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The role of entrepreneurship, innovation and socioeconomic development on circularity rate: Empirical evidence from selected European countries

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A B S T R A C T

Over the last years, member states have monitored the circular economy transition and reported specific indicators to Eurostat. This study analyzes the relationship of macro data between entrepreneurship, innovation, socio-economic development, and circularity progress using a panel dataset of eighteen European Union (EU) countries from 2010 to 2019. Estimators such as feasible generalized least squares, fully modified ordinary least squares, and dynamic ordinary least squares long-run estimators are employed to yield reliable estimators. Empirical findings document that entrepreneurship, innovation, and socio-economic development significantly affect the circularity rate over the study period. In particular, the circularity rate will increase by 0.19% if entrepreneurship in Europe increases by one percent, whereas “polluting” entrepreneurship seems to have a negative association with circularity. A 1% increase in research and development (proxy of innovation) will increase the circularity rate by 0.65% on average. The annual circularity rate will also increase by 0.73% if economic growth increases by 1%. Human development index also has a high impact on the circularity process amid EU economies. Based on the empirical results, the study argues that a faster process in progressing circularity can be reached if the EU provides opportunities for increased entrepreneurship, higher levels of innovation, and more equal and fair socio-economic advancement as measured by higher human development. As there is scarce literature in this area, this study aims to pave the way in looking into further macroeconomic drivers affecting circularity.

1. Introduction

Concerns about the impacts of an overcrowded planet have emerged due to demographic trends, the demand for resources, and high levels of production and consumption (Niccolucci et al., 2012). Nowadays, about 8 billion people are looking to set a higher level of wellbeing (Sachs, 2015), consequently compromising future generations. The concept of sustainability has received increasing interest from governments, industry, academics, and decision-makers. The United Nations (UN) established the Sustainable Developments Goals (SDGs) at the new UN 2030 Agenda to promote economic, social, and environmental development. Entrepreneurial and innovative actions have been increasingly recognized as essential vehicles to guarantee sustainable development (Cullen and De Angelis, 2021; Oliveira et al., 2021). However, the impact of entrepreneurship and innovation on circularity at the macro level has received limited attention in the literature so far, mainly due to the lack of quantitative data and longtime monitoring and reporting (Kostakis and Tsagarakis, 2021). At the same time, it is known that efficient waste management and circularity can be a significant driver of sustainability targets (D’ Adamo et al., 2021). Moreover, the cyclical use of resources minimizes environmental burdens while stimulating the economy through several social benefits and job creation (Oliveira et al., 2021). Several strategies, such as material flow analysis, input-output analysis, and waste-related legislation, have been approved as policies to promote circularity (Cullen and De Angelis, 2021).

Our study might consist of a pertinent example of the empirical investigation of the relationship between entrepreneurship and circularity rate at a macroeconomic level of analysis. In particular, the present work aims to investigate the effect of entrepreneurship, innovation, and socio-economic development on environmental quality to circularity. Therefore, our research hypotheses are listed as follows:

Hypothesis 1. Technological innovation increases the circularity rate.

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Hypothesis 2. Formal entrepreneurship simultaneously promotes the circularity rate.

Hypothesis 3. Socioeconomic development leads to higher circularity rates.

Based on data availability, these hypotheses are tested in selected European Union countries, but further validation and generalization are feasible.

To the best of the authors' knowledge, the discussions in relevant literature demonstrate limited empirical macroeconomic evidence regarding the impact of entrepreneurship, innovation, and socio-economic development on the circularity rate. Several preceding papers consider related issues, but they are not based on macroeconomic relationships between the aforementioned variables. However, the authors' perception is that there should be a link between several socio-economic parameters and circularity rate. Thus, to fill the previously mentioned gap, this study is an original investigation that aims to validate the key role that sustainable entrepreneurship, research and development (innovation), and economic development can play in achieving higher levels of circularity rate within Europe.

The objectives of this research are as follows. Firstly, the entrepreneurship-innovation-development induced circularity hypotheses are examined. Secondly, this paper explores possible long-run relations between the variables mentioned above, adding potential factors such as pollution and financial development in this pre-determined model. Thirdly, this study is unique in the adopted panel data methods that also take care of possible heterogeneity across countries and produce robust and reliable estimations, for this topic. Finally, it gives evidence of the effectiveness of policies that can drive sustainability by reducing the circularity gap and the circularity nexus with other key performance indicators taking advantage of existing macro-economic data. While several indicators have been monitored for decades, the newly established ones on circularity date back only a few years, so their continuous evaluation is an apparent need.

The rest of the paper is organized as follows. Section 2 reviews the evidence available from the literature on the interrelationships among sustainability, circularity, entrepreneurship, innovation, and socio-economic development topics. Section 3 sets out the research methodology, introduces the data used and the employed econometric methodology. Section 4 displays the empirical findings. Finally, Section 5 presents a discussion with policy recommendations, whereas Section 6 presents concluding remarks.

2. Research context

Climate change and other environmental impacts have led sustainability issues to be a significant topic of conversation today. However, although sustainability has been highlighted since 1972 at the United Nations conference in Stockholm (Limits of Growth report), humanity is still far from a sustainable development path, as the needs of modern society continue to push the planet beyond its ecological limits (Cancino et al., 2018; Hummels and Argyrou, 2021). In 1992, the Rio Earth Summit, making a historical decision, recognized the importance of a comprehensive action plan to build a global partnership for sustainable development that was the base for setting more specific goals, the Sustainable Development Goals (SDGs) adopted in 2015 (General Assembly, 2015). The main idea is that all countries should operate sustainably irrespective of income or size, which means that development requires the integration of social, economic, and environmental dimensions. The European Green Deal (European Commision, 2019) and the new Horizon Europe actions provide new pillars to boost the efficient use of resources by moving to a clean and circular society and restoring biodiversity by reducing pollution and using effectively and efficiently resources.

While environmental quality and its affecting parameters have gained interest among academic circles (Li et al., 2019), economic status has been highly characterized as an essential environmental performance factor. Berglund and Söderholm (2003) analyzed panel data from 49 countries and found that wealthier countries behave more environmentally friendly than low-income ones. Similarly, at a households and stakeholders level, Jenkins et al. (2003) and Abeliotis et al. (2021) support that income has a significant effect on the intensity of recycling or preparing for reuse respectively. At a macro level, Kostakis and Tsagarakis (2021) show that wealthier countries are expected to perform better for environmental issues compared to those with lower economic growth. Furthermore, wealthier citizens are more likely to demand a cleaner environment (Torgler and Garcia-Valinas, 2007) expressing higher willingness to pay for environmental protection and services (Tziakis et al., 2009; Tsagarakis et al., 2011) and higher awareness on resources conservation (Fan et al., 2013).

The relationship between entrepreneurship and economic growth dates back several decades (Schumpeter, 1934; Solow, 1957; Lucas, 1978; Romer, 1986; Baumol, 1996), while the role of entrepreneurship in resolving environmental issues has been a subject of debate (Dean and McMullen, 2007). Europe places entrepreneurship in the center of sustainability, promoting new business models that will mitigate impacts on the environment and lead to a greener economy (Colledani et al., 2014; Schaper, 2016; Rosa et al., 2019). There is no unanimous way to define entrepreneurship among authors and schools (see German, Austrian and Neo-classical schools), having different definitions and measures (Jian et al., 2021). Nevertheless, most studies highlight the significant impact of entrepreneurship on economic prosperity and progress (Urbano et al., 2019). Mueller (2006) highlights the role of knowledge and its transformation into products, processes, and organizations contributing to economic growth. Similarly, Audretsch and Keilbach (2008) explain how the knowledge investment imbalance can lead to differentiated and unequal economic growth. Morone and Testa (2008), analyzing a sample of 2600 SMEs, point out the vital role of new and innovative entrepreneurs in the economy. Valliere and Peterson (2009), investigating a group of emerging and developed countries in 2004 and 2005, determine the effect of different types of entrepreneurship on GDP growth, highlighting the weightiness of investments in knowledge creation and regulatory freedom. Dhahri and Omri (2018), analyzing data from 20 developing countries between 2001 and 2012, found that entrepreneurship has a positive and statistically significant effect on per capita GDP. Peprah and Adekoya (2020), based on data from the World Development Indicators of ten African countries, support that entrepreneurship stimulates economic growth. Similar results are obtained from Pradhan et al. (2020), who found that in a long-run horizon, entrepreneurship induces economic growth based on a sample of the Eurozone countries over the period 2001–2016.

Although the role of entrepreneurship in market and business could be significant, it can also be questionable as it might have negative externalities on the environment such as greenhouse gas emissions, global warming, air and water pollution, deforestation, soil erosion, etc. (Chick, 2008). Traditional growth models have been criticized for the social and environmental impacts they might cause (Zeng, 2018), and societies have become increasingly aware of the environmental consequences of their actions (Morone and Yilan, 2020). Sustainable entrepreneurship has been proposed as a framework in which sustainability and entrepreneurship have been enjoined (Schaltegger and Wagner, 2011; Soleymani et al., 2021), considering a significant channel to addressing several economic, environmental, and social concerns based mainly on its innovative technological power (Pachero et al., 2010; Klewitz, 2017). This means that entrepreneurship and innovation should focus on economic progress but being in equilibrium with the ecological limits (Cohen and Winn, 2007; Pachero et al., 2010), abase global environmental degradation (Dean and McMullen, 2007; Crecente et al., 2021) and promote a sustainable society. Innovation can lead to advanced environmental technology, decreasing the cost of addressing environmental degradation (Omri, 2020). More energy-efficient appliances, changes in fuel type mixes, more sustainable production and consumption could be achievable through a technological innovation pattern (Cancino et al., 2018).

In particular, several entrepreneurship opportunities can lead to a socially and ecologically sustainable society (see *inter alia*, Ardichvili et al., 2003; Nave and Franco, 2019; George et al., 2020). Optimizing the use of water resources, utilizing environmentally-friendly technology, obeying the limitations of resources and energy, transparency in financial affairs being ethics oriented (Soleymani et al., 2021), or inter-organization cooperations (Caloghirou et al., 2001; Nave and Franco, 2019) are only a few of the proposed strategies that could promote sustainable entrepreneurship. However, entrepreneurs often have to deal with market barriers that hinder their progress (Hummels and Argyrou, 2021), while many studies have also highlighted limited circular project implementation due to various barriers (Kirchherr et al., 2018; Hart et al., 2019). Additionally, SDGs progress relies only on independent researchers and national statistical authorities incommoding common criteria and comparison. At the same time, in the business sphere, there is a lack of a common data-driven approach to assess its contribution to sustainability (Horne et al., 2020) and a lack of adequate information about the parties involved in the business cycle (Gupta et al., 2019). Sustainable entrepreneurship should also be circular within today's modern societies.

Based on Zucchella and Urban (2019), the concept of circularity is archaic and has its roots in psychical phenomena and natural cycles. In their book, they narrate that in the 18th century, the French chemist Lavoisier declared the famous statement that "*Nothing is lost, nothing is created, everything is transformed*" that is a reformulation of the idea expressed by Anaxagoras (450 BC) that "*Nothing comes into existence nor perishes, but it is rather compounded or dissolved from things that are*". Moreover, Professor Boulding (1966) introduced the core idea of circularity, highlighting that everything on the planet can be used as an input into everything else. This prophetic theory, at that time, inspired economic and social sciences to reconsider the assumption that economic wealth is not exclusively synonymous with social wellbeing but should be seen as just one of the pillars of welfare. Circular, in contrast to lineal entrepreneurship, might play a pivotal role in a new international environment (Mhatre et al., 2021; Ellen Macarthur Foundation, 2019).

The challenge of circular entrepreneurship transition is to set business production into a vicious cycle regarding waste generation, decoupling economic growth from natural resource use (Moraga et al., 2019), and leading to cleaner production. In general, the methods used

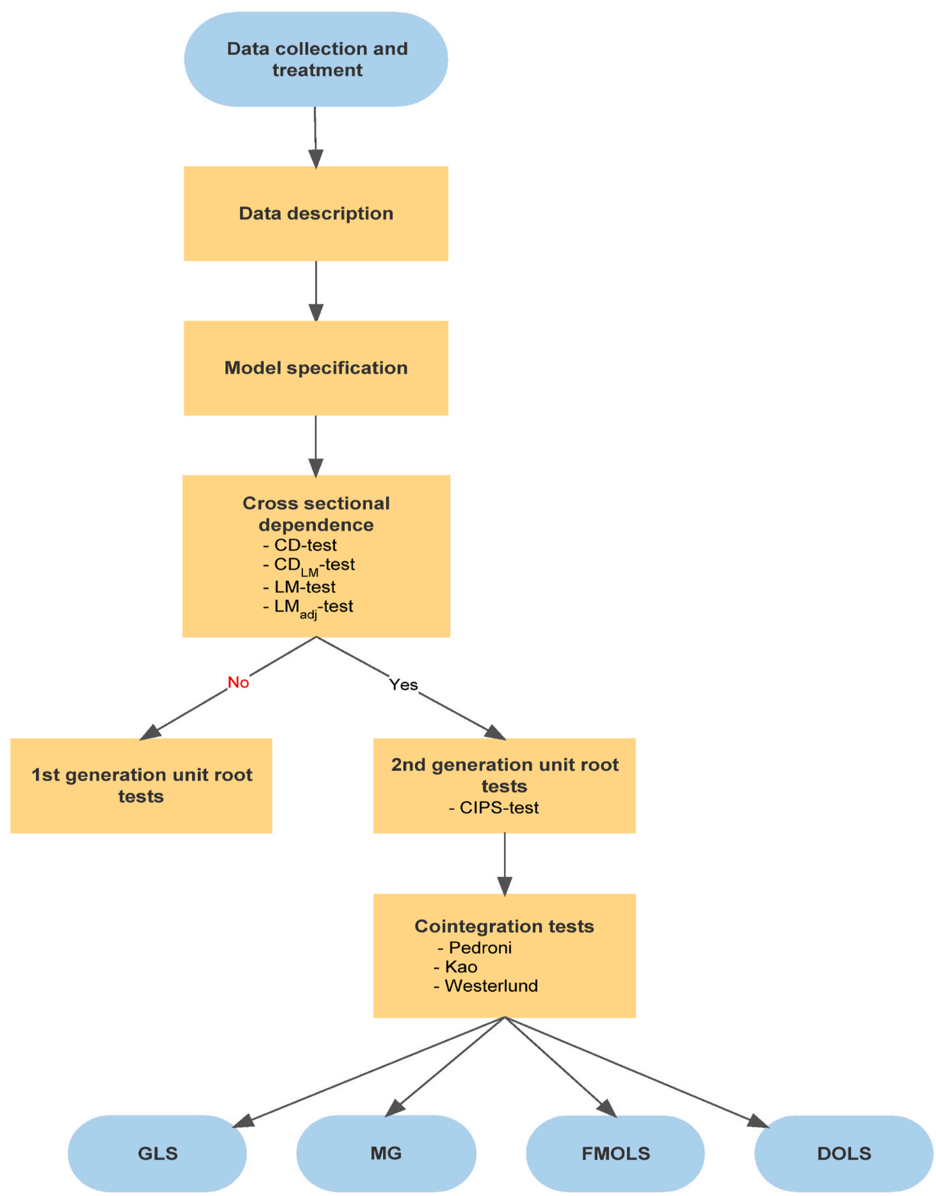

Fig. 1. Methodological schema of the study.

so far to measure and assess a system's circular performance or how they are used in practice have been highlighted by Sassanelli et al. (2019) and Vinante et al. (2021). New business models should create responsible enterprises focused on sustainability (Schaper, 2016; Cullen and De Angelis, 2021). Also, focusing on ecological and social value creation while setting ambitious targets and committing to the SDGs seems to be a promising parameter for leadership (GlobeScan, 2020). Employing several waste minimization strategies (like reduce, reuse, recycle), enterprises can manage to make as little waste as possible while unaffected materials are taken out of the waste flow to be reused without any processing; otherwise, materials can be used as a secondary resource promoting the process of circularity (Johansson and Henriksson, 2020).

3. Research methodology

According to the description of our hypotheses, we pinpoint the relationship between the circularity rate and the progression of the economy, formal entrepreneurship, and innovation within countries. More specifically, the detailed methodological schema is described in Fig. 1.

3.1. Data description

The data used is taken from Eurostat, the Global Entrepreneurship Monitor (GEM), the European Environment Agency, and the United Nations Education Science and Culture Organization (UNESCO). More specifically, panel data consists of circularity rate, real gross domestic product, formal entrepreneurship, innovation, human development index, gas emissions, and financial development variables listed and described in Table 1. Based on data availability, the present research uses annual panel data from eighteen selected European economies in 2010–2019. As some European economies do not have available data for entrepreneurship in the GEM dataset, and for some countries, the series analyzed have many missing values over time, they have been excluded from the analysis. As a result, the countries with data availability included in our analysis are Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Latvia, the Netherlands, Austria, Poland, Portugal, Slovenia, Slovakia, Finland, Sweden, and the United Kingdom.

3.1.1. Circularity rate

The Circularity Rate (CR) indicator expresses the share of material recovered and fed back into the economy based on Eurostat. The circularity rate measures the ratio of the circular use of materials to the overall material use. It is approximated by the amount of waste recycled in domestic recovery plants minus imported waste destined for recovery plus exported waste destined for recovery abroad. Thus, a higher circularity rate means higher environmental performance.

3.1.2. Real gross domestic product per capita

Real Gross Domestic Product (GDP) per capita is calculated as the ratio of real GDP to the average population of a specific year.

$$GDP\ per\ capita = \frac{Real\ GDP}{Population\ of\ the\ country} \quad (1)$$

It is widely used as a proxy measure for the economic development in a country's living standards. Higher GDP per capita is expected to be positively associated with the circularity rate. Data are in constant Euro per capita as collected from the Eurostat database.

3.1.3. Formal entrepreneurship

To measure the formal Entrepreneurship (E), we use the Total early-stage Entrepreneurial Activity (TEA) rate, and it is expressed as a percentage of the 18–64 population who are either nascent entrepreneurs or owner-managers of a new business. The GEM database provides this measure. More specifically, this index is equal to:

$$Entrepreneurship = \frac{Nascent\,entrepreneurs / business\,owner - manangers}{Working\,age\,population} \quad (2)$$

and is expected to be a positive contributor of circularity rate in Europe.

3.1.4. Innovation

Several previous studies have used several proxy variables for innovation activity, including the global innovation index or the number of patents. We use the Research and Development (RD) expenditure within the business enterprise sector to proxy for innovation. RD expenses increase the stock of knowledge of humans, culture, and society, leading to a higher rate of circularity in Europe. This variable is also collected from the Eurostat database.

3.1.5. Human development index

The Human Development Index (HDI) is based on three key dimensions of development: health, income, and education. More specifically, the HDI is a summary measure of the geometric mean of normalized indices of achievement for a long and healthy life (life expectancy), level of knowledge (education), and the level of standard of living (GDP). A higher level of socio-economic development could lead to a higher circularity rate in Europe. Data are retrieved from United Nations development reports.

3.1.6. Gas emissions

Greenhouse gas (GAS) emissions variable, proxied polluting entrepreneurship, contains data on carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). They are measured in thousand tones per capita and are collected from the European Environment Agency (EEA). Higher levels of gas emissions are expected to be negatively related to the circularity rate.

Table 1
Definition and sources of the variables used.

Variable	Measurement	Unit	Proxy of	Source
Circularity Rate (CR)	Share of material recovered and fed back into the economy	%	Circularity	Eurostat
Real gross domestic product per capita (GDP)	Ratio of real GDP to the population	%	Economic growth	Eurostat
Entrepreneurship (E)	Percentage of 18–64 population who are either a nascent entrepreneur or owner-manager of a new business	%	Formal entrepreneurship	Global Entrepreneurship Monitor
Human Development Index (HDI)	Geometric mean of normalized indices of achievement of long and healthy life (life expectancy), level of knowledge (education) and the level of standard of living (GDP)	Index	Socioeconomic development	United Nations
Research and Development expenditures (RD)	Research and development expenditure within the business enterprise sector as a share of GDP	%	Innovation	Eurostat
Gas emissions (GAS)	Thousand tones per capita	Tones/capita	Polluting entrepreneurship	European Environment Agency
Foreign direct investments, inflows (FD)	The objective of obtaining a lasting interest by an investor in one economy in an enterprise resident in another economy, share of GDP	%	Financial development	Eurostat

3.1.7. Financial development

Financial Development (FD) is proxied by the foreign direct investments (inflows) that, based on Eurostat, is the category of international investments that reflect the objective of obtaining a lasting interest by an investor in one economy in an enterprise resident in another economy. Foreign direct investments play a key role mainly amid developing countries where a higher level of financial development is expected to be positively associated with the circularity level.

3.2. Model specification

Understanding the mechanism nexus between formal entrepreneurship, innovation, socio-economic development, financial development, pollution, and circularity is highly complicated. To address this issue, we estimate the impact of these variables on the circularity rate in Europe. Before carrying out the empirical analysis, the variables are transformed into their natural logarithm form (limited negative figures of FD were turned to missing values) to reduce heteroskedasticity and outliers' issues within the data and find elasticities as double-log models are estimated. Then, the long-run influence of formal entrepreneurship, innovation, socio-economic, polluting entrepreneurship, and financial development on the circularity rate is explored relying on the following specified panel model:

$$lnCR_{it} = \beta_0 + \beta_1 lnE_{it} + \beta_2 lnD_{it} + \beta_3 lnRD_{it} + \beta_4 lnGAS_{it} + \beta_5 lnFD_{it} + \varepsilon_{it} \quad (3)$$

where ln denotes the natural logarithm of each variable in the equation, CR represents the circularity rate, E is the proxy variable of formal entrepreneurship, D is the proxy of socioeconomic development using real gross domestic product per capita (GDP) and the human development index (HDI) interchangeably, RD is the research and development expenditure as a proxy of innovation, GAS is quantity of gas emissions per capita proxy of polluting entrepreneurship, FD is the foreign direct investments as the proxy of financial development, while β_0, i,t, β_i and ε_{it} represent the constant term, country, time period, long run elasticities and error term, respectively.

Thereafter, econometrically, we follow a three-step empirical, methodological approach. First, the issue of common correlation bias is addressed in the panel data as it is important to come up with unbiased estimations. This is carried out by applying the LM (Breusch and Pagan, 1980), CD and CD_{LM}(Pesaran, 2004) and LM_{adj} (Pesaran et al., 2008) cross-dependence tests to our data. Considerable cross-sectional dependence might be present in error terms due to unobserved and common shock factors leading to biases in estimation. Pesaran CD statistical test does not depend on a particular spatial weight matrix, particularly when number of groups (n) is large and time (t) is short, and therefore is widely used; it is based on the pairwise correlation coefficient of the errors and computes as follows:

$$CD = \sqrt{\frac{2T}{n(n-1)}}\left(\sum_{i-1}^{n-1}\sum_{i+1}^{n}\widehat{\rho}_{ij}\right. \quad (4)$$

The hypotheses tested are: $H_0 : \widehat{\rho}_{ij} = \widehat{\rho}_{ji} = cor(\varepsilon_{it}, \varepsilon_{jt}) = 0 \; for \; i \neq j$ and $H_1 : \widehat{\rho}_{ij} = \widehat{\rho}_{ji} \neq 0 \; for \; i \neq j$. Pairwise correlation coefficient of the errors $\widehat{\rho}_{ij}$ equals:

$$\widehat{\rho}_{ij} = \widehat{\rho}_{ji} = \frac{\sum_{t=1}^{T}\varepsilon_{it}\varepsilon_{jt}}{\left(\sum_{t=1}^{T}\varepsilon_{it}^2\right)^{1/2}\left(\sum_{t=1}^{T}\varepsilon_{ij}^2\right)^{1/2}} \quad (5)$$

This test is used to select the appropriate unit root tests which identify the order of integration of the variables. If the null hypothesis of cross-sectional independency is rejected, the cross-sectional augmented panel unit root test (*CIPS*) developed by Pesaran (2007) should be utilized as first-generation unit root tests such as Breitung (2000), Hadri (2000), Levin et al. (2002), Im et al. (2003) may over reject the null hypothesis of unit root test giving less consistent and reliable results (Dhahri and Omri, 2018). CIPS test is a modified IPS test specified as follows:

$$CIPS = \frac{1}{n}\sum_{i-1}^{n} CADF_i \quad (6)$$

Where *CADF* is the individual augmented Dickey-Fuller test. The null hypothesis considers that variables are not stationary. If variables are integrated, the group of selected variables may be cointegrated in the long-run time horizon. Thus, panel cointegration tests should be employed in order to examine whether a long run relationship is present amid the variables. Pedroni (1999, 2004), Kao (1999) and Westerlund (2005) tests have a common null hypothesis of no cointegration. The alternative hypothesis of the Pedroni test is that the variables are cointegrated in all panels. It has proposed seven different statistics classified into four within dimension statistics and three between dimension statistics. The first tests depend on the within-dimension approach and include four statistics: panel ρ-statistic, panel ν-statistic, panel *PP*-statistic, and panel *ADF* statistic. These statistics take into account common time factors and heterogeneity across units. The second set of statistics is based on the between-dimension approach and includes three statistics (group-statistic, group PP-statistic, and group ADF statistic). On the other hand, the Westerlund test may have an additional alternative hypothesis in that the variables are cointegrated in some of the panels.

Finally, to estimate the long-run mechanism between selected variables, the present study employs several estimators. Initially, based on the Hausman (1978) test, we use Random Effects and Generalized Least Squares (GLS) cluster approaches that allow estimation in the presence of the first-order autocorrelation within panels and cross-sectional correlation and heteroskedasticity across panels (Parks, 1967). Additionally, we employ a mean group panel time-series estimator (MG) with heterogeneous slopes (Eberhardt and Teal, 2010). Finally, to carry out tests on the cointegrated vectors, Fully Modified Ordinary Least Squares (FMOLS) estimator suggested by Phillips and Hansen (1990) that addresses endogeneity and serial correlation issues, and Dynamic Ordinary Least Squares (DOLS) estimator suggested by Saikkonen (1991) and Stock and Watson (1993) which includes contemporaneous and lag values to also correct endogeneity and serial correlation problems, are employed.

4. Empirical results

Table 2 illustrates descriptive statistics of the variables across 18 selected European countries from 2010 to 2019. In particular, the table presents summary statistics (before getting logarithms) with a mean and standard deviation of circularity rate, real gross domestic product per capita, research and development expenditures, entrepreneurship, the human development index, foreign direct investment inflows, and gas emissions.

At a first glance, it can be seen that there exist significant disparities in circularity rate with the maximum rate in the Netherlands (27.2%) and the minimum in Ireland (1.78%). Furthermore, the highest level of entrepreneurship, GDP per capita, RD, HDI, and FD is for Estonia (15.56), Ireland (45,883€), Sweden (51.55%), Germany (0.94) and the Netherlands (19.08), respectively. As observed, country performance varies in all exploratory variables, due to different national policies, which are essential in explaining CR variations.

Thereafter, Table 3 scrutinizes whether cross-sections are independent or not as it is essential to select first or second panel unit root tests. The results show that cross sectional dependence exists among countries signifying the transmission of a shock that occurred in one country to the others. Beginning with the findings of cross-sectional dependence depicted in Table 3, empirical outcomes (Pesaran CD-test, CD_{LM} test, LM-test, LM_{adj} -test) reject the null hypothesis of cross-sectional independence for all variables under consideration.

Based on CD test statistics, all variables are significant at 1% except foreign direct investments due to their level proximity amid countries.

Table 2
Summary statistics of the employed variables for the studied European countries.

	CR		GDP		RD		E		HDI		FD		GAS	
Country	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev
Germany	11.28	0.60	34,135	1264	14.51	1.76	5.25	0.94	0.94	0.006	2.19	1.04	9389	608
Estonia	13.47	2.76	13,366	1425	27.52	2.46	15.56	3.73	0.87	0.010	5.68	4.23	14,556	1657
Ireland	1.78	0.17	45,853	9435	8.71	2.01	8.71	2.03	0.93	0.020	1.13	0.65	11,673	1463
Greece	2.45	0.83	17,461	1056	15.21	2.94	6.52	1.17	0.87	0.008	1.13	0.65	7815	682
Spain	9.10	1.03	23,333	1195	16.00	1.76	5.62	0.61	0.89	0.010	2.41	0.86	5926	305
France	18.29	1.19	31,734	834	14.51	1.91	5.24	0.64	0.89	0.007	1.46	0.62	5315	302
Croatia	3.94	1.14	10,977	784	27.41	1.30	8.24	1.33	0.84	0.010	2.00	1.47	4617	278
Italy	16.07	2.85	26,278	628	16.43	2.00	3.90	0.85	0.88	0.004	0.98	0.58	5814	536
Latvia	4.14	1.81	10,615	1280	36.99	3.16	13.45	1.64	0.85	0.010	2.96	1.24	5534	342
Netherlands	27.2	1.64	39,550	1353	5.72	1.47	9.53	1.63	0.93	0.008	19.08	20.62	10,527	439
Austria	9.67	2.04	36,588	839	32.91	0.89	9.76	0.78	0.91	0.007	−0.09	3.92	7120	347
Poland	10.61	1.06	10,910	1184	11.17	0.83	8.47	1.86	0.86	0.010	2.72	1.17	9470	215
Portugal	2.10	0.26	17,018	869	28.14	2.95	9.04	2.40	0.85	0.010	4.56	2.48	5384	225
Slovenia	8.74	1.30	18,461	1238	21.91	0.74	6.15	1.33	0.90	0.010	1.98	1.30	7379	419
Slovakia	4.98	0.51	14,086	1123	11.69	2.14	11.24	1.74	0.85	0.009	2.63	1.89	6740	293
Finland	8.97	3.92	35,518	979	37.83	3.70	6.20	0.52	0.93	0.007	2.40	3.92	10,562	1316
Sweden	7.10	0.49	41,957	1517	51.55	3.04	6.92	1.05	0.93	0.010	1.50	2.11	5176	483
UK	14.93	1.08	31,348	1155	7.58	3.02	8.22	1.29	0.92	0.009	3.12	3.32	6777	936

Note: CR: Circularity rate (%); GDP: Real Domestic Product per capita (€); RD: Research and Development, share of GDP (%); E: Formal entrepreneurship, Percentage of 18–64 population who are either a nascent entrepreneur or owner-manager of a new business (%); HDI: Human Development Index; FD: Foreign direct investments, inflows, share of GDP (%); GAS: Total gas emissions (tones per capita).

Table 3
Cross-section dependence tests and second-generation unit root test.

Variables	Cross-section dependence				Unit root tests (CIPS)	
	CD-test	CD_{LM}-test	LM-test	LM_{adj}-test	Level	Δ
lnCR	4.89[a]	19.21[a]	489.06[a]	18.21[a]	−2.506	−2.855[a]
lnE	10.21[a]	12.91[a]	378.78[a]	11.91[a]	−3.108[c]	−3.550[a]
lnGDP	28.19[a]	48.96[a]	1009.41[a]	47.96[a]	−1.951	−2.050[c]
lnRD	1.20	26.59[a]	618.19[a]	25.59[a]	−1.928	−2.690[a]
lnHDI	56.87[a]	160.17[a]	3492.6[a]	159.78[a]	−2.583	−2.627[b]
lnFD	−0.13	0.35	159.19	−0.65	−2.529	−3.229[a]
lnGAS	14.65[a]	28.97[a]	659.81[a]	27.97[a]	−2.373	−2.683[a]

Notes: a, b and c denote significance at 1%, 5% and 10% level, respectively. Δ denotes the first difference operator.

Thereafter, considering cross-sectional dependency results, we present second-generation unit root tests to provide accurate and more reliable findings in our study. These tests indicate that circularity rate, real gross domestic product per capita, entrepreneurship, RD expenditures, the human development index, and foreign direct investments have unit root at levels but not at first differences. After confirming that all series are integrated, panel cointegration analysis can be followed. The present study suggests Pedroni (1999, 2004), Kao (1999), and Westerlund (2005) cointegration tests to examine whether there is a long-run cointegrated relationship between the variables.

The results of cointegration tests are shown in Table 4. All reported results suggest that the null hypothesis of no cointegration is strongly rejected, indicating that the circularity rate, entrepreneurship, socio-economic development, innovation, financial development, and pollution are cointegrated in the selected countries. Once long-run relationships between the variables are confirmed, the coefficients are estimated subsequently.

Table 4
Pedroni (1999, 2004), Kao (1999) and Westerlund (2005) cointegration test results.

Cointegration tests	Statistic	*p*-value
Kao-ADF	−4.336[a]	0.000
Pedroni Modified PP	4.582[a]	0.000
Pedroni ADF	−6.094[a]	0.000
Westerlund – Variance ratio	3.769[a]	0.000

Notes: [a] denotes 1% significance level. Kao-ADF, Pedroni-PP and Pedroni ADF indicate ADF based on Kao (1999) and PP based and ADF based test of Pedroni (1999). Variance ratio statistic stands for cointegration test of Westerlund (2005). Pedroni and Westerlund cointegration vectors include time trend. Kernel method was used to estimate the long-run variance of each panel's series.

Table 5 presents long-run coefficient estimates by applying several econometric specifications. In particular, generalized least squares, Pesaran (2007) estimator, and the well-known FMOLS and DOLS techniques are employed. The estimated coefficients can be interpreted as long-run elasticities as a double log model is considered for all specifications.

As can be seen, by taking circularity rate as a dependent variable, formal entrepreneurship, innovation, economic growth, and socio-economic development variables are estimated positive and statistically significant in all econometric specifications. These factors may be significant contributors to a circular economy within Europe. In particular, the magnitude of 0.19 (average across all models) of entrepreneurship implies that a 1% increase in formal entrepreneurship raises the circularity rate in Europe by 0.19% on average. This result shows that formal entrepreneurship constitutes a key driving factor affecting the industry sector's circularity rate. On the contrary, there is evidence that "polluting" entrepreneurship and activity proxied by the total gas emissions per capita is negatively related to the circularity rate. This result implies that more friendly environmental entrepreneurs may be considered a possible solution for sustainability.

Accordingly, technological innovation seems to be an important contributor to circularity and consequently to sustainability in Europe. However, it can be observed that the contribution of innovation to the circularity rate is higher (0.65) compared to formal entrepreneurship. This magnitude implies that a 1% rise in research and development expenditures increases the circularity rate by 0.65% on average. In this context, technological innovation seems to play a crucial role in coping with the circularity rate and sustainability issues. This result can be explained as technological innovation is synonymous with more knowledge, clean energy technology, institutional quality, innovative production, and more environmentally friendly developments.

Regarding the effect of economic growth, empirical results provide some evidence of relative decoupling between the economy and environmental degradation. In particular, the magnitude of real gross domestic product per capita implies that an increase of 1% on GDP per capita leads to an average 0.73% increase in the circularity rate. Alternatively, it can be said that more prosperous countries follow a more

Table 5
Regression results. Dependent variable: natural logarithm of circularity rate (lnCR).

Variables	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
lnE	0.091[a]	0.073[b]	0.066[c]	0.082[b]	0.081[b]	0.239[b]	0.351[a]	0.273[b]	0.252[b]	0.227[c]	0.269[b]	0.271[c]
	(0.035)	(0.032)	(0.035)	(0.038)	(0.038)	(0.109)	(0.128)	(0.122)	(0.126)	(0.133)	(0.131)	(0.128)
lnGDP		0.579[a]	0.545[a]	0.517[a]	–	–	0.783[a]	0.924[a]	–	–	0.844[b]	0.925[a]
		(0.170)	(0.166)	(0.173)			(0.308)	(0.318)			(0.309)	(0.320)
lnRD			0.582[a]	0.573[a]	0.524[a]	0.776[c]	0.741[a]	0.747[a]	0.593[a]	0.620[a]	0.560[b]	0.743[a]
			(0.097)	(0.104)	(0.107)	(0.454)	(0.211)	(0.196)	(0.202)	(0.196)	(0.231)	(0.210)
lnFD				−0.000	0.005	−0.013	−0.029	−0.023	−0.040	−0.026	−0.047[c]	−0.023
				(0.008)	(0.008)	(0.023)	(0.026)	(0.027)	(0.026)	(0.028)	(0.028)	(0.028)
lnHDI					2.888[a]	6.419[b]	–	–	6.293[a]	5.035[a]	–	–
					(0.830)	(2.965)			(1.891)	(2.052)		
lnGAS											−0.519[c]	−0.017
											(0.312)	(0.301)
Constant	2.273[a]	−3.738[b]	−3.999[b]	−3.722[b]	1.907[a]	1.738[a]	–	–	–	–	–	–
	(0.063)	(1.764)	(1.734)	(1.803)	(0.156)	(0.633)	–	–	–	–	–	–
Specification	FGLS	FGLS	FGLS	FGLS	FGLS	MG	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
Obs.	174	174	174	162	162	162	162	162	162	162	162	162
Number of groups	18	18	18	18	18	18	18	18	18	18	18	18

Notes: Standard errors in parentheses. [a], [b] and [c] denote significance at 1%, 5% and 10% level, respectively.

friendly environmental behavior than poorer ones, as they implement policies that increase circularity.

Another important finding in the present empirical study is that apart from economic growth, socio-economic development is also a significant contributor to Europe's circularity rate. This result highlights that economic status can be an essential contributor to circularity and sustainability, but it is not a panacea. Human development that measures the overall achievement in social and economic dimensions might be a more appropriate index to monitor circularity. In this study, the human development index is found to be highly positive statistically related to the circularity rate. The size of its magnitude (5.66) is to be expected based on the values of this index. This finding signifies that a sound, stable and fair society with a high standard of living could lead to higher circularity rates and thus sustainability.

Regarding financial development proxied by foreign direct investments, results do not indicate that foreign direct investments significantly affect the circularity rate within the examined dataset. The importance of foreign direct investing is expected to be higher for developing economies, while its impact on developed economies is lower (Kostakis et al., 2017). The statistically significant variables on circularity rate are depicted in Fig. 2.

5. Discussion and policy implications

As the nexus between circularity rate, economic growth and development, formal and informal entrepreneurship, and innovation for European countries has been assessed, we could proceed with drawing policy implications for researchers, policymakers, and key stakeholders. The study's empirical results indicate that sustainable entrepreneurship can be a vehicle of the circularity process and the success of SDGs in Europe. It should be noted that Europe is a pioneer in implementing the objectives of sustainability goals, and so the findings of this study could help in designing policies towards this direction.

First, findings confirm that income per capita has a highly significant

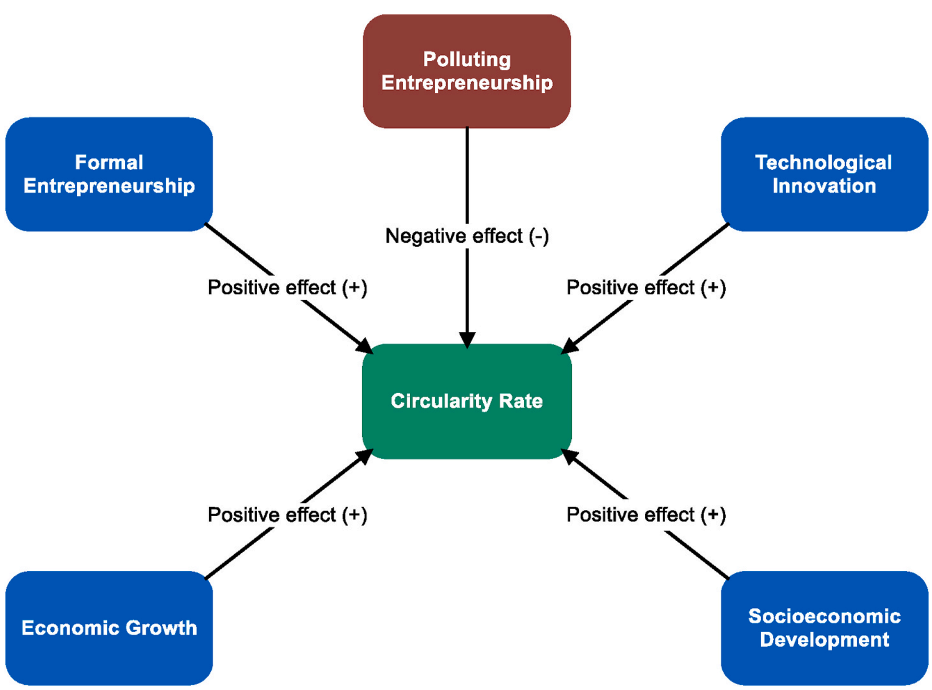

Fig. 2. Estimation results from GLS, MG, FMOLS and DOLS methods.

and positive relation to circularity rate, confirming that richer economies circulate materials at a higher level than those with lower incomes. Similarly, the human development index that was used as a supplementary variable of income per capita in our analysis is also evidenced to be positively related to circularity rates confirming that not only economic growth but also and, probably, more importantly, socio-economic development can be a contributor of sustainability goals related to circularity. It is known that European citizens enjoy a high economic level, and so a higher demand for consumption and production is necessary in order to achieve that level of economic status. For fulfilling that level of lifestyle, Europe is highly based on the non-sustainable model of take-make-dispose. Therefore, for promoting sustainable development in Europe, a fundamental shift in economic values and procedures is needed, a phase-wise shift that refers to the gradual transition from the linear to the circular economic models. In this process, consumers, firms, institutions, and governments can make a significant difference by implementing and increasing circularity in each stage of economic growth.

Second, key findings, resulting from the long-run estimation, reveal that entrepreneurship and innovation positively affect the circularity rate among European economies. These results confirm that the combination of entrepreneurship and innovation in developed countries could be an important contributor to sustainable development. However, the effect of "polluting" entrepreneurship, proxied by the total gas emissions per capita in our empirical analysis, seems to be negative. Thus, policymakers should use entrepreneurship and innovation as a way to push forward higher circularity rates and subsequently reduce the global circularity gap. This can be implemented by giving incentives to the industry to develop endogenous cleaner production processes, increase environmental awareness, apply better and cleaner technologies, also increasing circularity rates. In this way, the industry will gradually decouple from dirty technologies while the economy can benefit from a more circular economy. If policymakers foster a continuous effort towards a more circular economy, it would be easier for people, industry, and institutional entities to replace the decade-long conventional approaches to production and consumption take-make-use-dispose to the sustainable and circular model take-make-use-reuse and reuse again and again. Governments should push consumers and producers to squeeze the maximum waste out of the system to curtail the use of new economic resources. When these activities occur, several green jobs will be created, European citizens will experience a new but decent growth-oriented lifestyle, and countries will make significant progress towards achieving SDGs. Furthermore, European countries are highly interconnected in a globalized world through several socio-economic, cultural, and environmental networks. Our empirical findings confirm that a circularity shock in one of the panel countries is highly probable to spread its outcome to other European countries.

Despite these findings, empirical inferences should be interpreted with caution. First, the empirical investigation was carried out within a short period of time (2010–2019) and has also been influenced by an unprecedented financial crisis in the developed economies. Also, our analysis examines the direct impact of entrepreneurship, innovation, and socio-economic development using only one indicator of the circularity process, the circularity rate. However, other micro, meso, or macro circularity indicators could also be considered in future studies. In addition, more data and a longer time span in future studies would present the opportunity for alternative, complementary, and more advanced econometric specifications.

6. Concluding remarks

The present study clarified the links between entrepreneurship, innovation, socio-economic development, and a circular economy for eighteen European economies during 2010–2019. A cross-sectional dependence test was empirically applied to examine cross-section independence, whereas the stationarity of the series was employed through specific panel unit root tests. Thereafter, a long-run equilibrium relationship between the variables using panel cointegration tests was examined. Finally, GLS, MG, FMOLS, and DOLS techniques estimations on the long run mechanism offered important findings with regard to the circularity development process.

The panel-based empirical findings illustrate that circularity, economic and socio-economic development, entrepreneurship, and innovation nexus is present in Europe. Furthermore, it was discovered that the circularity rate increases by a rise in economic growth and development, entrepreneurship, and innovation, whereas polluting industry leads to its down surge. These findings contribute to the literature of environmental economics by uncovering the impact of several macro-economic parameters on circularity rate and to the perspective of attaining the objectives of SDGs.

Countries should improve environmental regulations, especially in circularity implementation. In particular, through several information dissemination actions, policymakers should increase environmental awareness among entrepreneurs to reduce the negative environmental externalities caused by them and provide incentives for cleaner production. Also, regulatory measures can be focused on squeezing gas emissions and waste out of the economic system and promoting resource reuse. Research and development should focus on the existence of a more circular supply chain that will extend the life cycle of each product and its life. However, when implementing these policies and shifting the linear with the circular model, policymakers should take care not to underestimate the economic growth path.

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Availability of data and material

Data and materials are available upon request.

CRediT authorship contribution statement

Ioannis Kostakis: collected data and carried out statistical and econometric analysis. **Konstantinos P. Tsagarakis:** formulated the research idea, provided suggestions on empirical methods and policy implications. All authors read and approved the final manuscript.

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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