

Figure 1 shows the cross-country scatter plot on the relationship between average per capita carbon emissions and the recycling rate of municipal waste. The figure shows a negative correlation between the two variables.

Before proceeding to our main estimations, we examine the time series properties of the data by performing panel unit root tests. We employ the panel unit root test procedure proposed by Im et al. (2003).[3] This test relaxes the homogeneity assumption imposed in other unit root test approaches by allowing heterogeneous autoregressive parameters. The test statistic is computed as the average of the traditional individual Augmented Dickey–Fuller statistics with the null hypothesis of a common unit root in all series and an alternative hypothesis that allows for some series to be stationary. The panel unit root test results are reported in Table A2. Most of the variables have a unit root in levels, while the variables are stationary at the first difference, indicating that the variables are integrated of order one, I(1).

4 | EMPIRICAL RESULTS AND DISCUSSIONS

4.1 | Benchmark results

As a benchmark exercise, we begin by discussing our results from the baseline pooled OLS model. Table 2 presents the basic estimates of the effect of progress in the circular economy on per capita carbon emissions. Standard errors are robust against heteroscedasticity in all regressions. As shown in Table 2, the coefficient on each circular economy indicator (the recycling of municipal waste, biowaste and packaging) is negative and statically significant at a 1% significance level. Our results suggest that progress towards a circular economy reduces environmental degradation. The economic interpretation of our estimates is that, on average, a 1 percentage point increase in the recycling rate of municipal waste is associated with emission reductions ranging from about 0.02% to 0.04%. The estimated coefficients on recycling rates of manucipal waste, biowaste and packaging indicate the effectiveness of the progress towards a circular economy in reducing emissions.

While the pooled OLS estimates are informative of the association between the performance of the circular economy and carbon emissions, they could be biassed and inconsistent in the presence of serial correlation and endogeneity. To deal with this empirical issue, we perform alternative estimations using fully modified OLS (FMOLS) and instrumental variable approaches in the following section.

4.2 | Main results

The pooled OLS estimates are useful for establishing the association between circular economy performance and per capita carbon emissions. However, they do not necessarily indicate causality due to the limitations of pooled OLS technique in addressing unobserved common factors and endogeneity issues. Therefore, this section employs the FMOLS and an instrumental approach developed by Lewbel (2012).

The FMOLS approach is an effective method to deal with the problems of asymptotic bias and nuisance parameter dependency associated with cointegrating vector estimates (Phillips and Hansen, 1990). As confirmed in later studies (e.g., Pedroni, 2001; Phillips, 1995), the attractive feature of the FMOLS estimator is that it performs relatively well in empirical studies for making inferences in cointegrated panels with heterogeneous dynamics, even for panels with relatively short time-series dimensions. The advantage of the FMOLS estimator is that it accounts for the issues of potential serial correlation and endogeneity of the regressor so that the estimates are unbiased and consistent even under the presence of endogenous

[3]Since we have unbalanced panel data, it does not allow us to perform the Pesaran (2007) panel unit root test that allows cross-sectional dependence in addition to heterogeneity.

regressors. Furthermore, the FMOLS estimator employs a non-parametric approach to correct the endogeneity bias. The non-parametric approach avoids the risk of misspecifications (Hailemariam et al., 2019).

In Table 3, we report the Fully Modified (FMOLS) estimates. As can be seen from the Table, the estimated coefficients on each circular economy indicator are negative and statistically significant at a 1% significance level. These estimates are consistent with the benchmark results qualitatively. However, the FMOLS estimates are quantitatively larger than the basic Pooled OLS estimates suggesting the downward bias of the estimates from the benchmark model.

In a more rigorous approach to addressing the issue of endogeneity, we employ the innovative heteroscedastic-based instrumental variable approach proposed by Lewbel (2012). While the FMOLS estimators help address unobserved effects, they may not necessarily pin down the causal effect of progresses in circular economy on the environment. This is likely mainly due to the endogeneity bias that may arise from measurement error or reverse causality. Failure to address the endogeneity issue will lead to biassed and inconsistent estimates of the effect of the circular economy on carbon emissions. To address this issue, we utilise an instrumental variable estimation approach using heteroscedasticity-based instruments following the procedure proposed by Lewbel (2012). This method is commonly applied in empirical research as a proper identification strategy in the absence of valid external instruments, and the zero conditional mean assumption is potentially violated (e.g., Dzhumashev & Hailemariam, 2021).

Table 4 presents the instrumental variable estimates using Lewbel's (2012) two-stage least square estimator. The results show that the estimated coefficients on the circular economy indicators are negative and statistically significant at the 1% significance level. The results suggest that circular economy progress reduces carbon dioxide emissions and improves environmental quality. Specifically, a 1% increase in the recycling rate of municipality waste leads to a 0.068% reduction in per capita carbon emissions. Compared to the pooled OLS estimates reported in Table 2, the IV estimates are quantitatively larger for all circular economy indicators used in this study. Our results emphasise the importance of controlling for endogeneity to minimise the downward bias in the estimates of the effect of the circular economy on carbon emissions.

Looking at the diagnostic test for the heteroscedastic-based instruments' quality, the *p* values for the Hansen-J test of overidentification restriction are way above 0.1 (Columns 1 and 2 of Table 4). This indicates that the instruments satisfy the assumptions for the exclusion resection; hence, the test statistic cannot reject the null hypothesis that the heteroscedastic-based instruments are valid. The null is rejected only in Column 3.

How do our results compare with the findings of the existing studies? While only scanty literature has examined the effect of progress towards a circular economy on CO_2 emissions, our results are consistent with the findings of the few existing studies (e.g., Aguilar-Hernandez et al., 2021; Gallego-Schmid et al., 2020; Xue et al., 2019). Specifically, Aguilar-Hernandez et al. (2021) find that implementing ambitious circular economy scenarios could generate significant environmental benefits by reducing CO_2 emissions estimated at an inter-quartile range of −34.0% to −8.2% by 2030. Along these lines, Pao and Chen (2021) find that a circular economy effectively reduces CO_2 emissions in European Union (EU) countries. Furthermore, their study found that a 1% increase in the recycling rate of municipal waste is associated with a reduction in CO_2 emissions by 0.5%. This finding is similar to our IV estimate of the effect of an increase in the recycling rate of municipal waste on CO_2 emissions for EU countries. Several other studies document evidence on the environmental benefit of a circular economy (see, e.g., di Maio & Rem, 2015; Geissdoerfer et al., 2018; MacArthur, 2013; Schwarz et al., 2021; Laurijssen et al., 2010; Razzaq et al., 2021).

What explains the observed results in the relationship between circular economy and environmental quality? Environmental degradation can be significantly reduced by promoting a circular economy that facilitates environmentally friendly technologies to minimise the use

TABLE 3 FMOLS estimates

	(1)	(2)	(3)
Recycling rate of municipal waste	−0.624*** (0.040)		
Recycling of biowaste		−0.746*** (0.018)	
Recycling rate of packaging waste			−0.680*** (0.247)
Real GDP per capita	11.535*** (0.938)	5.651*** (0.664)	19.219*** (2.029)
Real GDP per capita squared	−0.540*** (0.046)	−0.228*** (0.032)	−0.894*** (0.098)
Trade openness	0.783*** (0.062)	0.511*** (0.033)	1.180*** (0.106)
Urbanisation	1.228*** (0.196)	−0.259** (0.101)	1.144*** (0.330)
Democracy	−0.369*** (0.044)	−0.320*** (0.021)	−1.088*** (0.151)
Globalisation	0.014* (0.008)	0.127*** (0.005)	0.001 (0.017)
Observations	467	454	400

Note: The dependent variable is per capita CO2 emission. Robust standard errors in parenthesis.
*Statistically significant at 10% significance level.
**Statistically significant at 5% significance level.
***Statistically significant at 1% significance level.

of virgin materials, design for recovery, and use low-carbon materials (Joensuu et al., 2020; Mhatre et al., 2021; Preston, 2012). In line with this, the evidence from the Circularity Gap Report (2021) indicates that a transition to a circular economy could reduce greenhouse gases by 39% and ease pressure on virgin materials by 28%. To sum up, our findings of the emission reduction effect of the transition to a circular economy are well placed in the literature.

4.3 | Robustness checks and extensions

To ascertain the robustness of our main findings, we perform a series of sensitivity checks using an alternative measure of the outcome variable and an alternative estimation approach. In Table 5, we report the IV estimates of the effect of a circular economy on the environment using per capita greenhouse gas (GHG) emissions as a dependent variable. The results show that the coefficients on the three circular economy indicators are negative and statistically significant, suggesting that progress towards a circular economy significantly reduces environmental degradation.

In Table 6, we employ the difference generalised method of moments (GMM) estimator, a popular workhorse in empirical literature with dynamic panel data. The GMM estimator is appealing for its capability to address the issue of endogeneity using internal instruments (Arellano & Bond, 1991). Table 6 reports the GMM estimates of the effects of a circular economy on per capita CO_2 emissions

TABLE 4 Lewbel (2012) IV estimates of the effect of circular economy on CO2 emissions

	(1)	(2)	(3)
Recycling rate of municipal waste	−0.068*** (0.013)		
Recycling of biowaste		−0.042** (0.017)	
Recycling rate of packaging waste			−0.470*** (0.130)
Real GDP per capita	6.006*** (1.043)	8.094*** (2.039)	1.578*** (0.286)
Real GDP per capita squared	−0.291*** (0.054)	−0.402*** (0.105)	−0.065*** (0.017)
Trade openness	−0.154* (0.082)	−0.282*** (0.092)	−0.235** (0.094)
Urbanisation	−2.717*** (0.461)	−2.159*** (0.517)	−1.416*** (0.253)
Democracy	0.015 (0.029)	−0.033** (0.015)	0.056 (0.040)
Globalisation	−0.015** (0.006)	−0.010 (0.008)	−0.010 (0.009)
Observations	468	455	401
R-squared	0.412	0.434	0.489
Hansen J *p* value	0.59	0.277	0.01

Note: The dependent variable is per capita CO2 emission. Robust standard errors in parenthesis.
*Statistically significant at 10% significance level.
**Statistically significant at 5% significance level.
***Statistically significant at 1% significance level.

TABLE 5 Lewbel (2012) IV estimates of the effect of circular economy on GHG emissions

	(1)	(2)	(3)
Recycling rate of municipal waste	−0.119** (0.056)		
Recycling of biowaste		−0.102*** (0.034)	
Recycling rate of packaging waste			−0.388*** (0.129)
Real GDP per capita	4.294* (2.472)	5.649*** (1.648)	6.336*** (0.370)
Real GDP per capita squared	−0.190 (0.120)	−0.267*** (0.084)	−0.301*** (0.020)
Trade openness	0.038 (0.064)	−0.056 (0.084)	0.312*** (0.085)
Urbanisation	−2.049*** (0.411)	−1.646*** (0.406)	−3.897*** (0.392)
Democracy	0.033 (0.037)	−0.019 (0.018)	0.103*** (0.034)
Globalisation	−0.018*** (0.006)	−0.008 (0.007)	−0.019*** (0.007)
Observations	272	278	240
R-squared	0.475	0.363	0.998

Note: The dependent variable is per capita GHG emission. Robust standard errors in parenthesis.
*Statistically significant at 10% significance level.
**Statistically significant at 5% significance level.
***Statistically significant at 1% significance level.

TABLE 6 GMM estimates of the effect of circular economy on CO2 and GHG emissions

	(1)	(2)	(3)
Panel A: The dependent variable is per capita CO2 emission			
Recycling rate of municipal waste	−0.058** (0.023)		
Recycling of biowaste		−0.063** (0.026)	
Recycling rate of packaging waste			−0.231*** (0.065)
Controls	Yes	yes	Yes
Observations	438	424	377
AR (2)	0.20	0.47	0.10
Hansen J-test (*P* value)	1.00	1.00	1.00
Panel B: The dependent variable GHG emission			
Recycling rate of municipal waste	−0.049** (0.019)		
Recycling of biowaste		−0.091*** (0.023)	
Recycling rate of packaging waste			−0.205*** (0.064)
Controls	Yes	Yes	Yes
Observations	341	352	303
AR (2)	0.10	0.25	0.08
Hansen J-test (*P* value)	1.00	1.00	1.00

Note: Robust standard errors in parenthesis.
**Statistically significant at 5% significance level.
***Statistically significant at 1% significance level.

(Panel A) and GHG emissions (Panel B). The results in Panels A and B of Table 6 clearly show that promoting a circular economy significantly affecting the quality environment via reducing emissions.

The diagnostic test results, as shown by the second-order autoregressive (AR[2]) and the *p* value of Hansen J tests, indicate that there is no issue of serial correlation and that the instruments are valid. In sum, our main findings remain strongly robust to the various sensitivity checks. Further, we also check the sensitivity of our results by adding the lagged value of the dependent variable in our main estimation procedure. The results reported in Table A3 confirm the robustness of our main findings.

Since the EU countries are strongly interdependent, it could be the case that spatial correlation could potentially affect the estimates by underestimating the standard errors. To ascertain that our results are robust to this potential issue, we adjust the standard errors for spatial autocorrelation following the approach proposed by Conley (1999). Table A4 reports our estimates with Conley standard errors adjusted for spatial correlation. Controlling for spatial autocorrelation changes the standard errors slightly but does not change the coefficients and statistical significance reported in Table 2. The estimates show that our main findings are robust to spatial autocorrelation, suggesting that they are unlikely to be biassed with potential misspecification of the degree of spatial autocorrelation among the countries in our sample.

5 | CONCLUSION AND POLICY IMPLICATIONS

The rising global temperature and pressing climate change issues require the transition from a linear economy to a circular economy in major advanced economies and developing countries. A successful transition towards a circular economy has been identified as one of the preconditions for sustainability in the United Nation's Sustainable Development Goals (SDGs). However, limited empirical evidence exists in the extant literature on the effectiveness of the circular economy on environmental quality and sustainability.

This paper examines the role of a circular economy in reducing carbon dioxide emissions. Using indicators of circular economy (namely the recycling rates of municipal waste, recycling of biowaste and packaging waste) for a broad panel of 29 European countries for the period from 2000 to 2020 and employing recently innovated econometric methods, we find that progress towards a circular economy is effective in reducing CO_2 emissions.

Our findings have important policy implications. First, policymakers should promote business with strategies and practices that facilitate a successful transition from a linear economy to a circular economy. Specifically, it is important to promote business models that foster municipal waste recycling, design durable and recyclable products and reuse of materials in the production cycle. It is possible to substantially reduce CO_2 and other GHG emissions in a manner consistent with the Paris climate agreement through appropriate policies for effective materials management, eco-design and reuse.

Second, supportive institutions and infrastructure are needed to facilitate the transition and action towards circular practices at the firm level. The government must lead by example to demonstrate the feasibility and convince private companies to take similar actions. In some cases, government incentives can be provided to firms using grants, subsidies, or tax credits if they protect the environment. Furthermore, governments can use government subsidies to encourage firms to adopt circular business practices to reduce GHG emissions substantially. Embracing more environmentally friendly practices as part of a business strategy can be accomplished through policy interventions designed to interrupt business behaviour. As a result, we argue that businesses' strategies are more likely to reflect and maintain positive behaviour towards CO_2 reduction when provided with sustained support and positive reinforcement.

Third, it is important to communicate circular economy knowledge and information in a way that links to businesses' concerns and interests. An effective method of mitigating carbon emissions might be to relate them to business objectives and strategies, emphasising that reducing emissions reduces operating costs and increases productivity. Since businesses' business strategies are typically stable over time, feeding business strategies with circular economy knowledge can be useful for understanding how such interventions reduce carbon emissions. In addition, communication within a company can effectively stimulate circular knowledge among its employees, which can positively affect the company's environmental impact.

Fourth, stronger regulatory frameworks may be necessary to activate mitigation measures against carbon emissions. Businesses have different responses to carbon emissions: Some may take voluntary actions to reduce carbon emissions, whereas others will not be willing to act without external pressure. Regulation has become necessary today to address carbon emissions in a fair, cooperative manner and to illustrate the seriousness of the problem and the need for action. An educational programme that creates firm values and environmental citizenship, along with an incentive framework, can gradually lead to deep-rooted strategy changes towards a circular economy.

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APPENDIX A.

TABLE A1 List of countries in the sample

Austria	Ireland	Romania
Belgium	Italy	Serbia
Bulgaria	Latvia	Slovakia
Croatia	Lithuania	Slovenia
Denmark	Luxembourg	Spain
Estonia	Malta	Sweden
Finland	Netherlands	Switzerland
Greece	Norway	Turkey
Hungary	Poland	United Kingdom
Iceland	Portugal	

TABLE A2 Panel unit root test results

	Levels		First difference	
Variable	*t* statistics	*p* value	*t* statistics	*p* value
Per capita carbon emissions	−2.144**	0.017	−15.888***	0.000
Recycling rate of municipal waste	−0.980	0.100	−17.170***	0.000
Recycling of biowaste	−2.408***	0.008	−18.801***	0.000
Recycling rate of packaging waste	−3.458***	0.000	−16.058***	0.000
Real GDP per capita	2.778	0.998	−5.352***	0.000
Real GDP per capita squared	7.733	0.997	−5.413***	0.000
Trade openness	−1.055	0.146	−13.048***	0.000
Urbanisation	3.635	1.000	−7.198***	0.000
Globalisation	0.877	0.810	−14.240***	0.000

Note: The dependent variable is per capita CO2 emission. Robust standard errors in parenthesis.
**Statistically significant at 5% significance level.
***Statistically significant at 1% significance level.

TABLE A3 Robustness checks accounting for persistence

	(1)	(2)	(3)
Lagged CO2 emission	0.036*** (0.011)	0.046*** (0.012)	0.045*** (0.014)
Recycling rate of municipal waste	−0.106*** (0.024)		
Recycling of biowaste		−0.112*** (0.026)	
Recycling rate of packaging waste			−0.328** (0.134)
Controls	Yes	yes	Yes
Observations	353	339	305
R-squared	0.415	0.369	0.549

Note: The dependent variable is per capita CO2 emission. Robust standard errors in parenthesis.
**Statistically significant at 5% significance level.
***Statistically significant at 1% significance level.

TABLE A4 Robustness checks controlling for spatial autocorrelation (Conley, 1999)

	(1)	(2)	(3)
Recycling rate of municipal waste	−0.023*** (0.009)		
Recycling of biowaste		−0.038*** (0.008)	
Recycling rate of packaging waste			−0.247*** (0.039)
Real GDP per capita	4.548*** (0.543)	6.713*** (0.824)	5.062*** (0.894)
Real GDP per capita squared	−0.217*** (0.028)	−0.320*** (0.042)	−0.241*** (0.045)
Trade openness	−0.334*** (0.061)	−0.392*** (0.063)	−0.270*** (0.069)
Urbanisation	−1.656*** (0.259)	−0.991*** (0.216)	−1.235*** (0.312)
Democracy	0.015 (0.020)	−0.017 (0.011)	0.061*** (0.023)
Globalisation	−0.009** (0.004)	−0.010** (0.004)	−0.006 (0.005)
Observations	468	455	401
Spatially Correlated SE	Yes	Yes	Yes
R-squared	0.412	0.434	0.489

Note: The dependent variable is per capita CO2 emission. Conley-adjusted standard errors in parenthesis.
**Statistically significant at 5% significance level.
***Statistically significant at 1% significance level.