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The impact of the circular economy on sustainable development: A European panel data approach

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ABSTRACT

The circular economy (CE) has attracted considerable attention because of its potential to help achieve sustainable development (SD). This paper presents a comprehensive analysis of the effect of the CE on the three dimensions of SD at the country level. We analysed the impact of each CE source of value (renewable energy, reuse, repair, recycling) and the influence of an overall factor-analysis-derived measure of the CE on the economic, environmental and social dimensions of SD. The aim was to compare the individual impacts and outcomes of the CE and its sources of value in a single study. Panel data analysis was performed using a sample of 25 European countries for the period 2010 to 2019. The findings show a major impact of the CE on achieving SD, which has positive effects on the economy, environment and society. However, the results show that the impact of each CE value source on the three SD dimensions varies. While renewable energies and reuse reduce the impact on the environment, recycling has no effect, and repair increases GHG emissions. However, repair is the only CE source with a positive economic impact at the country level. Finally, renewable energy, repair and recycling reduce unemployment. Decision makers should conduct impact analysis to design suitable, efficient and targeted measures depending on each country's specific objectives.

1. Introduction

The combination of global resource scarcity, climate change and increasing resource consumption has made the challenge of sustainable development (SD) a major priority. SD was first defined in the Brundtland Report titled *Our Common Future* as, "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). The report highlights the importance of balancing the environmental, social and economic dimensions of human activity. The circular economy (CE) could make economic growth compatible with reducing dependence on raw materials and energy (Ellen MacArthur Foundation, 2015b). Accordingly, the CE has become an increasingly prominent area of economics in recent years (Stahel, 2016; Korhonen et al., 2018; Alnajem et al., 2021). The CE means promoting the responsible and cyclical use of resources and can potentially contribute to achieving the goal of SD (Moraga et al., 2019).

To achieve the Sustainable Development Goals (SDGs) adopted by the United Nations (UN) in 2015, the CE is receiving intense attention from policymakers, companies and governments (Stahel, 2016; Elia et al., 2017; Dantas et al., 2021), particularly in Europe and China (McDowall et al., 2017). Through the Chinese Circular Economy Promotion Law, passed in 2009, and the Circular Economy Action Plan of the European Union (EU), launched in 2015, European countries and China have adopted plans to create a more circular economy (Fellner and Lederer, 2020; Kuo and Chang, 2021). In fact, prior research has emphasised the relationship between CE principles and the SDGs (Rodriguez-Anton et al., 2019; Pla-Julián and Guevara, 2019) because of the potential of the CE to contribute to meeting the SDGs (Kirchherr et al., 2017; Schroeder et al., 2019). Schroeder et al. (2019) and Rodriguez-Anton et al. (2019) found evidence of a positive relationship between the CE and SDG 12, whose aim is to achieve a significant reduction in waste generation through prevention, reduction, recycling, reuse and the sustainable use of natural resources.

Companies all over the world are exploring ways to transition to CE business models (Elia et al., 2017; Schroeder et al., 2019; Nesterova, 2022). The idea is to transform the linear business model of production-consumption-disposal into a sustainable process of make-use-reuse-remake-recycle (Mhatre et al., 2021). The Organisation for

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Economic Co-operation and Development (OECD) has proposed four main CE business models: (1) circular supply models, using renewable energy (RE) instead of raw materials; (2) resource recovery models, recycling waste into secondary raw materials; (3) product life extension, repairing and remanufacturing products instead of throwing them away; and (4) sharing models, reducing demand for new products and raw materials through sharing and second-hand principles (OECD, 2018). The aim of the current study is to map CE business models and investigate their value for SD. A strong CE model should balance any tensions between environmental, economic and social priorities (Johansson and Henriksson, 2020).

Although the economic and environmental impacts of the CE have already been analysed (Nikolaou and Tsagarakis, 2021), its social impact has received little attention, and in some cases no consideration at all (Korhonen et al., 2018; Schroeder et al., 2019; Padilla-Rivera et al., 2021). This paper attempts to fill this research gap by examining the economic, social and environmental impacts of the CE in a single study. The study investigates whether the CE is an effective instrument to achieve SD. Moreover, the impact of each of the CE value sources on the three dimensions of SD is examined. This paper presents carefully chosen indicators that make it possible to compare the degree of the CE. Thus, our findings are relevant for decision makers, managers and policymakers seeking to apply national and international environmental policies aimed at transitioning towards a CE.

Factor analysis is used to condense several variables into a single overall CE indicator. Our study addresses the lack of quantitative indicators at the country level (Haas et al., 2015; Elia et al., 2017; Haupt and Hellweg, 2019) and the scarcity of data and metrics for reuse and sharing and for repair and remanufacturing (Ellen MacArthur Foundation, 2015a).

European countries provide a suitable context in which to study the impact of the CE on SD. Because these countries have an interest in improving their resource availability, they have started implementing CE strategies earlier than other nations, and the impact of these strategies can be analysed. Moreover, different European countries are at different stages of their implementation of CE strategies. Therefore, the following research question (RQ) is proposed:

RQ 1. How do circular business models influence each of the dimensions of sustainable development?

To answer this research question, the paper is organised as follows. Section 2 explains the CE hierarchy employed in this study and provides the theoretical background, addressing the four sources of value of the CE and their implications for SD. Section 3 presents the research design, including the variable definitions. Section 4 presents the results. Section 5 provides a discussion. Section 6 offers the conclusions and limitations of the study, as well as some future lines of research.

2. Theoretical background

The CE is based on three principles: designing out waste and pollution, keeping products and materials in use at the highest possible value, and regenerating natural systems (Ellen MacArthur Foundation, 2022). Respecting these three principles leads to a cascading order of the sources of value of the CE: (1) renewable resources, (2) reuse and sharing, (3) repair and remanufacturing, and (4) recycling. The reasons for this order are explained in the following paragraph.

The use of renewable resources respects all CE principles. The shift to RE is a key step on the way to building a CE (Korhonen et al., 2018). Indeed, it is the top measure of the Ellen MacArthur Foundation's ReSOLVE framework (Ellen MacArthur Foundation, 2015a), and can create major synergy effects (IRENA, 2016). Reuse and sharing also respect the three principles of the CE by keeping finite materials in the economic cycle and preserving the whole value of the product. Doing so reduces the demand for new resources and increases resource efficiency at the macro level (Ellen MacArthur Foundation, 2022). Repair and remanufacturing are also focused on maintaining the highest possible value of products, but they require more work and resources to keep value in the economy. Therefore, repair and remanufacturing appear third in the cascade. Finally, reuse and repair reflect a greater commitment to the CE than the use of secondary raw materials and recycling (Llorente-González and Vence, 2020). Indeed, recycling is less efficient in terms of resource and energy consumption than reuse and repair (Llorente-González and Vence, 2020). Matsumoto et al. (2016) concluded that remanufacturing and repair processes are generally superior to material recycling because they preserve more original energy and material in the economic flow.

2.1. Renewable resources

Energy is an input for almost all products and services in the economy. Therefore, the energy sector has a major impact on a country's economy (IRENA, 2016). Non-renewable energy sources cause global warming through greenhouse gas (GHG) emissions (Venkatraja, 2020). Without RE sources, energy-related CO2 emissions will more than double by 2050 (Huaman and Jun, 2014). Most European countries face a conflict of interest between a rising energy demand (Xie et al., 2021) and the need to reduce GHG emissions (Apergis et al., 2010; IRENA, 2016). Prior research provides evidence that renewable resources play a key role in achieving SD (Lee, 2019; Güney, 2021; Aboul-Atta and Rashed, 2021). Countries, governments and companies should therefore increasingly invest in RE to reduce CO2 emissions and regulate fluctuations in the price of fossil fuels. The fact that RE production costs have decreased in recent years makes the use of RE sources increasingly economically attractive (Sadorsky, 2012; Mukoro et al., 2021; Kostakis and Tsagarakis, 2022b).

Some studies provide support for the positive impact of RE use on economic growth (Fang, 2011; Al-mulali et al., 2013; Inglesi-Lotz, 2016). For example, Fang (2011) estimated that a 1 % increase in renewable energy consumption (REC) in China would raise economic growth in form of the GDP per capita by 0.162 percentage points. Consistent with these results, Cetin (2016) found support for a positive long-run relationship between REC and economic growth for the Emerging 7 (E7) countries. The International Renewable Energy Agency (IRENA) has predicted that doubling the share of renewables in the global energy mix by 2030 would lead to GDP growth of up to 1.1 % (IRENA, 2016). In contrast, Venkatraja (2020) showed a negative impact of REC on economic growth in Brazil, Russia, India and China. Finally, studies have also shown no support for either short- or long-run Granger causality between REC and economic growth in Europe (Menegaki, 2011).

The question of how renewable resources affect the environment and GHG emissions is also of great interest. Some scholars have argued that RE leads to decarbonisation and a reduction in dependence on energy imports for fuel poor countries (Mendonça et al., 2020; Mukoro et al., 2021). Lee (2019) found support for the link between REC, economic growth and CO2 emissions in the short and long term in the EU.

The literature provides support for the social impact of RE in the form of job creation in Sweden (Johansson and Henriksson, 2020), South Africa (Khobai et al., 2020), the Mercosur countries of Argentina, Brazil, Paraguay, Uruguay and Venezuela (Koengkan and Fuinhas, 2020), and worldwide (Domac et al., 2005; Topcu and Tugcu, 2020). Bulavskaya and Reynès (2018) analysed the influence of RE on job potential in the Netherlands, predicting 50,000 new full-time jobs. IRENA found that doubling REC by 2030 would provide direct and indirect employment opportunities for 24.4 million people worldwide in the RE sector (IRENA, 2016).

In sum, the evidence of the impact of renewable resources on SD is inconclusive. Although most studies have examined the relationship between REC and economic growth (Xie et al., 2021), their results vary (Lee, 2019; Venkatraja, 2020). Meanwhile, studies of the influence of renewable resources on the environmental and social dimensions of sustainability are still scarce. Therefore, the following research question is proposed:

RQ 2. How does renewable energy influence each of the dimensions of sustainable development?

2.2. Reuse, sharing and second-hand principles

Sharing and second-hand policies have enormous potential and can increase the lifespans of products (Mhatre et al., 2021). Sharing and second-hand principles allow material resources to be reused multiple times by different individuals (Vezzoli et al., 2015) and address key issues such as overconsumption and income inequality (Muñoz and Cohen, 2017). Due to the sharp increase in the number of online platforms, many consumers reuse, borrow or rent goods from others (Tukker et al., 2016; Frenken, 2017). According to several studies, the sharing economy offers great potential and opportunities to achieve SD (Plewnia and Guenther, 2018; Jabour et al., 2020; Schwanholz and Leipold, 2020).

Cheng (2016) concluded that sharing brings opportunities in the form of job creation, strong community resilience and economic growth at the macro level. From an environmental point of view, Kathan et al. (2016) argued that sharing significantly reduces overall resource use, total waste and GHG emissions. Furthermore, sharing principles reduce the importance of ownership. This reduced importance contributes to lowering the total number of newly manufactured products (Frenken, 2017), which could lead to material savings. Schwanholz and Leipold (2020) analysed the car sharing sector and concluded that sharing can save numerous parking spaces, as well as empty building and infrastructure costs, leading to economic, environmental and social benefits. Underwood and Fremstad (2018) reached similar conclusions, finding evidence that sharing within households leads to a mitigation in transport-related emissions and residential energy use. Harris et al. (2021) analysed the potential impacts of sharing in Sweden, concluding that the sharing of cars, electrical tools and office spaces can decrease GHG emissions. The literature also discusses the social impacts of sharing. Fang et al. (2016) found empirical evidence that sharing economy principles can create new employment in the tourism industry.

Despite numerous arguments supporting the impact of sharing on the dimensions of SD, as well as evidence of the relationships between them for specific sharing platforms, closer examination of the overall impact of sharing is needed. Therefore, the following research question is proposed:

RQ 3. How do reuse and sharing influence each of the dimensions of sustainable development?

2.3. Repair and remanufacturing

Repairing is where defective components in goods are replaced with new or as-good-as-new components to prevent the disposal of fixable goods (Wakiru et al., 2018). In remanufacturing processes, products are restored to their original condition or manufactured with remanufactured or reused parts to extend their life (Hunka et al., 2021; Koop et al., 2021). Repair and remanufacturing promotes the basic principle of the CE of maintaining the value of resources and products in the economic cycle for as long as possible (Fellner and Lederer, 2020). Extending the life of a product and maintaining its value can increase resource efficiency and lead to resource savings (Mhatre et al., 2021). Furthermore, it has the advantage of lower economic and environmental costs because fewer resources are extracted and less waste is generated than under other strategies (Mhatre et al., 2021).

From an environmental point of view, Jansson (2016) argued that repair and remanufacturing reduce the need for primary raw materials, increase product lifetimes and decrease CO2 emissions and waste. Consistent with these arguments, Lieder et al. (2018) concluded that repair and remanufacturing processes can reduce CO2 emissions. According to the Ellen MacArthur Foundation, the French car manufacturer Renault was able to save 88 % water, 80 % energy and 77 % waste through its remanufacturing plant instead of producing new products (Ellen MacArthur Foundation, 2014). The Automotive Parts Remanufacturers Association (APRA) has found evidence that remanufacturing saves up to 85 % of materials compared to the manufacture of new products, using only 55 % of the energy needed to produce a new unit in the EU-28 (APRA, 2015).

In addition to their environmental potential, repair and remanufacturing also have major economic and social benefits. For example, the UK's All-Party Parliamentary Sustainable Resource Group found that remanufacturing can contribute £2.4 billion to the UK economy and provide thousands of skilled jobs (All-Party Parliamentary Sustainable Resource Group, 2014). Zero Waste Scotland reported that an increased level of repair and remanufacturing would lead to GDP growth and numerous new and highly skilled jobs (Zero Waste Scotland, 2015).

From a social perspective, Matsumoto et al. (2016) found support for the positive link between repair and remanufacturing, job creation and social wealth. Jansson (2016) argued that remanufacturing creates a large number of jobs for skilled personnel and can exploit the value of a product, leading to high profit margins. Llorente-González and Vence (2020) identified repair and remanufacturing activities as labour-intensive circular activities and concluded that these activities lead to job creation. In addition, the Ellen MacArthur Foundation found that Renault's remanufactured products are sold at 50 % to 70 % of their original price, which increases the benefits for consumers (Ellen MacArthur Foundation, 2014). Alexander and Smaje (2008) and Bovea et al. (2017) pointed out further social benefits associated with repair services, including skills development and reintegration programmes for people who have been excluded from the labour market. Therefore, repair and remanufacturing represent a win-win-win situation for the economy, environment and society. Accordingly, the following research question is proposed:

RQ 4. How do repair and remanufacturing influence each of the dimensions of sustainable development?

2.4. Recycling

As a source of value, recycling is linked to a variety of activities in which waste materials are collected, sorted and used to make new products (Mhatre et al., 2021). The recycling process supports the principles of a CE by closing the loop and preventing primary resource extraction (EEA, 2021). Furthermore, the use of recycled secondary raw materials can limit the steadily increasing demand for primary raw materials (Mathieux et al., 2017; Kostakis and Tsagarakis, 2022a), which is especially attractive for countries with a high dependence on primary raw material imports. In their systematic literature review, Mhatre et al. (2021) pointed out that the recycling process is the most commonly used CE strategy by most industries and sectors to return resources to the system.

Although recycling is often strongly associated with the CE, it is the least sustainable solution under CE principles (Ghisellini et al., 2016). Fellner and Lederer (2020) concluded that the recycling rate is probably not the best indicator to measure a country's CE level because the direct link between reduced primary raw material demand and higher recycling rates is only an assumption. Haupt and Hellweg (2019) argued that the recycling process could drastically increase energy demands, which may offset environmental gains. Potting et al. (2017) reported high volumes of low-grade recycling, where the material does not retain its original quality. They argued that this kind of low-grade recycling is closely linked to a linear economy. Reuse and sharing principles, as well as repair and remanufacturing, are more in line with CE principles and are better able to reduce waste. Nevertheless, for the transformation towards a CE, it is important to recycle resources (Kostakis and Tsagarakis, 2022a). Murray et al. (2017) also affirmed that "a circular economy cannot be achieved without recycling".

Empirical evidence of the effect of recycling on economic growth is limited (Cerqueira et al., 2021). Although Busu (2019) and Hysa et al. (2020) showed that recycling can have a significant influence on economic growth, Guoyan et al. (2022) found mixed results, observing that effects vary with time. Razzaq et al. (2021) examined the relationship between municipal solid waste (MSW) recycling and economic growth, concluding that 1 % growth in MSW recycling leads to an increase in economic growth in the form of GDP. Kostakis and Tsagarakis (2022a) argued that recycling can provide not only a significant boost for sustainable economic growth but also substantial environmental improvements.

Recycling can help countries reduce pollution and GHG emissions with respect to a system based on primary raw materials, thus protecting the environment. Cudjoe et al. (2021) found that 2186.3 Mt of solid waste recycled from 2005 to 2017 in China avoided 3743.3 Mtce (megatonne of coal equivalent) of energy and reduced CO2 by 4765.9 billion kg. Ayodele et al. (2018) reported that 307,364 ktons of CO2 and 89.99 toe (tonne of oil equivalent) of energy could be saved by recycling solid waste in Nigeria. In addition, it could result in economic benefits of 11.71 million USD.

Some authors have focused on specific forms of recycling. For example, Yang et al. (2020) found that e-waste recycling in China makes a significant contribution to reducing GHG emissions, saving 390 million tonnes of CO2. Jang et al. (2020) found evidence that recycling plastic packaging in South Korea could lead to savings of 6.6 Mt CO2eq (CO2 equivalent) per year. However, Stijn Ewijk et al. (2021) found evidence that paper recycling can lead to higher emissions (up to 10 % more GHG emissions) than using primary raw materials. Huysman et al. (2017) examined plastic recycling and also found mixed results. The authors argue that recycling low-quality plastic waste can lead to greater environmental impacts than incineration. A similar conclusion was reached by Schäfer and Schmidt (2021), who studied metal recycling.

From a social perspective, Beccarello and Di Foggia (2018) found that high recycling rates have a positive impact on job creation in Italy. The Ellen MacArthur Foundation (2015b) has identified large employment potential in the labour-intensive recycling sector. Indeed, Tellus (2013), found that recycling processes create two jobs per 1000 t of waste, whereas waste disposal generates only 0.1 jobs per 1000 t. Thus, the following research question is proposed:

RQ 5. How does recycling influence each of the dimensions of sustainable development?

3. Methods

To answer the research questions, this paper analyses the impact of the sources of value of the CE on the three dimensions of SD. A panel data set based on a sample of 25 European countries for the period 2010 to 2019 was used to avoid the problem of unobserved heterogeneity (Arellano, 2005). This time frame was chosen because not all data for 2020 onwards or 2009 and earlier were available at the time of data analysis. This lack of data was particularly noticeable in relation to repair and remanufacturing and reuse and sharing. To check whether a random or fixed effects model was appropriate, the Hausman test was applied (Hausman, 1978). According to Hausman, any rejection of the null hypothesis H0 means that fixed and random effects are different. Therefore, fixed effects are preferable to random effects. In this empirical example, the standard Hausman test presented in Table 4 led to the rejection of the hypothesis of orthogonality of unobservable individual-specific effects and regressors, which is why the fixed effects model is appropriate. The empirical analysis examined 24 EU member states plus the United Kingdom. The EU member states were Austria, Belgium, Bulgaria, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden. Given the analysis period, the United Kingdom was included in the analysis despite its withdrawal from the EU in 2020. Due to non-existent or partially available data on sharing, three EU countries (Czechia, Ireland and Malta) were not included in the study. The data on the chosen 25 countries consisted of 247 observations and a minimum of seven observations per group (country).

The equations that specify the models are presented below. The term GDP_{it} stands for the logarithm of GDP per capita of country i in year t; GHG_{it} represents the natural logarithm of GHG per capita of country i in year t-1; UN_{it} is the level of unemployment of country i in period t; REC_{it} refers to the level of REC of country i in period t; $REUS_{it}$ represents the level of reuse of country i in period t; REP_{it} represents the level of repairing of country i in period t; $RECYC_{it}$ denotes the level of recycling of country i in period t; CE_{it} represents the overall CE performance of country i in period t; TAX_{it} denotes the ratio of environmental taxes to GDP of country i in period t; EDU_{it} is the level of education of country i in period t; $INNO_{it}$ is the innovation level of country i in period t; $POPDEN$ represents the population density of country i in period t; ECO_{it} is the value of the Eco-Index of country i in period t; IND_{it} is the percentage of employees working in services in country i in period t; $SERV_{it}$ is the percentage of employees working in services in country i in period t; γ_i denotes unobserved heterogeneity, assumed to be constant over the period of analysis; ε_{it} is the error term.

$$GDP_{it} = \alpha + \beta_1(CEi_{it}) + \beta_2(TAX_{it}) + \beta_3(EDU_{it}) + \beta_4(INNO_{it}) + \beta_5(POPDEN_{it}) + \beta_6(ECO_{it}) + \beta_7(IND_{it}) + \beta_8(SERV_{it}) + \gamma_i + \varepsilon_{it} \quad (1)$$

$$GHG_{it} = \alpha + \beta_1(CE_{it}) + \beta_2(TAX_{it}) + \beta_3(EDU_{it}) + \beta_4(INNO_{it}) + \beta_5(POPDEN_{it}) + \beta_6(ECO_{it}) + \beta_7(IND_{it}) + \beta_8(SERV_{it}) + \gamma_i + \varepsilon_{it} \quad (2)$$

$$UN_{it} = \alpha + \beta_1(CE_{it}) + \beta_2(TAX_{it}) + \beta_3(EDU_{it}) + \beta_4(INNO_{it}) + \beta_5(POPDEN_{it}) + \beta_6(ECO_{it}) + \beta_7(IND_{it}) + \beta_8(SERV_{it}) + \gamma_i + \varepsilon_{it} \quad (3)$$

$$GDP_{it} = \alpha + \beta_1(REC_{it}) + \beta_2(REU_{it}) + \beta_3(REP_{it}) + \beta_4(RECYC_{it}) + \beta_5(TAX_{it}) + \beta_6(EDU_{it}) + \beta_7(INNO_{it}) + \beta_8(POPDEN_{it}) + \beta_9(ECO_{it}) + \beta_{10}(IND_{it}) + \beta_{11}(SERV_{it}) + \gamma_i + \varepsilon_{it} \quad (4)$$

$$GHG_{it} = \alpha + \beta_1(REC_{it}) + \beta_2(REU_{it}) + \beta_3(REP_{it}) + \beta_4(RECYC_{it}) + \beta_5(TAX_{it}) + \beta_6(EDU_{it}) + \beta_7(INNO_{it}) + \beta_8(POPDEN_{it}) + \beta_9(ECO_{it}) + \beta_{10}(IND_{it}) + \beta_{11}(SERV_{it}) + \gamma_i + \varepsilon_{it} \quad (5)$$

$$UN_{it} = \alpha + \beta_1(REC_{it}) + \beta_2(REU_{it}) + \beta_3(REP_{it}) + \beta_4(RECYC_{it}) + \beta_5(TAX_{It}) + \beta_6(EDU_{it}) + \beta_7(INNO_{it}) + \beta_8(POPDEN_{it}) + \beta_9(ECO_{it}) + \beta_{10}(IND_{it}) + \beta_{11}(SERV_{it}) + \gamma_i + \varepsilon_{it} \quad (6)$$

3.1. Variables and data

Three dependent variables were used to measure the impact of the CE on each dimension of SD: the natural logarithm of GDP per capita measured economic impact, unemployment rate measured social impact, and the natural logarithm of GHG emissions per capita measured environmental impact. The data were taken from Eurostat, the European Environment Agency (EEA) and the International Labour Organization (ILOSTAT).

We introduced one independent variable for each CE source of value. Specifically, renewable resources were measured as the share of RE in gross final energy consumption. Reuse and sharing were measured as the number of employees working in shops selling second-hand goods per 100,000 inhabitants. Repair and remanufacturing were measured as the factor analysis score for the following variables: number of enterprises per 100,000 inhabitants repairing machinery, number of enterprises per 100,000 inhabitants repairing computers and household goods, and number of enterprises per 100,000 inhabitants repairing motor vehicles. The results revealed a one-component solution using complementary criteria of eigenvalues and interpretability. Generating these factors condensed the information of several variables measuring a single value source. This approach made sense in particular for repair, remanufacturing and recycling because it was not possible to capture the entire scope of the value source with a single variable. Di Maio and Rem (2015) and Gutowski et al. (2013) have criticised the use of individual recycling rates because they are calculated based on the amount of material entering recycling facilities, and their numerator and denominator are inconsistently chosen. Di Maio and Rem (2015) argue that recycling rates are not appropriate indicators because they are not directly related to what we want to achieve. They add that their relationship to the economy, employment and environment is ambiguous. To overcome this criticism, the value source of recycling was measured as a factor analysis score for the following variables: recycling rate of municipal waste (ratio of recycled municipal waste to total municipal waste), circular material use rate (ratio of circular use of materials to overall material use) and trade in recyclable raw materials (amount of waste shipped across intra- and extra-EU borders). The results revealed a one-component solution using complementary criteria of eigenvalues and interpretability. Based on the previous items, factor analysis gave the values for recycling and for repair and remanufacturing. To examine the overall performance of the CE on the dimensions of SD, an overall CE indicator was used. This indicator was the score of the principal component analysis of the four value source variables. The results revealed a one-component solution using complementary criteria of eigenvalues and interpretability. Factor analysis condensed the information of all CE value sources into a single score. Factor analysis is a widely used exploratory tool for reducing the dimensionality of multivariate data (Bartholomew, 1980). Fig. 1 illustrates the indicators used, their targets and the corresponding sources of value.

We used seven control variables: innovation (R&D expenditure as % of GDP), education (% of people with at least a tertiary degree), environmental taxes (environmental taxes as % of GDP), eco-innovation index, population density and sector composition ratio of industry and services (% of population employed in industry or services). Educational level is a well-accepted driver of environmental policy decisions (Kostakis and Tsagarakis, 2022a). Therefore, the number of people with at least tertiary education was used as a proxy for education under the assumption that a higher education level could lead to better performance in SD indicators. Population density was included because of the controversial empirical results on the link between urbanisation and GHG emissions. Some researchers have shown that population density increases emissions (Cole and Neumayer, 2004; York, 2007; Zhu and Peng, 2012), whereas several studies imply that urbanisation improves efficiency and thus reduces energy consumption and emissions (Chen et al., 2008; Dodman, 2009; Liddle, 2014). Gross domestic expenditure on research and development (R&D) as a percentage of a country's GDP offered a proxy for innovation. Several researchers have argued that innovation plays a key role in economic development (Ildırar et al., 2016) and that SD cannot be achieved without innovation (Schroeder et al., 2019; Hidayatno et al., 2019). Many studies have also examined the impact of environmental taxes on CE metrics (Robaina et al., 2020; Kostakis and Tsagarakis, 2022a). The index of eco-innovation was included because eco-innovation is linked to the CE (Smol et al., 2017). Hence, a high score on the eco-innovation index was expected to have a positive impact on the dimensions of SD. The distribution of employees by sector (industry and services) was included to examine whether an increase or reduction in the percentage of employees in these sectors could improve the individual dimensions of SD. Table 1 illustrates and describes all variables used.

4. Results

This section contains the results of the analysis, which are visualised in the form of diagrams and tables and subsequently explained in detail. Tables 2 and 3 show the correlation matrix and descriptive statistics. The variance inflation factors range from 1.09 to 1.29, indicating no problems of multicollinearity.

Table 4 presents the results of the panel data analyses. Models 1 to 3 show the effects of the CE factor of all four value sources on the three dimensions of SD: GDP per capita (Model 1), GHG emissions (Model 2) and unemployment (Model 3). Models 4 to 6 look into the individual

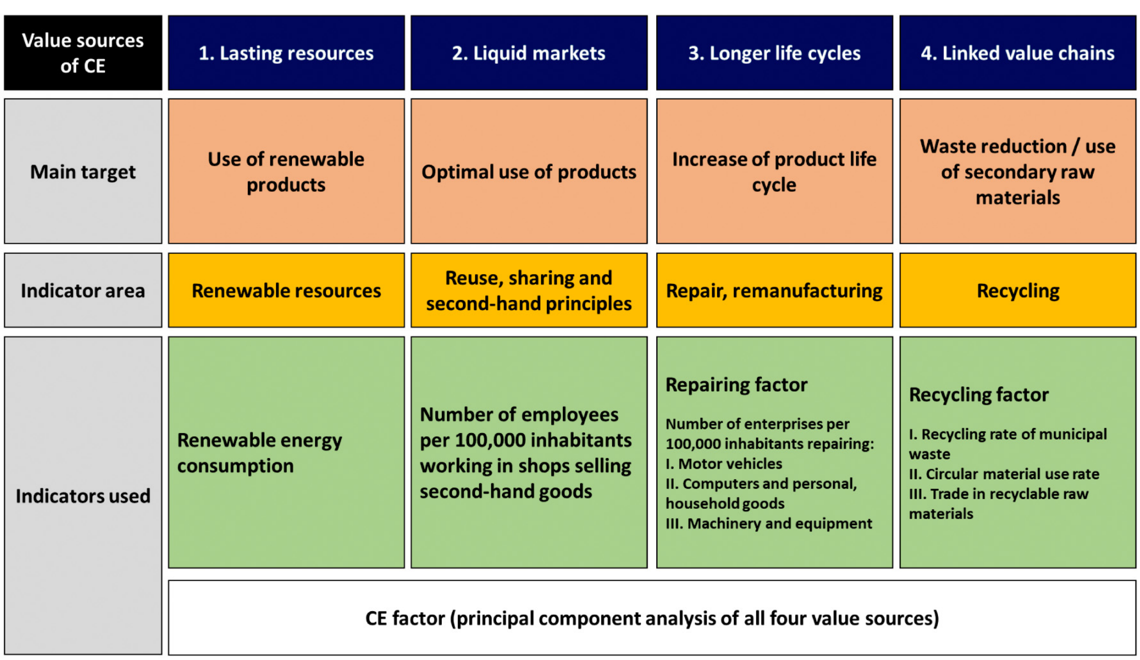

Fig. 1. Circular economy (CE) value sources.

Table 1
Definition and sources of variables.

Variable	Description	Unit	Proxy of	Source
GDP	Natural logarithm of GDP per capita as total real GDP divided by midyear population	US $	Economic dimension of SD	Eurostat
GHG	Natural logarithm of GHG emissions per capita as total national emissions divided by total population	Tonnes	Environmental dimension of SD	European Environment Agency (EEA)
Unemployment	Total unemployment rate as ratio of unemployed persons to total labour force	%	Social dimension of SD	International Labour Organization (ILOSTAT)
REC	Renewable energy consumption (REC) as ratio of REC to final energy consumption	%	Renewable Energy	Eurostat
Reuse	Number of employees working in second-hand shops per 100,000 inhabitants	Number	Reuse, sharing	Eurostat
Repair (Factor)	Number of enterprises repairing motor vehicles per 100,000 inhabitants	Number	Repair	Eurostat
	Number of enterprises repairing machinery per 100,000 inhabitants	Number	Repair	Eurostat
	Number of enterprises repairing computers and household goods per 100,000 inhabitants	Number	Repair	Eurostat
Recycling (Factor)	Recycling rate of municipal waste as ratio of recycled municipal waste to total municipal waste	%	Recycling	Eurostat
	Circular material use rate as ratio of circular use of material to overall material use	%	Recycling	Eurostat
	Trade in recyclable raw materials as amount of waste shipped across intra- and extra-EU borders	Tonnes	Recycling	Eurostat
CE (Factor)	Score of principal component analysis that represents the 4 value sources (REC, Reuse, Repair, Recycling)	Number	Circular economy	Eurostat
Taxes	Environmental taxes as ratio of environmental taxes to GDP	%	Control variable	Eurostat
Education	Education level as percentage of population with tertiary education	%	Control variable	Eurostat
Innovation	Innovation level as % of R&D expenditure to GDP	%	Control variable	Eurostat
Population d.	Population density as ratio of annual average population to land area	Persons per km^2	Control variable	Eurostat
Eco-Index	Eco-innovation index as index of 16 sub-indicators of economic, social and environmental performance	Index, EU = 100	Control variable	Eurostat
Industry	Sector employment as % of total employees working in industry	%	Control variable	ILOSTAT
Services	Sector employment as % of total employees working in services	%	Control variable	ILOSTAT

effect of each CE value source (renewable energy, reuse, repair, recycling) on GDP per capita (Model 4), GHG emissions (Model 5) and unemployment (Model 6).

4.1. The effect of the circular economy on sustainable development

Model 1 shows that the principal component analysis of all four CE value sources has a positive and strongly significant impact on GDP per capita ($p < 0.001$). Model 2 shows a negative and significant impact of the CE on GHG emissions in EU countries ($p < 0.10$). However, Model 3 provides strongly significant evidence that the CE has a negative influence on the unemployment rate ($p < 0.001$). The CE therefore has a significant impact on the three dimensions of SD by increasing GDP (economic), reducing GHG emissions (environment) and reducing unemployment (social). These results confirm the potential of the CE for achieving SD.

4.2. The effect of renewable energy on sustainable development

Looking more closely at the individual effect of each CE value source, no significant impact of REC on GDP per capita is observed (Model 4). The results of Model 5 show that REC reduces GHG emissions per capita ($p < 0.001$). Model 6 shows strongly significant evidence that REC reduces the unemployment rate ($p < 0.001$). Despite no significant impact of renewable energy on national GDP, this value source reduces GHG emissions and unemployment and therefore has a positive effect on the environmental and social dimensions of SD.

4.3. The effect of reuse and sharing on sustainable development

The empirical analyses provide no significant evidence that reuse has an impact on GDP per capita (Model 4). The results of Model 5 provide significant evidence that reuse has a negative effect on GHG

Table 2
Correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
GDP (1)	1.000													
GHG (2)	0.495**	1.000												
Unemployment (3)	−0.287**	−0.288**	1.000											
REC (4)	−0.037	−0.472**	−0.007	1.000										
Reuse (5)	−0.354**	−0.272**	−0.047	0.226**	1.000									
Repair (6)	−0.379**	−0.343**	0.263**	0.155**	0.154**	1.000								
Recycling (7)	0.623**	0.324**	−0.405**	−0.320**	−0.142**	−0.391**	1.000							
Taxes (8)	0.007	0.082	0.025	0.085	−0.088	0.139*	−0.116	1.000						
Education (9)	0.507**	0.296**	−0.116*	0.151**	0.130*	−0.049	0.269**	0.004	1.000					
Innovation (10)	0.685**	0.200**	−0.312**	0.378**	−0.260**	−0.270**	−0.589**	0.089	0.416**	1.000				
Pop. density (11)	0.441**	0.351**	−0.286**	−0.608**	−0.189**	−0.371**	0.743**	0.086	0.107	0.177**	1.000			
Eco-index (12)	0.825**	0.176**	−0.263**	0.214**	−0.277**	−0.390**	0.578**	−0.087	0.370**	0.746**	0.246**	1.000		
Industry (13)	−0.667**	−0.225**	−0.076	0.015	0.139*	0.236**	−0.265**	−0.070	−0.621**	−0.296**	−0.321**	−0.463**	1.000	
Services (14)	0.820**	0.353**	−0.050	−0.082	−0.127*	−0.205**	0.495**	0.090	0.724**	0.492**	0.399**	0.588**	−0.820**	1.000

* $p < 0.05$.
** $p < 0.01$.

Table 3
Descriptive statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
GDP	400	10.186	0.670	8.269	11.724
GHG	375	2.195	0.326	1.588	3.331
Unemployment	399	8.676	4.324	3.14	27.47
REC	399	18.869	11.602	1.281	60.124
Reuse	295	20.222	22.477	0	113.802
Repair	299	−0.010	0.791	−1.729	2.435
Recycling	270	0.069	0.896	−1.216	2.330
Taxes	394	2.641	0.612	1.39	4.92
Education	399	29.223	8.644	11.1	47.5
Innovation	399	1.583	0.905	0.37	3.73
Pop. density	300	132.898	109.667	17.5	507.3
Eco-index	247	90.733	31.738	20	165
Industry	375	25.346	6.005	10.76	40.13
Services	375	68.466	9.486	37.26	88.51

emissions per capita ($p < 0.1$). Model 6 shows no significant relationship between reuse and sharing and the unemployment rate. The value source thus has an influence on one dimension of SD (environment).

4.4. The effect of repair and remanufacturing on sustainable development

Regarding the value source of repair and remanufacturing, Model 4 shows a positive and significant effect on GDP per capita ($p < 0.001$). Model 5 provides evidence that repair and remanufacturing have a positive and significant impact on GHG emissions per capita ($p < 0.001$). Model 6 reveals a significant negative relationship between repair and the unemployment rate ($p < 0.001$). Although this value source influences all dimensions of the CE, it affects the environment in the opposite way. Repair and remanufacturing can increase GDP and lower the unemployment rate in European countries, but it also increases GHG emissions.

4.5. The effect of recycling on sustainable development

For recycling, the results of Model 4 and Model 5 show no significant effect on GDP per capita or GHG emissions. The results of Model 6 reveal a significant negative relationship between recycling and the unemployment rate ($p < 0.001$). The value source thus has an influence on one dimension of SD (social).

In terms of control variables, population density has a negative and significant impact on GDP per capita ($p < 0.001$, $p < 0.05$). These results are consistent and stable in both models (Model 1 and Model 4). The same models reveal a negative and significant effect of environmental taxes on GDP per capita ($p < 0.001$, $p < 0{,}001$). Furthermore, both models confirm that the industrial sector has a positive and highly significant influence on GDP ($p < 0.001$, $p < 0.001$).

Model 2 provides evidence that education has a negative and strongly significant influence on GHG emissions ($p < 0.001$). This result is consistent with Model 5 ($p < 0.05$). The results of Model 2 and Model 5 present strongly significant evidence that population density has a negative influence on GHG emissions ($p < 0.001$, $p < 0.001$). Model 2 also shows a positive and strongly significant influence of the industrial sector on GHG emissions ($p < 0.001$). The same result is confirmed in Model 5 ($p < 0.1$).

Model 3 and Model 6 confirm that the industrial sector has a highly significant negative impact on unemployment ($p < 0.001$, $p < 0.001$).

5. Discussion

Based on analysis of a 10-year sample of 25 European countries, the results show that the CE has a strong influence on the three dimensions

Table 4
Regression results.

Variables	[Model 1]	[Model 2]	[Model 3]	[Model 4]	[Model 5]	[Model 6]
CE	0.146****	−0.037*	−4.088****			
	(0.030)	(0.203)	(0.789)			
REC				0.004	−0.016****	−0.357****
				(0.004)	(0.002)	(0.083)
Reuse				0.001	−0.001*	−0.024
				(0.001)	(0.001)	(0.031)
Repair				0.164****	0.069****	−3.831****
				(0.027)	(0.163)	(0.651)
Recycling				−0.018	−0.005	−2.869***
				(0.040)	(0.238)	(0.950)
Taxes	−0.114****	0.006	0.636	−0.135****	−0.021	1.394*
	(0.032)	(0.021)	(0.828)	(0.031)	(0.019)	(0.747)
Education	−0.004	−0.008****	−0.452****	−0.001	−0.004**	−0.078
	(0.003)	(0.002)	(0.068)	(0.003)	(0.002)	(0.079)
Innovation	0.051	0.032	−1.536	−0.034	0.031*	−0.522
	(0.031)	(0.021)	(0.816)	(0.031)	(0.019)	(0.739)
Pop. density	−0.006****	−0.007****	0.105**	−0.004**	−0.006****	0.028
	(0.002)	(0.001)	(0.043)	(0.002)	(0.001)	(0.039)
Eco-index	0.001*	0.001*	−0.028**	0.001	0.000	−0.019
	(0.001)	(0.000)	(0.013)	(0.001)	(0.000)	(0.012)
Industry	0.041****	0.024****	−1.346****	0.034****	0.009*	−1.279****
	(0.008)	(0.005)	(0.198)	(0.008)	(0.004)	(0.193)
Service	0.010	0.001	−0.006	0.015**	0.004	−0.154
	(0.006)	(0.004)	(0.161)	(0.006)	(0.004)	(0.147)
Constant	9.330****	2.615****	45.679***	9.112****	2.958****	56.392****
	(0.617)	(0.412)	(16.050)	(0.603)	(0.360)	(14.418)
Specification	FE	FE	FE	FE	FE	FE
Hausman	87.91****	58.22****	37.71****	78.55****	43.33****	45.35****
Obs.	247	247	247	247	247	247
No. groups	25	25	25	25	25	25

Dependent variable: GDP per capita (Models 1 and 4); GHG emissions per capita (Models 2 and 5); unemployment rate (Models 3 and 6). Standard error in parenthesis.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

of SD (economic, social and environmental), thereby answering RQ 1. Therefore, the results evidence that the CE helps countries achieve SD. The results find support for the arguments that the CE has a positive influence on the economy (Su et al., 2013; Bocken et al., 2018; Busu, 2019), society (Ellen MacArthur Foundation, 2015a; WRAP, 2015) and the environment (Deloitte, 2016; Material Economics, 2018). Because the CE has huge potential to achieve SD, policymakers should encourage companies and consumers to contribute to the transition to a CE. For example, through social marketing, European countries can motivate consumers to become willing to pay a "circular premium" price (Colasante and D'Adamo, 2021), which would incentivise companies to introduce CE strategies.

Despite the overall results, each source of value of the CE has a different impact on the three dimensions of SD. First, the findings show that REC has a significant and negative influence on GHG emissions (environment). This result is consistent with prior research (Lee, 2019; Mendonça et al., 2020; Mukoro et al., 2021) and confirms the importance of using renewable energies to meet climate targets. Furthermore, no significant effect of REC on GDP per capita (economy) was found. This result is consistent with those reported by Menegaki (2011), also for Europe. However, it differs from the results reported for China (Fang, 2011). Finally, we found that REC has a strongly significant negative impact on the unemployment rate (social). This result is consistent with previous studies in a range of contexts, including South Africa (Khobai et al., 2020) and the Mercosur countries (Koengkan and Fuinhas, 2020), but also in Sweden (Johansson and Henriksson, 2020) and the Netherlands (Bulavskaya and Reynès, 2018) in Europe. The results show that renewable energies play a key role in achieving SD, in line with the findings of several studies (Lee, 2019; Güney, 2021; Aboul-Atta and Rashed, 2021).

Second, the findings indicate that reuse and sharing principles lead to lower GHG emissions per capita. This result is consistent with research by Kathan et al. (2016) and Harris et al. (2021) and confirms the potential of reuse and sharing business models to reduce GHG emissions. However, reuse and sharing are not found to influence GDP per capita or the unemployment rate. To the authors' knowledge, there is no prior research on this issue.

Third, the findings show that the end-of-life strategy of repair and remanufacturing create noticeable sustainability benefits, in line with the findings of Yang et al. (2018) and Liu et al. (2016). The present research implies that repair and remanufacturing are essential for the transition towards a CE (Rogers et al., 2021). Furthermore, the results show that repair and remanufacturing lead to economic growth in the form of GDP per capita. This finding is consistent with prior research (All-Party Parliamentary Sustainable Resource Group, 2014; Zero Waste Scotland, 2015). The study also provides evidence that repair and remanufacturing reduce the unemployment rate in European countries. This result is in line with previous research (Jansson, 2016; Llorente-González and Vence, 2020). The results reveal a positive relationship between repair and remanufacturing and GHG emissions. One reason for this positive relationship could be that repair and remanufacturing generate GHG emissions locally, whereas new products are imported from abroad and thus generate GHG emissions elsewhere. Europe is the only region in the world that imports more natural resources and pollution than it exports (Tukker et al., 2016). Therefore, in Europe, repairing and remanufacturing have a greater environmental impact than replacing products with new imports. In net-producing regions, the environmental impact of repair and remanufacturing may differ.

Fourth, the results do not indicate an impact of recycling on economic growth in the form of GDP per capita or GHG emissions. Therefore, we did not find support for the results of Busu (2019), Hysa et al. (2020) and Razzaq et al. (2021). One reason for these findings may be the difference in indicators used for the recycling variable. Busu (2019), Hysa et al. (2020) and Razzaq et al. (2021) applied the recycling rate of municipal waste, which has been criticised for being an inaccurate and misleading indicator (Gutowski et al., 2013; Di Maio and Rem, 2015). To address this criticism, we used a factor analysis score composed of three recycling variables, including the circular material use rate. Our results are in line with those of Guoyan et al. (2022), who found mixed effects. In regard to the environmental impacts of recycling, the results support the findings of Stijn Ewijk et al. (2021), Huysman et al. (2017) and Schäfer and Schmidt (2021) that the impact of recycling depends on the specific product and method. In terms of the social impacts of recycling, the results are consistent with the literature (Tellus, 2013; Ellen MacArthur Foundation, 2015b; Beccarello and Di Foggia, 2018), suggesting that recycling decreases unemployment. The results show that recycling, which is often used as a synonym for the CE, is currently unable to contribute to SD on its own. Depending on the sector and material, the impact of recycling on SD can vary (Stijn Ewijk et al., 2021). The full benefits of recycling can only be achieved if it is powered by renewable energy. However, it is still mostly fossil fuels that are used in the recycling process (Stijn Ewijk et al., 2021).

Fig. 2 graphically illustrates the individual effects of the CE value sources and their influence on each dimension of SD. Red arrows show a negative relationship, and green arrows a positive relationship.

The results show that the CE and all its sources of value, except reuse and sharing, have a positive impact on the social dimension of SD and reduce unemployment. Although prior studies of the CE pay scant attention to or completely ignore the social dimension of SD, this research highlights the effect of the CE on the social dimension of SD. The findings should encourage scholars to include this dimension in further research. These findings are in line with those of Appolloni et al. (2022), who suggest that sustainability should be seen not only as a brand or lifeline in the face of climate change but also as an effective form of civil society development.

Our results are also relevant in relation to the criticisms raised by Stiglitz et al. (2019) over the limitations of GDP as a possible measure of SD. GDP alone is not sufficient to study SD. Nevertheless, the results show that GDP, when used to measure the economic dimension of a country's SD, is consistent with the CE and the other dimensions of SD. GDP can still be used as a measure of economic progress if the other dimensions of SD (social and environmental) are considered. The results show that the overall CE has a positive impact on all dimensions of SD, including GDP per capita (economic). However, only one source of value (reuse and sharing) has a positive relationship with GDP.

In relation to the control variables, the results show that an increase in environmental taxes lowers GDP per capita and economic development. This finding echoes previous research on this influence in a similar context (Robaina et al., 2020). However, an influence of environmental taxes on GHG emissions or on the unemployment rate was not found. For this reason, environmental taxes, which currently only reduce national GDP, should be reconsidered and adjusted to achieve the targeted effects on SD.

The results also show that a higher level of education leads to better performance in environmental sustainability in the form of a reduction in GHG emissions, supporting the results of Kostakis and Tsagarakis (2022a).

The finding that urbanisation reduces GHG emissions is consistent with the results reported by Yao et al. (2018) and Ahmed et al. (2019), and supports those of Zhang et al. (2022), who reported that urbanisation positively affects a country's carbon stocks, based on analysis conducted in China. The relevance of cities in the achievement of climate targets should be highlighted. The statement of the Ellen MacArthur Foundation is that the transformation to circular cities and urbanisation is an essential step towards building a CE. This statement is supported in terms of the environment (Ellen MacArthur Foundation, 2022). However, studies have shown that urbanisation leads to a reduction in GDP, which is consistent with the research of Rachmawati (2017).

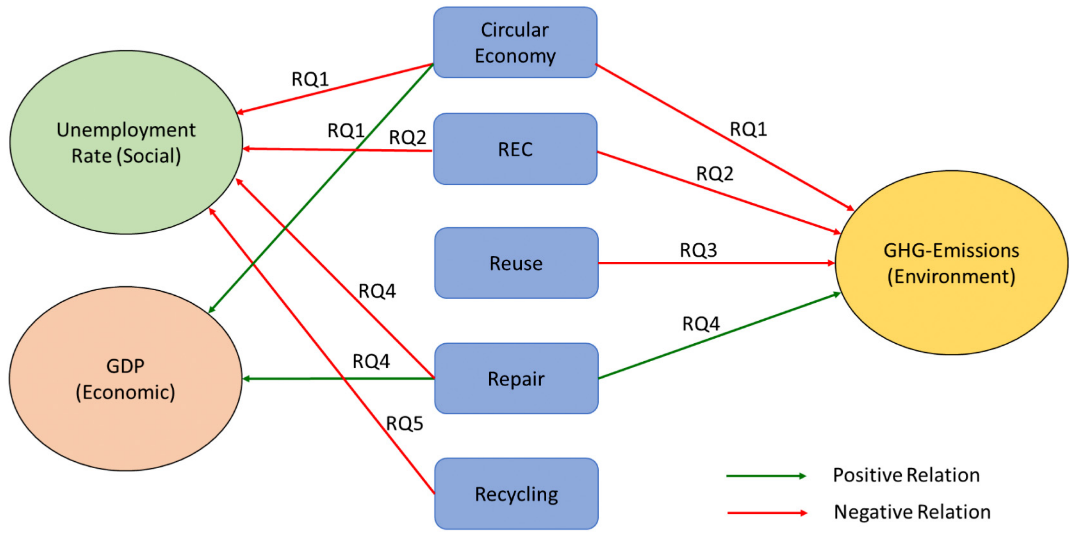

Fig. 2. Summary of findings.

Our results for the industrial sector are consistent with the literature (Uddin, 2015; Clemes et al., 2016; Murselzade and Cavusoglu, 2021). Although the industrial sector has a positive impact on GDP (economy) and a negative impact on the unemployment rate (social), GHG emissions are higher in countries with a high share of industry.

Although this paper makes considerable contributions to the academic literature, it has some limitations. One such limitation is the incompleteness of the reuse and sharing proxy. The only available data on this value source were captured by the measure we applied (i.e. employees in second-hand shops per 100,000 inhabitants). This indicator only reflects a small part of a country's sharing activities because most sharing and second-hand behaviour takes place on online platforms. This currently unavailable data on reuse and sharing behaviour at the macro level may become available in the future. Moreover, although the results indicate that context is important in explaining some of the impacts of the CE, this idea could not be tested because the countries in the sample were net importers of raw materials and manufactured products. Researchers are encouraged to analyse these relationships in other contexts with different characteristics.

6. Conclusions

The CE is conducive to SD, but not all value sources influence the three dimensions of SD in the same way. Some of the results indicate that context plays an important role in the impact of the CE.

This study contributes to the CE literature by offering empirical analysis of the impact of the four CE value sources on the three dimensions of SD. The consistent application of the same method means that the paper presents comparable results and effects in all cases. To the best of the authors' knowledge, no other paper presents a similar overview and similarly comparable results.

This research has important implications. The findings can provide policymakers with relevant insights into the consequences of policies that promote the CE. In particular, the research highlights the difference in outcomes depending on the CE value source. None of the sources of value has a positive impact on all three dimensions of SD in isolation. Despite having an impact on all dimensions, repair and remanufacturing also increases a country's GHG emissions. Renewable energy and reuse and sharing both reduce GHG emissions. In the comparison of these two value sources, renewable energy also has a negative impact on unemployment (social), which is not observed for reuse and sharing. For recycling, only a reduction in the unemployment rate is observed. No influence of this value source on a country's economy or environment is found.

We also emphasise the importance of the interactions between the different CE value sources. It is simply not possible to achieve SD with a single value source. Each one is important in its own right. We also reiterate that recycling in its current form, which is often used as a synonym for the CE, is not capable of achieving SD on its own. Renewable energies should be used to reduce GHG emissions from recycling. Another important implication is that politicians must be aware that CE value sources may have different consequences depending on the context. Decision makers must consider which value sources and policies are suitable for certain specific objectives. Otherwise, policies may have the opposite effect, and unachievable climate goals may be set.

The findings suggest possibilities for new lines of research to study the relationship between the CE and SD. First, currently unavailable data on reuse and sharing behaviour at the macro level may become available in the future. For example, Eurostat has already collected data on collaborative consumption across European countries. However, this form of consumption could not be included in the current study because of the small number of observations. Furthermore, the impacts of repair and remanufacturing on SD may vary depending on the context. Further analysis should be conducted in different geographical areas or in individual countries to reach to more robust conclusions.

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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