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Transforming power of research and development on inequality and well-being: a European Union perspective within the circular economy framework

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To establish a "well-being economy" that prioritizes human and environmental welfare, understanding the relationship between income inequality, research and development (R&D) potential, and human development is crucial. This study delves into these relationships in European Union (EU) countries, focusing on the adoption levels of a circular economy (CE). Analyzing data from the 27 EU member countries spanning 2010 to 2020, a cluster analysis was utilized to categorize nations based on their CE adoption levels. The panel regression analysis findings revealed a marked positive correlation between income and R&D, with countries having a more robust CE adoption showing stronger ties. Furthermore, a notable positive link was discerned between R&D and human development indicators. Despite these significant relationships, the government R&D sector exhibited inefficiencies, especially in countries with heightened CE adoption. These findings carry profound implications for policymakers, urging a redefinition of economic growth metrics and a shift toward a well-being economy that emphasizes human and environmental health.

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Introduction

In the last two decades, there has been a significant increase in the interest in investigating the issue of income inequality and wealth from a global and historical perspective. The available research studies on this issue need to be more knowledgeable about income inequality and its factors. This is caused by a need for more transparency of the financial systems and policies within the individual countries and the conceptual problems preventing the tracking of income and wealth. This complicates the policy-making process significantly; it is necessary to consider the future factors of inequalities within. Income can be a barrier to economic growth due to the use of the redistribution policy as one of the fiscal policy instruments. A strong criticism of the increased redistribution is its negative impact on innovation and technological progress. The research studies often declare the opposite effects of redistribution on innovation, prompting a deeper investigation of its mechanisms (Brzezinski, 2022; Prettner and Strulik, 2020; Charron et al., 2021).

Although the role of public policies in the processes of innovation aiming has been very significant, there is a strong assumption that it will increase even more in the future (Mazzucato & Semieniuk, 2017; Mazzucato & Perez, 2015). Many forecasts declare that climate change's negative impacts on the countries' inequality will increase (Taconet et al., 2020) and within the countries (Paglialunga et al., 2022; Markkanen & Anger-Kraavi, 2019). Climate change will hurt income and wealth inequality, and thus, it will create intense pressure to develop appropriate strategies to protect the low-income groups of inhabitants. There are also concerns about the regressive policies that will hit the low-income population groups and require adequate compensation mechanisms within the countries (Sheng et al., 2023; Malafry and Brinca, 2022). Therefore, it will be necessary to consider the environmental policies' consequences and implement them as part of the countries' development policies. (Arndt et al., 2023).

This will require systematic monitoring of the inequalities and a continuous investigation of their impacts, including identifying the institutional, political, and ideological conditions necessary to implement the relevant policies. These processes are also supported by circular economy (CE) and human development (HD).

Studies have been created investigating the adaptability and compatibility of the CE and HD concepts, ensuring sustainable development and solving global environmental challenges (Schröder et al., 2020). According to many experts, it is fundamental to explore the possibilities of linking these concepts and to identify the procedures in the CE processes to implement the sustainable development goals in a field of social plans that are explicitly associated with HD (Mies & Gold, 2021; Corvellec et al., 2022). This will support the solution of the environmental and development problems. The concept of CE is criticized for the missing human and social dimensions. The HD concept pays little attention to environmental sustainability (Stewart, 2019). In both concepts—CE and HD, innovations play a significant role. Their importance is also growing about the growing multidisciplinarity of both approaches (Konietzko et al., 2020; Prieto-Sandoval et al., 2018).

The investigation of the innovation trajectories in the concept of CE and HD is methodologically demanding, determined not only by the sectoral differentiation but also by the changes in the structural processes of the economies, the effects of the various policies, the financial schemes and mechanisms (Lerner, 2018). Some studies confirm that innovations and investments significantly reduce environmental degradation, but higher investments do not affect resource efficiency (Lehmann et al., 2022). The impact of innovation on economic development and income inequality remains disputable due to their contrasting outcomes. Also, the investigation of this research trajectory within the countries with different levels of CE use has yet to be present. The availability and use of various indicators and methods for measuring innovation and income will complicate the solution of this issue and thus create many limitations.

These consistent facts were the motivation for us to carry out this research, whose main goal was to quantify and evaluate the relationships between income inequality, the research and development (R&D) potential indicators, and economic output represented by the Human Development Index (HDI) within the European Union member countries with a lower and higher level of the CE use. The importance of the study lies in the effort to relate the concepts of CE and HD and, thus, to uncover the factors that can impact the countries' innovative development and economic development. The standard of living is closely related to human life too (Streimikiene and Kyriakopoulos, 2022). At the same time, they will reflect on the level of income inequality.

The study results will be significant for policymakers, the strategic development plans, and the support mechanisms. They will also support the further development of the methodological processes, allowing us to reflect on the dynamic changes and thus create a forecasting platform. From the perspective of the research sphere, the study outcomes will initiate a subsequent deeper examination of the components within the interconnected concepts of CE and HD that are necessary to tackle the global environmental challenges and the sustainability of economies.

Literature review

The issue of income inequality, its impact on innovation, and the economic development of the countries has been studied for a long time in various research areas, and it has become a part of multidisciplinary solid topics in recent years. It also links the issue with economic and environmental sustainability concepts that create a space for investigating further causal relationships and for the new comparative dimensions. To achieve the research objectives, attention was focused on the relevant research studies and their results aggregated in the following content lines: the investigation of income and its impact on R&D and innovation, the inquiry of R&D and its effect on HDI economic outputs, as well as the investigation of the relation between income inequality and environmental and economic sustainability expressed through CE and HDI.

Relation between income inequality and innovations, sustainability, and economic development. Income inequality, its development, and its impact on the various macroeconomic indicators are the subject of long-term research interest of researchers and economists. Income inequality steadily increases among advanced and developing countries (OECD, 2015; Chancel, 2019). Antoneli a Gehringer (2017) and Benos and Tsiachtsiaras (2019) point out that innovation is associated with lower income inequality, especially in interstate environments. Brzezinski (2022) explains in his study that causality in the relationship between income redistribution and innovation can also occur in the direction of innovation to redistribution. Innovations leading to higher income inequality could also generate a higher level of income redistribution. Aghion et al. (2019) perceive the positive effects of higher rates of innovation through innovation in companies with the effect of an increased share of entrepreneurs at income. The effects of redistributive policies on innovation have been demonstrated as ambiguous, and higher income taxes can reduce incentives to innovate. The study's results by Brzezinski (2022) confirm that no negative impacts of income redistribution on patent-based innovation activities were found, and reducing income inequality through income redistribution does not hurt innovation. On the other hand, Włodarczyk (2017) mentions the number of patent applications and the value of the Creative Economy Index reduce income inequalities. The increase in income inequalities has been proved by higher gross domestic expenditure to R&D as a percentage of gross domestic product. The different results obtained from studies can be the result of the use of different geographical comparison units (regions, countries), as well as the use of different indicators and methods to measure innovation and income inequality. This fact, emphasizing methodological aspects, is also highlighted by a study by Berg et al. (2018a). The authors in the mentioned study recommend considering the differences between inequality in a market (before tax and transfer) and net inequality (after tax and transfer). In their study, Aghion et al. (2019) confirmed a positive and significant correlation between innovation and the inequality of the highest incomes. The authors found that innovation is positively linked to social mobility and recommend studying other sources of the highest income inequality, for instance, lobbying.

A positive impact of R&D spending on innovation is declared in many studies (Huang et al., 2010; Ejermo et al., 2011; Czarnitzki & Lopes-Bento, 2014; Beck et al., 2016), while only a part of R&D spending turns into innovation. When quantifying the direct impact of R&D expenditures on innovation, the variable R&D expenditures or the ratio of R&D expenditures to total revenues expressed as R&D intensity is often applied (Dzhukha et al., 2017; Fredrich et al., 2022; Lopes & Serrasqueiro, 2017). Beck et al. (2016) investigated the causes of the overall R&D investment gap between the EU and the US, confirming that overall R&D performance is influenced by sector composition (structural effects), company demographics, relative fiscal, and the monetary positions in business cycles, as well as the company strategies. The indicator of effective innovations is also increasingly applied since not all efforts in the field of R&D are transformed into effective activities and promising technologies. In contrast, only a small part of R&D activities turns into innovation. R&D investments directly generate innovations but also create conditions for the use of external knowledge produced by the R&D of other organizations—for instance, suppliers, competitors, clients, government, etc. (Falk, 2006). The concentration of strong research potential at the regional and national levels encourages the construction of innovation networks that generate more innovative outputs (Risso & Carrera, 2019; Lyytinen et al., 2016). Patents and R&D have a strong internal relationship with innovation and represent one of the outputs of the innovation process, according to the Global Innovation Index. Patents and intellectual property rights (IPR) are often examined within the dimension of knowledge and technology outputs (Bican et al., 2017). According to Dang & Motohashi (2015), patent statistics are a good indicator of innovation. Still, many companies do not prefer obtaining a patent due to the risk of copying the results of their innovation process (Mihm et al., 2015). There are also other barriers to the effective introduction of patents to the market: the lack of commercial potential, infrastructure for making technology available, the strategic decisions of patent owners, and so on. According to these facts, the research question was formulated as follows:

RQ 1: Is there a relation between the general level of income and the outputs of R&D potential among European countries with a higher and lower level of CE use?

Environmental innovations have been the subject of research in recent years, and their effects on macroeconomic indicators have been studied very little. There needs to be more relevant empirical research in this area. In their study, Zecca and Nicolli (2021) confirm that reducing inequalities, economic growth, and democratization are the key determinants to support green technological innovation. However, an explicit examination of the direct impacts of environmental innovations on sustainable development needs to be included in studies. Many authors cautiously outline basic research trajectories on how a favorable policy situation can positively impact adopting development policies and thus promote innovative development. The role of political innovation and informal management is increasingly coming to the fore (Ayres, 2017). Their impact on developing environmental innovation and sustainable growth must be carefully studied. According to Yang et al. (2021), wage distortion is important in green technological progress. Its higher level was proven in the subsectors with a low level of wage distortion, and its lower level in the subsectors with a significant level of wage distortion. Income inequality and carbon emission efficiency are the most important issues for sustainable development. This is also confirmed by the study of Wang et al. (2023), whose results declare that income inequality has an inhibitory effect on improving carbon emission efficiency. It was also confirmed that sustainable social and ecological economic development goals are consistent, and no contradiction exists between them. Bai et al. (2020) investigated the relationships between income inequality, renewable energy technological innovation, and CO_2 emissions. The study results show that if income inequality is lower than a threshold value, the impact of renewable energy technological innovations has a positive effect on reducing CO_2 emissions per inhabitant. Thus, an increase in income inequality prevents technological innovations from affecting the reduction of CO_2 emissions leading to a diverse effect meaning an increase in CO_2 emissions as seen also in the study by Kyriakopoulos (2021a, 2021b). Also, in this study, an important correlation between the goals of sustainable social development and the goal of sustainable ecological development was confirmed. The consumption of renewable energy is also related to these facts. Uzar (2020) confirmed in his study that a decrease in income inequality will increase the consumption of renewable energy, and hence, policymakers can influence the reduction of income inequality, and at the same time, they can eliminate the deterioration of the environment. Weinhold & Nair-Reichert (2009) wanted to investigate whether income inequality explains innovation in the countries. They confirm that a large middle class could influence institutions, including intellectual property rights (IPRs), which could affect innovation. IRPs were also investigated in the study by Hudson & Minea (2013). Their goal was to determine whether the impact of IRPs on innovation depends on the initial level of IRPs or the economic development level. The effect of IRPs shows important nonlinear relations depending on the initial levels of IRPs and gross domestic product per capita. The creation and development of innovation potential depends on the dynamics between the geographical, socio-economic, political, and legal subsystems and is formed by these subsystems. Waste management is a part of the whole circular economy system with a treatment of all the waste types for their future evaluation (Kyriakopoulos et al., 2019). Oliveira Paula and Silva (2021) investigated the mediating role of the patents between R&D expenditure and national development. They confirmed the positive impact of R&D spending on the patents and the economic development of the countries. The results of these studies supported the formulation of the successive research question:

RQ 2: Is there a relation between the outputs of R&D potential and economic development represented by the HDI among the European countries with a higher and lower level of CE use?

Relation between income inequality and environmental and economic sustainability. Antonelli and Gehringer (2017) studied the impact of income inequality on economic growth and technological changes. The results of their study confirm that rising levels of income inequality are a consequence of the slowing pace of technological changes, but they are not the cause. The impact of technological changes on reducing income inequality has a greater impact in countries where wealth concentration is stronger and where income asymmetry is. Benos and Tsiachtsiras (2019) studied the impact of innovation on income inequality across 29 countries by applying patent data. Their results confirm that innovative activities reduce personal income inequality. Berg et al. (2018b) are based on the premise that income inequality harms the pace and sustainability of economic growth over the medium term. The authors say inequality is associated with lower human and physical capital investment and weak political institutions. Permana (2017) has intensively studied various innovation structures within the EU countries and regions. According to the author, income inequality also significantly impacts the concentration of innovation activities (technological specialization). Also, the diversification of innovation activities into many sectors affects income inequality. Tselios (2011) examined 102 regions based on data from international institutions and found that, given the level of income inequality in the EU, the inequality increase in the regions supports innovation. The geographical factor has been confirmed to explain the heterogeneous link between innovation and inequalities. Geographical aspects in the study of causal relationships between income and innovation are often considered in research studies and form a fundamental platform for comparative analysis at the international level (Yigitcanlar and Inkinen, 2019; Crescenzi et al., 2020). This is confirmed by Lee & Rodríguez-Pose (2013), who described the relationships in which innovation leads to inequality. Lee et al. (2013) draw attention to growing concerns about the consequences of innovation in cities or regions and confirm that too little innovation can be very drastic. A global view of this issue is offered by Biurrun (2022), who confirmed that the unresolved relationship between innovation and income inequalities results from turbulence in the global economy. According to the author, investment in R&D is essential for each country's economic and social development. Law et al. (2020) confirmed that the relationship between innovation and inequalities depends on a country's globalization and financial development level. Globalization and financial development are causing income inequality. Aghion & Griffith (2022) identified the directions of the impacts of innovation on income inequality. They found that innovation can affect income inequality positively and negatively and duly justified these impacts. Similar findings were found in the study by Kharlamova et al. (2018), in which the authors confirm that the deeper the income inequality in a country, the more the country reacts to technological changes, while the impact of income inequality on technological change can be positive and negative.

The CE concept and its components have caused significant debate in the academic sphere and among policymakers. It is criticized for the absent social as well as human dimensions. The HD concept is criticized for its lack of environmental sustainability. This conceptual discrepancy was addressed by Schröder et al. (2020), who tried to develop a conceptual framework for CE and HD. His ambition was to harmonize the socio-economic components of the transformation from linear to circular economic models with the components of HD. At the same time, several authors draw attention to the absent connection between CE and HD, such as Kirchherr et al. (2017), Androniceanu et al. (2021), Alshater et al., (2022), Lin et al. (2022), Stewart (2019), Lemille (2017), Gower and Schröder (2016). They all mainly criticize the insufficient connection of the social dimensions with the environmental components. Kirchherr et al. (2017) analyzed 114 definitions focused on CE, and thus, they explicitly confirmed this fact. The new conceptual framework of mutually relating CE and HD should effectively link the technological and biological spheres (Leemille, 2017). Korhonen et al. (2018) criticize the concept of CE from the point of view of its environmental sustainability. Only after this is achieved does the concept of CE ensure global sustainability. The authors see applying the combined concept of CE and HD as problematic, both on a practical and a political level. Experimental and research approaches can eliminate these problems.

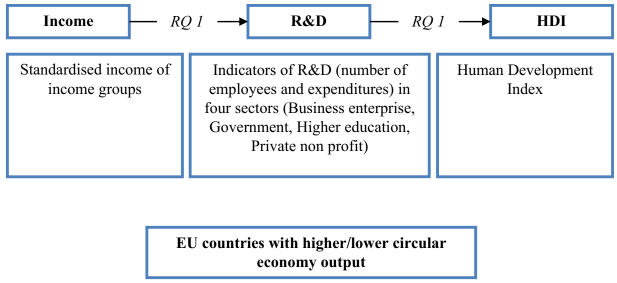

Fig. 1 Association of the fundamental research components and the research questions.

The study's results declare an extensive research scope when examining the issues of innovation, income inequality, and sustainable development. However, comparative dimensions defined through international concepts such as CE and HD still need to be included. Using these dimensions will allow us to examine the positions of research trajectories—income inequality—innovations—and sustainable development and reveal new factors and causes of differences between countries with different economic characteristics. The outcomes of these analyses will primarily benefit policymakers, strategies, and development plans. Thus, they will support international comparison processes for creating national and international benchmarking indicators and forecasting platforms.

Methodology

Basic research trajectories were established on the platform of the relevant scientific resources and after identifying the research gap. Our research was aimed at evaluating the relations among the general income level (Earnings), indicators of R&D potential (R&D), and economic output represented by the HDI.

Figure 1 shows the basic components of the research and their relation to the research questions.

RQ 1: Is there a relation between the general level of income and the outputs of R&D potential among European countries with a higher and lower level of CE use?

RQ 2: Is there a relation between the outputs of R&D potential and economic development represented by the HDI among the European countries with a higher and lower level of CE use?

Materials. This section includes a description of all the variables and their reasoning in relation to the research questions as well as a description of the sources, which they were obtained from. These aspects influenced also the selection of the methods listed in the "Materials" subsection.

One variable (income level) was included in the analytical processes from the Earnings area. This variable was created by averaging the standardized (from 0 to 1, where 1 is the highest income) 13 groups of average annual incomes in the purchasing power standard metric ((1) Single person without children earning 50% of the average earning, (2) Single person without children earning 67% of the average earning, (3) Single person without children earning 80% of the average earning, (4) Single person without children earning 100% of the average earning, (5) Single person without children earning 125% of the average earning, (6) Single person without children earning 167% of the average earning, (7) Single person with two children earning 67% of the average earning, (8) One earner couple with two children earning 100% of the average earning, (9) Two earner couple with two children one earning 100% and the other 33% of the average earning, (10) Two earner couple with two children one earning 100% and the other 67% of the average earning, (11) Two earner couple with two children both earning 100% of the average earning, (12) Two earner couple without children one earning 100% and the other 33% of the average earning, (13) Two earner couple without children both earning 100% of the average earning). The average of the listed standardized groups was calculated according to a high correlation value between these groups ($r > 0.9$). Another large area that represented the input of the analysis was the area of R&D. This area was formed by the two groups of the indicators—(i) number of employees converted to the full-time and (ii) gross domestic expenditure on R&D. Each of these two indicators was calculated for the four sectors (Business enterprise sector, Government sector, Higher education sector, Private non-profit sector). A total of 8 variables were analyzed in the field of R&D. The last variable that entered the analytical processes was the indicator illustrating economic development—the HDI indicator was selected for this purpose. The whole regression analysis was carried out in two ways—firstly, from a perspective of the countries with a higher level of CE use and secondly, from a view of the lower level of CE use. These were the groups of the countries that were classified according to the two indicators—(I) the number of Patents related to recycling and secondary raw materials and (II) the Circular material use rate.

The research group consisted of all the countries of the European Union ($n = 27$: Austria (AUT), Belgium (BEL), Bulgaria (BGR), Croatia (HRV), Cyprus (CYP), Czechia (CZE), Denmark (DNK), Estonia (EST), Finland (FIN), France (FRA), Germany (DEU), Greece (GRC), Hungary (HUN), Ireland (IRL), Italy (ITA), Latvia (LVA), Lithuania (LTU), Luxembourg (LUX), Malta (MLT), Netherlands (NLD), Poland (POL), Portugal (PRT), Romania (ROU), Slovakia (SVK), Slovenia (SVN), Spain (ESP), Sweden (SWE)) in period from 2010 to 2020. The analysis covered the data from the Eurostat database: Earnings (Eurostat, 2022a), R&D—Total researchers by sectors of performance—full-time equivalent (Eurostat, 2022b), R&D—GERD by sector of performance and fields of R&D (Eurostat, 2022c), Circular material use rate (Eurostat, 2022d), Patents related to recycling and secondary raw materials (Eurostat, 2022e), and the United Nations Development Program database (2022), which the HDI variable was obtained from. Table 1 describes all the variables used in the analytical processes.

Table 1 demonstrates the elementary description of the variables together with the outputs of the descriptive analysis. Column 1 describes the variable, followed by the name, which the variable appeared in analytical processes under, and the unit of the variable. In the next stage, a descriptive analysis was carried out. It would be appropriate to draw attention to the relatively high frequency of the missing values in R_FTE_Private_non_profit_sector and GERD_Private_non_profit_sector. At the same time, we perceive this shortcoming as a limitation of our research. When focusing on average values in the R&D indicators, it is obvious that the Business enterprise sector (mean: R_FTE_Business_enterprise_sector = 177.675 ± 132.213) and the Higher education sector dominate (mean: R_FTE_Higher_education_sector = 140.370 ± 61.984). These are the extreme differences as, for comparison, the Private non-profit sector is assigned an average value of the number of researchers equal to 4.179. Table 2 describes the analytical procedures applied.

Methods. The entire process of analytical processing can be divided into two stages. The cluster analysis was applied in the first stage, followed by the panel regression analysis. The cluster analysis was employed in order to illustrate the relation of the two variables, visualizing a geographical aspect of the two elementary variables. The panel regression analysis was employed in order to achieve the evaluation of the research questions. A panel form of the regression analysis is selected as the most appropriate for examination of the data set that keeps the panel form as there are two perspectives—geographical and time. When selecting the most appropriate model, the significance of the panel structure was verified through the *F*-test. Subsequently, the Hausman test was applied. As this test demonstrated significant values, the fixed (within) effects model was used to estimate the coefficients, and in the opposite case, the Random effect model was used. Heteroscedasticity was evaluated through the Breusch-Pagan test. In the case of significant heteroscedasticity, the White estimator was used in the Random effects model and the Arellano estimator in the Fixed effects model. The programming language R v. 4.2.1—Funny-Looking Kid (Team RC, 2022) was employed for this analytical processing in the R Studio provided by RStudio, Inc., Boston, MA, U.S. Table 2 mentions an overview of the applied methods or models in the analytical procedures, definition of their purpose as well as the applied packages of the R programming language.

Results

This part of the study was focused on investigating and evaluating the research questions and calculating and interpreting the results. The first part focuses on dividing the European Union member countries into groups according to the CE use level. In the second section, the panel regression analysis was carried out to investigate (i) the relationship between income and the selected indicators of R&D potential and (ii) secondly, the relationship between the selected indicators of R&D potential and the development of EU countries.

Classification of the countries into groups according to the level of CE use. This analysis aimed to classify the countries into homogeneous groups using cluster analysis using the indicators (i) the Circular material use rate and (ii) the Patents related to recycling and secondary raw materials per 1,000,000 inhabitants. These indicators were averaged for the individual countries (the average in the country was created of the values for the individual years). Subsequently, the 2 most suitable clusters were estimated by applying the Silhouette method. The cluster analysis was carried out through the Partitioning Around Medoids method, and its output is presented in Fig. 2.

Figure 2 demonstrates the division of the countries into individual groups, where the lower left corner represents the lowest level of CE use and the upper right corner the highest level on the contrary. The countries with a higher level of CE use are represented by the cluster 1 (Austria, Belgium, Czechia, Denmark, Estonia, Finland, France, Germany, Italy, Luxembourg, Netherlands, Poland, Slovenia, Spain) and the countries with a lower level by the cluster 2 (Bulgaria, Croatia, Cyprus, Greece, Hungary, Ireland, Latvia, Lithuania, Malta, Portugal, Romania, Slovakia, Sweden). The following outcomes of the panel regression analysis will be arranged according to the classification of countries in clusters 1 and 2.

Table 1 Elementary characteristics of the variables.

Variables	ID	Unit	Descriptive statistics				
			Missing	Min	Mean	Std. dev.	Max
Annual net earnings—standardized average of 13 income categories by income group (Eurostat, 2022a)	Earnings	Purchasing power parity (EUR)	9 (3.0%)	0.000	0.469	0.220	0.949
Researchers full-time equivalent FTE business enterprise sector per 100,000 Inhabitants (Eurostat, 2022b)	R_FTE_Business_enterprise sector	Number of full-time equivalent researchers	1 (0.3%)	17.417	177.675	132.213	557.129
Researchers Full-time equivalent FTE government sector per 100,000 inhabitants (Eurostat, 2022b)	R_FTE_Government sector	Number of full-time equivalent researchers	1 (0.3%)	2.026	44.503	26.005	145.944
Researchers full-time equivalent FTE higher education sector per 100,000 inhabitants (Eurostat, 2022b)	R_FTE_Higher_education sector	Number of full-time equivalent researchers	1 (0.3%)	29.736	140.370	61.984	289.193
Researchers full-time equivalent FTE private non-profit sector per 100,000 inhabitants (Eurostat, 2022b)	R_FTE_Private_non_profit sector	Number of full-time equivalent researchers	92 (31.0%)	0.000	4.179	6.254	52.702
Gross domestic expenditure on R&D business enterprise sector million purchasing power standards PPS per 100,000 inhabitants (Eurostat, 2022c)	GERD_Business_enterprise sector	EUR	0 (0.0%)	1.692	30.831	25.990	94.080
Gross domestic expenditure on R&D government sector million purchasing power standards PPS per 100,000 Inhabitants (Eurostat, 2022c)	GERD_Government sector	EUR	0 (0.0%)	0.154	5.529	4.790	28.603
Gross domestic expenditure on R&D higher education sector Million purchasing power standards PPS per 100,000 Inhabitants (Eurostat, 2022c)	GERD_Higher_education sector	EUR	0 (0.0%)	0.559	12.228	8.803	41.296
Gross domestic expenditure on R&D private non-profit sector million purchasing power standards PPS per 100,000 inhabitants (Eurostat, 2022c)	GERD_Private_non_profit sector	EUR	86 (29.0%)	0.000	0.443	0.545	3.197
Patents related to recycling and secondary raw materials per 1,000,000 inhabitants (Eurostat, 2022e)		Number of patents	27 (9.1%)	0.000	0.809	1.249	11.860
Circular material use rate (Eurostat, 2022d)		Percent	0 (0.0%)	1.200	8.671	6.427	30.900
Human Development Index (Human Development Index, 2022)	HDI	Index <0;1>	0 (0.0%)	0.790	0.884	0.038	0.998

Table 2 Applied analytical tools.

Analysis	Methods/models	Purpose	Source	Used R packages
Cluster analysis	Partitioning around medoids—manhattan distance	Country grouping based on CE use	Kassambara, 2017	cluster, factoextra
Silhouette analysis		Optimal number of clusters	Struyf et al. (1996)	factoextra
Regression model assumptions	*F*-test, Hausman test, Breusch-Pagan	Evaluation of assumptions and selection of an appropriate model	Wooldridge, 2010	plm, lmtest,
Panel regression analysis	Random effect model (white estimator), within effect model (Arellano estimator)	Quantifying the significance of selected relationships	Wooldridge, 2010; Arellano, 1987	plm, sandwich

The relationship between the income level and the selected indicators of R&D potential. The first step of quantifying the relationships was to evaluate the income level of the individual countries to their indicators of R&D potential. An analysis of the conditions shown in Table 3 offers the outcomes of the test about the classifying conditions of the particular panel regression model. The robustness of the models is mentioned in the conclusions section of the results.

The results of the condition tests in Table 3 declare that the structure of the countries is significant. Therefore, it is appropriate to apply the panel regression model; the significance of the structure of the years is rather random and did not manifest itself significantly in any case—that is why attention was paid to the application of the individual effects models. The Hausman test decided on the appropriateness of applying the Within and Random effects model, and the Breusch-Pagan test pointed out the occurrence of significant heteroscedasticity. According to these tests, the most suitable models were selected, whose results are shown in Table 4.

Table 4 represents the outputs of the process of evaluating the relationships between the indicators of the income level of the European Union member countries and the selected indicators of the R&D potential. It is obvious that in most cases, we can talk about a statistically significant relation. In the countries with a higher level of CE use (Cluster 1), more significant relationships were manifested than in the countries with a lower level. All the relationships are assigned a positive β coefficient meaning an increase in the income level can be associated with a higher level of the R&D potential. When we focus specifically on the results of Cluster 1, it is possible to observe that the closest connection, the largest coefficient of determination, is found in the relationship with the dependent variable R_FTE_Business_enterprise ($R^2 = 0.448$) and GERD_Higher_education ($R^2 = 0.466$). Both of these relationships are significant at the $\alpha < 0.001$ level. The results indicate that a general increase in wages in the countries with a higher level of CE use will most likely have the greatest effect on the increase in the number of researchers in the Business enterprise sector and the increase in the research expenditures in the Higher education sector. At this point, it is appropriate to remind that the biggest creator of innovations is the Business enterprise sector, and an increase in the number of employees predicts an increase in the output of this sector similarly. In order not to forget the expenses in the business sector, the coefficient of determination for expenses stands at a level of 0.309 (Earnings→GERD_Business_enterprise: $\beta = 54.273$, p-value = <0.001) that can be understood as a positive output. On the contrary, the government research sector appears to be immune to the increase in the level of income in the explored countries (Earnings→R_FTE_Government: $\beta = -10.875$, p-value = 0.26; Earnings→GERD_Government: $\beta = 6.418$, p-value = 0.083). As mentioned above, the three relationships appear to be significant in the countries with a lower level of CE use. Of these three relationships, two are in the Business enterprise research sector exactly and these are the relationships with the highest coefficient of determination (R^2: R_FTE_Business_enterprise = 0.173; GERD_Business_enterprise = 0.195) in the observed group of the countries. Thus, the increase in the income level will have little effect on the increase of a number of new employees and the increase of the expenses related to the R&D in the Business enterprise sector. An increase in the research expenses in the Higher education sector is also expected with an increase in income. The above-mentioned facts indicate certain differences in the relationship between income and research among the countries with higher and lower levels of CE use. In this relationship, it is obvious that the relationship is stronger in the countries with a higher level of CE use.

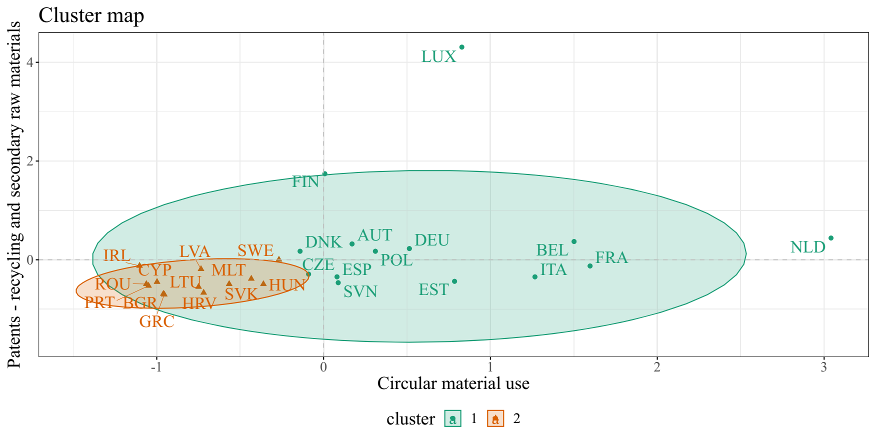

Fig. 2 Cluster map—classification of the countries into the groups according to the level of CE use.

Table 3 Tests of panel regression model conditions—Earnings→indicators of R&D potential.

Dependent variables	*F*-test country (sig)	*F*-test year (sig)	Robust Hausman (sig)	Breusch-Pagan (sig)	Model
Cluster 1 (independent variable: Earnings)					
R_FTE_Business_enterprise	170.91 (<0.001)	0.62 (0.797)	8.55 (0.003)	0.01 (0.915)	Within
R_FTE_Government	116.58 (<0.001)	0.07 (1)	0.13 (0.723)	18.43 (<0.001)	Random white
R_FTE_Higher_education	253.66 (<0.001)	0.4 (0.946)	5.13 (0.024)	0.14 (0.704)	Within
R_FTE_Private_non_profit	86.61 (<0.001)	0.21 (0.995)	3.12 (0.077)	7.71 (0.005)	Random white
GERD_Business_enterprise	136.75 (<0.001)	0.18 (0.998)	0.91 (0.34)	1.59 (0.208)	Random
GERD_Government	169.79 (<0.001)	0.12 (1)	1.51 (0.219)	64.82 (<0.001)	Random white
GERD_Higher_education	314.25 (<0.001)	0.07 (1)	0.14 (0.704)	1 (0.318)	Random
GERD_Private_non_profit	82.65 (<0.001)	0.1 (1)	0.36 (0.548)	12.76 (<0.001)	Random white
Cluster 2 (independent variable: Earnings)					
R_FTE_Business_enterprise	118.25 (<0.001)	0.06 (1)	0.3 (0.586)	16.76 (<0.001)	Random white
R_FTE_Government	95.81 (<0.001)	1.56 (0.127)	40.19 (<0.001)	2.18 (0.14)	Within
R_FTE_Higher_education	107.78 (<0.001)	0.07 (1)	0.06 (0.801)	6.25 (0.012)	Random
R_FTE_Private_non_profit	4.82 (<0.001)	0.94 (0.507)	1.89 (0.17)	4.98 (0.026)	Random white
GERD_Business_enterprise	360.45 (<0.001)	0.03 (1)	0.01 (0.914)	17.82 (<0.001)	Random white
GERD_Government	30.95 (<0.001)	0.94 (0.501)	8.7 (0.003)	16.55 (<0.001)	Within Arellano
GERD_Higher_education	354.64 (<0.001)	0.06 (1)	0.2 (0.654)	10.58 (0.001)	Random white
GERD_Private_non_profit	13.14 (<0.001)	0.45 (0.917)	5.34 (0.021)	21.16 (<0.001)	Within Arellano

Table 4 The regression model outcomes in the clustering approach—dependent variable: R&D; independent variable: Earnings.

Dependent variables	Cluster 1 (independent variable: Earnings)				Cluster 2 (independent variable: Earnings)			
	Model	Coeff	Estimate coeff (Std. Error) sig	R^2	Model	Coeff	Estimate coeff (std. error) sig	R^2
R_FTE_Business_enterprise	Within	α	-	0.448	Random White	α	31.696 (33.02) 0.339	0.173
		β	339.641 (32.002) < 0.001			β	194.223 (23.837) < 0.001	
R_FTE_Government	Random	α	57.665 (8.707) < 0.001	0.001	Within	α	-	0.025
	white	β	−10.875 (9.616) 0.26			β	11.116 (6.415) 0.086	
R_FTE_Higher_education	Within	α	-	0.402	Random	α	117.621 (21.821) < 0.001	0.01
		β	115.39 (11.94) < 0.001			β	31.103 (22.553) 0.168	
R_FTE_Private_non_profit	Random	α	0.145 (0.934) 0.877	0.226	Random white	α	1.76 (1.848) 0.345	0.017
	white	β	6.482 (0.938) < 0.001			β	7.605 (4.271) 0.08	
GERD_Business_enterprise	Random	α	16.145 (6.914) 0.02	0.309	Random white	α	7.022 (6.019) 0.245	0.195
		β	54.273 (6.581) < 0.001			β	22.668 (2.188) < 0.001	
GERD_Government	Random	α	6.418 (1.584) < 0.001	0.026	Within	α	-	0.087
	white	β	2.827 (1.621) 0.083		Arellano	β	2.52 (1.303) 0.055	
GERD_Higher_education	Random	α	6.81 (2.313) 0.003	0.466	Random white	α	5.928 (2.15) 0.007	0.094
		β	18.115 (1.574) < 0.001			β	5.072 (1.269) < 0.001	
GERD_Private_non_profit	Random	α	0.12 (0.107) 0.267	0.103	Within	α	-	0.001
	white	β	0.539 (0.114) < 0.001		Arellano	β	−0.198 (0.52) 0.704	

Table 5 Tests of panel regression model conditions—the indicators of the R&D potential→Human Development Index.

Independent variables	*F*-test country (sig)	*F*-test year (sig)	Robust Hausman (sig)	Breusch-Pagan (sig)	Model
Cluster 1 (dependent variable: HDI)					
R_FTE_Business_enterprise	15.45 (<0.001)	1.52 (0.137)	0.02 (0.888)	5.04 (0.025)	Random white
R_FTE_Government	25.7 (<0.001)	2.27 (0.017)	3.61 (0.058)	5.12 (0.024)	Random white
R_FTE_Higher_education	19.87 (<0.001)	1.68 (0.091)	0.22 (0.639)	4.45 (0.035)	Random white
R_FTE_Private_non_profit	22.93 (<0.001)	1.69 (0.09)	2.11 (0.146)	1.85 (0.174)	Random
GERD_Business_enterprise	7.97 (<0.001)	2.2 (0.021)	1.73 (0.188)	5.51 (0.019)	Random white
GERD_Government	22.21 (<0.001)	2.13 (0.026)	0.88 (0.349)	5.22 (0.022)	Random white
GERD_Higher_education	19.36 (<0.001)	1.77 (0.071)	2.58 (0.108)	5.02 (0.025)	Random white
GERD_Private_non_profit	21.78 (<0.001)	1.6 (0.116)	0.74 (0.391)	1.17 (0.279)	Random
Cluster 2 (dependent variable: HDI)					
R_FTE_Business_enterprise	39.97 (<0.001)	0.91 (0.53)	0 (0.988)	0.54 (0.464)	Random
R_FTE_Government	47.4 (<0.001)	2.43 (0.011)	11.54 (<0.001)	0.01 (0.929)	Within
R_FTE_Higher_education	46.96 (<0.001)	1.32 (0.227)	0.21 (0.644)	2.78 (0.096)	Random
R_FTE_Private_non_profit	60.99 (<0.001)	0.47 (0.9)	0.17 (0.681)	1.8 (0.18)	Random
GERD_Business_enterprise	40.09 (<0.001)	1.41 (0.184)	4.74 (0.03)	2.88 (0.09)	Within
GERD_Government	61.07 (<0.001)	1.18 (0.311)	0 (0.993)	0.2 (0.658)	Random
GERD_Higher_education	26.82 (<0.001)	2.17 (0.023)	1.97 (0.16)	0.03 (0.857)	Random
GERD_Private_non_profit	71.72 (<0.001)	0.56 (0.844)	0.44 (0.507)	2.88 (0.09)	Random

Table 6 The outputs of the regression model in the cluster classification—dependent variable: HDI; independent variables R&D.

independent variables	Cluster 1 (dependent variable: HDI)				Cluster 2 (dependent variable: HDI)			
	Model	Coeff	Estimate coeff (std. error) sig	R^2	Model	Coeff	Estimate coeff (std. error) sig	R^2
R_FTE_Business_enterprise	Random	α	0.87 (0.008) < 0.001	0.221	Random	α	0.839 (0.008) < 0.001	0.294
	white	β	0.00015 (0) < 0.001			β	0.00021 (0) < 0.001	
R_FTE_Government	Random	α	0.909 (0.008) < 0.001	0.004	Within	α		0.046
	white	β	−0.00009 (0.0001) 0.306			β	0.001 (0) 0.014	
R_FTE_Higher_education	Random	α	0.862 (0.009) < 0.001	0.12	Random	α	0.835 (0.012) < 0.001	0.104
	white	β	0.00028 (0) < 0.001			β	0.00021 (0.0001) < 0.001	
R_FTE_Private_non_profit	Random	α	0.889 (0.007) < 0.001	0.831	Random	α	0.856 (0.015) < 0.001	0.631
		β	0.00367 (0.0011) < 0.001			β	−0.00041 (0.0002) 0.074	
GERD_Business_enterprise	Random	α	0.873 (0.006) < 0.001	0.238	Within	α		0.316
	white	β	0.00072 (0.0001) < 0.001			β	0.002 (0) < 0.001	
GERD_Government	Random	α	0.897 (0.008) < 0.001	0.014	Random	α	0.851 (0.012) < 0.001	0.029
	white	β	0.00097 (0.0005) 0.039			β	0.00395 (0.0019) 0.039	
GERD_Higher_education	Random	α	0.865 (0.008) < 0.001	0.204	Random	α	0.825 (0.008) < 0.001	0.284
	white	β	0.00244 (0.0003) < 0.001			β	0.00467 (0.0006) < 0.001	
GERD_Private_non_profit	Random	α	0.893 (0.007) < 0.001	0.746	Random	α	0.856 (0.016) < 0.001	0.558
		β	0.02073 (0.0087) 0.018			β	−0.00333 (0.004) 0.408	

The relationship between the selected indicators of R&D potential and the HDI. The second part of the research was focused on evaluating the relationship between the R&D potential and HDI. In the first step, based on the conditions, the most suitable panel regression models were selected (Table 5). Successively, these models were applied, and the results of the panel regression models are visualized in Table 6 in the end, the robustness of the models was investigated.

Table 5 demonstrates the process of evaluating the conditions to select the most suitable model to picture the investigated relationships. In the first step, the *F*-test was applied, which clearly demonstrated the appropriateness of considering the countries' structure. The structure of the years is significant in only the two cases. According to these facts, applying the individual effects models suits this situation. The robust implementation of the Hausman test decided on applying the within and random effects models. The Breusch-Pagan test evaluated the normal distribution of the origin of the residuals. The last column of the table shows the name of the most suitable model.

The results of quantifying the relationships between the selected indicators of the R&D potential and the HDI listed in Table 6 declare a significant positive relationship between them. Significance was demonstrated in a majority of the cases. For the countries with a higher level of CE use (Cluster 1), the relationship did not manifest itself in only one case (R_FTE_Government→HDI) and for the group of the countries with a higher level of CE use possesses two cases (R_FTE_Private_non_profit→HDI; GERD_Private_non_profit→HDI). It can be concluded that there is a significant relationship between the R&D potential in the European Union member countries.

Suppose we focus on the results visualized in Table 6, particularly in countries with higher CE use. In that case, it is possible to see an extremely high level of the coefficient of determination in the relationship of the R&D Private non-profit sector with the HDI (R^2: R_FTE_Private_non_profit = 0.831; GERD_Private_non_profit = 0.746). Nevertheless, it should be noted here that only the relationship with R_FTE_Private_non_profit is significant at the $\alpha < 0.001$ level. This result can be considered the strengthening of the R&D in the Private non-profit sector, which is likely to be reflected in HDI growth. The interesting results can be seen in the Business enterprise sector (R^2: R_FTE_Business_enterprise_sector = 0.221, GERD_Business _enterprise_sector = 0.238) which showed a significant relationship with HDI at a statistical significance level lower than 0.001. Enhancing research in this sector will likely lead to an increase in the HDI. The countries with a lower level of CE use represent the most significant and closest effect when interconnecting the Business enterprise of the research sector with the HDI. Thus, if the Business enterprise research sector develops more in these countries, a considerable increase in HDI can be expected. The differences between the country groups were evident in only a few relationships. These are only moderately significant differences. The most significant one compared to the countries with a higher level of CE use was the non-confirmation of the Private non-profit research sector with the HDI. A slight difference was also seen in the business enterprise sector. When associating the Business sector with HDI, a higher level of interconnection appears in the countries with a lower level of CE use precisely (Cluste 1–R^2: R_FTE_Business_enterprise→HDI = Cluste 1–0.221, Cluste 2–0.294; GERD_Business_enterprise→HDI = Cluste 1–0.238, Cluste 2–0.316). This result can be explained exactly by the principles of β and σ convergence.

Robustness. There is also to note the outcome of the robustness testing. The entire sample entered this process (without sorting into the individual clusters), and the assessment itself was carried out by comparing the consistency of the results with the results in Tables 4 and 6. In the first step, the conditions of the panel regression model were assessed, and the most suitable model was selected successively (Table 7). The outputs of these models are shown in Table 8.

In this case (Table 7), only the two most important conditions were evaluated, namely the Hausman and Breusch-Pagan tests. In all the cases, the p-value of the Hausman test was higher than 0.05, thus choosing the random effects method. In the cases where the p-value (sig) of the Breusch-Pagan test is lower than 0.05, the White estimator was employed.

The robustness testing was evaluated by estimating the models without sorting the individual clusters of the countries according to CE use. The results indicate that consistency of the results is maintained in a vast majority of the cases. There is practically no disparity in the change of the sign of the coefficients, and the only partially visible differences are seen in the Earnings→R&D models, where the robustness results are more similar in the outcome of the first Cluster (the countries with a higher level of CE use). There are more statistically significant coefficients. According to these facts, it is possible to consider the outputs presented in Tables 4 and 6 sufficiently consistent and credibly robust.

Discussion

The outputs of the analytical processes brought many interesting findings, and thus, they created an extensive interpretive framework. Due to the two analytical lines supported by the research questions, the outcomes were aggregated into two parts, whose outputs are procedurally followed. Achieving the research objective was supported by the research questions RQ1 and RQ2.

RQ 1: Is there a relation between the general level of income and the outputs of research and development potential among European countries with a higher and lower level of circular economy adaptation?

RQ 2: Is there a relation between the outputs of research and development potential and economic development represented by the HDI among the European countries with a higher and lower level of circular economy adaptation?

Within RQ1, according to the analytical outputs, it is possible to state the following findings (A–D):

Table 7 Tests of panel regression model conditions—robustness (Earnings→R&D; R&D→HDI).

Variables	Robust Hausman (sig) Earnings→R&D	Breusch-Pagan (sig)	Model	Robust Hausman (sig) R&D→HDI	Breusch-Pagan (sig)	Model
R_FTE_Business_enterprise	1.92 (0.166)	3.31 (0.069)	Random	0.9 (0.343)	11.41 (<0.001)	Random white
R_FTE_Government	0.79 (0.375)	67.56 (<0.001)	Random White	0.12 (0.734)	1.29 (0.257)	Random
R_FTE_Higher_education	0.51 (0.474)	0.74 (0.39)	Random	0.44 (0.507)	0.46 (0.499)	Random
R_FTE_Private_non_profit	0.69 (0.405)	6.17 (0.013)	Random White	0.1 (0.756)	1.02 (0.312)	Random
GERD_Business_enterprise	0.06 (0.8)	13.87 (<0.001)	Random White	1.69 (0.194)	23.3 (<0.001)	Random white
GERD_Government	0.78 (0.376)	177.55 (<0.001)	Random White	2.56 (0.109)	6.38 (0.012)	Random white
GERD_Higher_education	0.16 (0.689)	13.15 (<0.001)	Random White	0.54 (0.463)	5.73 (0.017)	Random white
GERD_Private_non_profit	2.71 (0.1)	52.22 (<0.001)	Random White	0.45 (0.501)	2.81 (0.093)	Random

Table 8 Outputs of the regression model—robustness analysis.

Variables	Earnings→R&D				R&D→HDI			
	Model	Coeff	Estimate coeff (std. error) sig	*R*-squared	Model	Coeff	Estimate coeff (std. error) sig	*R*-squared
R_FTE_Business_enterprise	Random	α	52.274 (27.158) 0.054	0.288	Random	α	0.851 (0.006) < 0.001	0.272
		β	264.564 (24.49) < 0.001		white	β	0.00019 (0) < 0.001	
R_FTE_Government	Random	α	45.388 (5.352) < 0.001	<0.001	Random	α	0.883 (0.009) < 0.001	0.003
	white	β	−1.795 (5.6536) 0.751			β	0.00002 (0.0001) 0.836	
R_FTE_Higher_education	Random	α	106.932 (13.147) < 0.001	0.097	Random	α	0.849 (0.009) < 0.001	0.102
		β	71.52 (12.637) < 0.001			β	0.00025 (0) < 0.001	
R_FTE_Private_non_profit	Random	α	1.771 (0.973) 0.07	0.013	Random	α	0.885 (0.008) < 0.001	0.668
	white	β	4.93708 (1.7767) 0.006			β	−0.00027 (0.0002) 0.225	
GERD_Business_enterprise	Random	α	12.267 (4.904) 0.013	0.244	Random	α	0.853 (0.005) < 0.001	0.258
	white	β	39.3286 (3.6798) < 0.001		white	β	0.00102 (0.0001) < 0.001	
GERD_Government	Random	α	4.272 (0.93) < 0.001	0.033	Random	α	0.874 (0.007) < 0.001	0.022
	white	β	2.65007 (0.8807) 0.003		white	β	0.00182 (0.0005) < 0.001	
GERD_Higher_education	Random	α	6.671 (1.662) < 0.001	0.277	Random	α	0.842 (0.006) < 0.001	0.259
	white	β	11.7909 (1.1611) < 0.001		white	β	0.00348 (0.0003) < 0.001	
GERD_Private_non_profit	Random	α	0.178 (0.098) 0.07	0.03	Random	α	0.884 (0.008) < 0.001	0.564
	white	β	0.54254 (0.1726) 0.002			β	0.00017 (0.0036) 0.963	

A. An increase in income in the countries with a higher level of CE use will possess the largest effect on the increase in the number of researchers in the Business enterprise sector. The significant income effects in these countries were also demonstrated in Higher education and Private non-profit R&D sectors.
B. An increase in income in the countries with a higher level of CE use will possess the largest effect on the increase in research expenditures in the Business enterprise sector. The significant income effects in these countries were also demonstrated in Higher education and Private non-profit R&D sectors.
C. An increase in income in the countries with a lower level of CE use will possess the largest effect on the increase in the number of researchers in the Business enterprise sector. The other areas of R&D did not demonstrate a significant relation to income.
D. An increase in income in the countries with a lower level of CE use will possess the largest effect on the increase in research expenditures in the Business enterprise sector. The significant income effects in these countries were also demonstrated in the Higher education R&D sector.

Within RQ2, the findings formulated in points E–H were confirmed:

E. An increase in the number of researchers in the Private non-profit sector in the countries with a higher level of CE use will significantly affect HDI growth. Moreover, a significant effect was also demonstrated in the Business enterprise and Higher education R&D sector.
F. An increase in expenditures in the Private non-profit sector in countries with a higher level of CE use will significantly affect HDI growth. A significant effect in this area was demonstrated in all the sectors.
G. An increase in the number of researchers in the Business enterprise sector in countries with a lower rate of CE use will significantly affect HDI value growth. Moreover, a significant effect was also demonstrated in the Government and Higher education R&D sector.
H. An increase in R&D expenditures in the Business enterprise sector in countries with a lower rate of CE use will significantly affect HDI value growth. Moreover, a significant effect was also demonstrated in the Government and Higher education R&D sector.

RQ1—income level. The analytical processes that quantify the relationships between income and research potential revealed that in most cases, there is a positive significant relationship in the countries with a higher level of CE use. Significance did not appear in this group of the countries for the indicators related to R&D of government institutions (the number of scientific researchers and expenditures). The countries with a lower level of CE use demonstrated less significant relationships. At the $\alpha < 0.05$ significance level, only the three relationships were significant (Earnings→R_FTE_Business_enterprise; Earnings→ GERD_Business_enterprise; Earnings→GERD_Higher_education).

These results can also be related to the sectoral structure of the R&D investments and the innovation inequality of the individual subjects (Xu et al., 2023). Experimental and applied R&D investments positively affect productivity growth in the near term, especially for elementary research by the three periods (Sun et al., 2016). This is also pointed out by the study of Yazgan & Yalçinkaya (2018), in which the authors recommend directing R&D investments made by the various sectors to the selected innovative areas in which they would create added value. Hiring employees in the field of R&D can be very efficient economically.

Still, it requires the preparation of suitable policies and educational systems to the requirements linked to CE use in companies and sectors (Ren et al., 2022).

The difference in the outcomes in considering the level of CE use in the countries can be justified by the different investment requirements of innovation and the different distribution and aggregation of innovation resources that significantly affect innovation efficiency (Xu et al., 2023). These findings also confirm the results of the study by Yazgan & Yalçinkaya (2018), who found that all the R&D variables in the different qualifications within the OECD-20 countries, which have a higher income level in the explored period, show a positive and statistically significant effect on the economic growth. The private sector, universities, and the total R&D investment have a positive and statistically significant effect on the economic growth of the OECD-9 group countries with a much lower income level.

Thus, the impact of income inequality on economic growth through innovation and R&D spending was confirmed by our results and the numerous research studies (….). The sector type and the industry where the companies allocating investments for R&D operate also determine employment and economic growth. When evaluating this determinant, it is necessary to thoroughly examine the process side and interpret the results to the sector's characteristics and the specifics of the individual companies and their internal processes. The innovations are placed in the position of a factor with an individualized influence on the company's performance, causally associated with the other dimensions. This is evidenced by several studies. For instance, Barbiere et al. (2019) state that the positive effects of innovation activities on employment and R&D expenditures result from the activities of the companies operating in high-tech and large industries. According to these authors, no working positions created due to innovative and technical changes were detected in the traditional sectors and SMEs. According to Dosi & Mohnen (2019), product innovation does not lead to the disappearance of working positions but primarily to their polarization. According to these authors, the effects of the process innovations are much more controversial. This follows from the fact that at the basic company level, a significant negative impact of innovation on employment may not be observed. Still, the industry may have a more extensive sack of employees.

Within these sectoral aspects, examining the microeconomic level effects that may impact lower or higher employment rates due to the R&D corporate investments is important. For instance, a functional example can also be legislation protecting employment, as Tran (2023) reported. Companies with strong employment protection legislation may have lower R&D and investment efficiency. The effect of employment protection on R&D expenditures was confirmed stronger in financially restricted companies, and the effect of employment protection on the efficiency of R&D investments was confirmed stronger in financially unrestricted companies (Tran, 2023). Total R&D can only, with minimal probability, cause an increase in the number of employees in the self-employment group particularly. R&D increases the probability of transition from unemployment to paid employment, especially in routinized areas (Ciarli et al., 2020).

The difference in our results when considering the rate of CE use in the countries can be justified by the different innovation investment requirements in the companies and the sectors and the different distribution and aggregation of the innovation resources that significantly affect innovation efficiency. These results are also supported by the study by Xu et al. (2023). The quantification of this innovative efficiency is methodologically quite demanding precisely because of the mentioned aspects and their causal connections that make the creation of national and international benchmarking indicators significantly more difficult.

When focusing on the similarity of the relations of the significant relationships, a higher coefficient of determination was shown in the countries with a higher level of CE use. According to the above-mentioned outcome, it seems that income (especially in the countries with a higher level of CE use) can represent one of the predictors that can be associated with a higher level of R&D. These results are consistent with the results of the Baneliene & Melnikas (2020) study, which declare that R&D spending has a positive impact on economic growth. This impact is much higher in developed countries under sustainable development and globalization conditions. Similar findings can be found in several studies in which R&D effects are directly related to international competition and sustainable growth (Akcali & Sismanoglu, 2015). This will create strong pressure to increase R&D spending and create effective policies, while the right setting of active policies and resources will be important.

RQ2—Human Development Index. The link between R&D and economic development represented by the HDI confirmed a significant positive relationship in most cases. According to this, it can be assumed that with the growth of activities (and hence, outputs, for instance, in the form of innovations) linked to R&D, there will also be an increase in the economic development of the countries. These findings correspond with the results of the study by Anvari and Norouzi (2016), and Nair et al. (2020), who confirm the impact of R&D on economic development. R&D spending is considered a fundamental indicator of innovation, and HDI is an indicator of the economic growth quality that is confirmed not only by our findings but also by many research studies (Kaewnern et al., 2023; Gumus & Celikay, 2015; Kokko et al., 2015).

The empirical results show that R&D associated with developing ICT infrastructure effectively supports long-term economic growth in the OECD countries. The characteristics of these variables reveal the complex interrelationships that have to be the subject of systematic investigation. It is also necessary to take into account the so-called delay effect. According to Sun et al. (2016), investments in experimental and applied R&D positively affect productivity growth in the near period for elementary research by approximately three periods. R&D and innovation have been recognized as crucial factors for promoting long-term sustainable economic growth while simultaneously creating working positions and eliminating the inequalities in the developed and developing economies are required for the right setting of the policies and the activities necessary for the sectoral analyses and systematic creation of the analytical prognostic platforms.

According to our results, in the countries with a higher level of CE use, only one relationship appears insignificant: the connection of the government R&D sector with economic development. In the countries with a lower level of CE use, the significance of the relation did not appear for (i) the number of private non-profit sector researchers and (ii) private non-profit sector science and research expenditure.

Innovations are generally considered to be one of the fundamental attributes of economic development. R&D possesses an important position in the innovation processes. The government sector should be highly interested in supporting the development of the countries to produce quality innovations. The absence of a significant relationship within the government sector indicator creates space for further analysis and discussion. A surprising finding was that the government sector showed a non-significant link with HDI, even in countries with higher CE use. These findings highlighted the potential inefficiency of the government R&D sector. This situation may be due to the structure of R&D expenditures and their innovation transfer. The time aspect plays an important role in this process.

R&D spending has a positive and significant effect on the economic growth of all countries in the long run, while the effect of R&D spending for developing countries is weak in the short run but strong in the long run. This is confirmed by the study by Gumus & Celikay (2015) that examines these research relations. The innovation systems and their improvements will also play a significant role in the innovation processes of the countries with an emphasis on private sector R&D, as well as relations between the public and private sectors (Kokko et al., 2015). These links between sectors have yet to be explored so far. The allocation dimension is also important when deciding on the optimal structure of expenses for R&D financing. Thus, it can have a significant impact on employment as well as on economic growth. The public subsidies allocated to large and medium-sized companies can increase R&D employment in large and medium-sized companies (Boeing et al., 2022) and, thus, change the innovation structure in the sectors.

Within innovative development, it is appropriate to examine the qualification structure of R&D employees not only from a point of view of income but also from a point of view of the changes in employment during the introduction of innovations in the various sectors and to quantify its impact on economic growth. This is also confirmed by the study of the authors Yazgan & Yalçinkaya (2018), who found that all the R&D variables in the different qualifications within the OECD-20 countries have a higher income level in the observed period and a positive and statistically significant impact on economic growth. The private sector, universities, and the total R&D investment have a positive and statistically significant effect on the economic growth of the OECD-9 group countries with a much lower income level. Examining the qualification structure of employees due to the impact of the innovative changes to income characteristics will require access to more deeply structured data. Their absence will make national and international comparisons and the creation of the relevant methodologies more difficult.

Implications. Innovation is a key driving force for the development of the regions and the countries. Innovation activities strongly correlate with income inequality, so one possible solution is to diversify innovation into many sectors that would help the EU countries and the regions within them to reduce income inequality.

Recently, studies have confirmed that technological diversification can create a more equal society and generate higher economic growth. Many countries have tried to concentrate their innovation activities in their strong sectors for a long period. At the same time, it is now very important to diversify their innovation activities into sectors previously considered economically weak and not supported. The innovation potential of the companies within the sectors is also different, and thus, it is affected by many microeconomic and macroeconomic influences. Access to innovation capital is also different depending on the characteristics of the companies as well as their strategic direction. The latest studies confirm that technological diversification can create a more equal society and generate higher growth.

SMEs with limited innovation activity will need financial support, including green innovation. Public financial support is and will be one of the effective tools to facilitate the transition to a sustainable economy (Flachenecker et al., 2022). The green innovations will have a different position; the character and processes of their introduction are determined by international and national policies. The green innovations have a strong positive impact on long-term working position creation, even much higher than the impact of the other innovations (Gagliardi et al., 2016). They are triggered through R&D (knowledge capital). Therefore, it is impossible to examine the dynamic nature of green innovations that will reduce the processes of quantifying its impacts and influences in the future (Horbach, 2008). Therefore, it is important to investigate the causal relations between the individual determinants of innovation and to evaluate to what extent the growth of green working positions will be influenced by the microeconomic and macroeconomic factors and what support tools will be possibly created according to them.

For the success of the innovation policies in the future, a detailed examination of sectoral and company characteristics and their relation to innovation and financial mechanisms will be important. According to some studies, process innovations have little role in increasing employment. On the other hand, raising the efficiency of the unchanged product production, related to innovations, tends to reduce employment. Product innovations stimulate employment (Hou et al., 2019). Still, the innovation and product policies in the sectors can affect employment change to varying levels and create the potential for maintaining regional inequalities. It is typical in locations with significant industrial specialization or geographical specificities. For the construction of active policies in the field of employment in the individual sectors, it will be necessary to examine the net effects of product innovation and the net growth of total employment, which will also create a platform for comparative analyses. A similar innovative approach was employed by Aravossis et al. (2019), who implemented a pilot co-integrated scheme based on an innovative in-house evaluation that is composed of the Holistic Assessment Performance Index for Environment as an industry tool, which covers the principles of circular economy through the Eco-innovation Development and Implementation Tool.

The structure of R&D expenditures will continue to be an important determinant of the R&D investment effectiveness, as the various stakeholders may have limited resources. Our findings highlighted the potential inefficiency of the government R&D sector. The introduction of the appropriate financial mechanisms can support the efficiency of investments even within the sectors and at different levels. In this context, many authors recommend investigating the effects of institutional support and public policies on R&D that can bring new information to forecast processes and prepare effective policies (Beck et al., 2016). From a procedural point of view, it is important to state that only a certain part of R&D expenditures will be converted into innovations, which is confirmed by several research studies (Ameer et al., 2022; Yu et al., 2022). This consistent fact will significantly complicate the future economic quantification of the effects of the innovation policies. A systematic investigation of this aspect would bring new insights into the effectiveness of R&D expenditure on economic and environmental sustainability and support the development and modification of the CE and HD concepts.

Investigating this aspect would bring further new insights into the effectiveness of R&D spending on economic and environmental sustainability. Some experts are sensitive to these aspects and state that it is important from a political point of view to design the right national policies that would enable the transition from investment-based strategies to innovation-based strategies at the appropriate periods (Kacprzyk & Świeczewska, 2019).

Within these national innovation policies, it is important to examine and define the positions of the public R&D subsidies to the private R&D expenditures in large companies. The R&D

subsidies can increase R&D in smaller companies and companies with a real interest in R&D (Szücs, 2020). This can support a reduction of the regional disparities and discrepancies in the economic development of the regions within the countries and ensure the economic and environmental sustainability of these regions. Thus, attention is paid to reassessing the current state of the innovation policies to the three dimensions of sustainable development: economic, social, and environmental.

Conclusions

The primary objective of this research was to illuminate the intricate relationships between income inequality, R&D potential indicators, and HDI within European nations, contrasted against their levels of CE adoption. Through a meticulous analysis of panel data from all 27 EU countries spanning a decade (2010–2020), our findings not only bridge the divide between traditional economic metrics and emerging paradigms of human and environmental well-being but also provide a sector-specific perspective, particularly underscoring the Business enterprise sector's pivotal role.

Scientifically, this study contributes to the field by offering a holistic understanding of economic indicators that transcend the limitations of GDP-centric metrics. The empirical evidence from the comprehensive data analysis lends statistical rigor to the burgeoning discourse on the "well-being economy". Furthermore, the nuanced insights derived from different research sectors, especially the prominence of the Business enterprise sector, pave the way for specialized policy-making and targeted interventions.

From a practical standpoint, our findings carry significant implications for improving societal and environmental well-being:

1. R&D emerges as a crucial lever for fostering well-being. An intensified focus on R&D, particularly in sectors exhibiting a strong relationship between Earnings and R&D, can catalyze innovations that resonate with societal well-being and environmental stewardship.
2. A shift in policy orientation is warranted, where human and environmental well-being supersedes mere economic expansion as primary national goals.
3. The evident benefits of CE in countries with higher adoption rates in this study underscore the urgent need for a more rapid global transition towards a circular economy.
4. To holistically gauge a nation's progress, implementing alternative progress indicators encapsulating health, environmental sustainability, and human satisfaction is imperative.
5. The onus is on governments to initiate and nurture collaborations with diverse stakeholders—businesses, NGOs, academia—fostering innovation networks and partnerships in pursuit of well-being-centric objectives.
6. Lastly, the significance of public awareness and education must be balanced. A paradigm shift towards a "well-being economy" necessitates an informed and educated citizenry, advocating for and working towards human and environmental well-being in all economic endeavors.

In closing, this research underscores the paramount importance of re-envisioning economic success through holistic well-being. We hope these findings enrich the limited scientific sources on this topic and galvanize policymakers and stakeholders into collective action, driving forward the ambitious yet crucial agenda of a true "well-being economy".

Limitations and future research. For certain variables, the Eurostat database shows no values. The largest number of the missing values was for Private_non-profit_sector (Researchers Full-time equivalent $n = 92$; GERD Private non-profit sector $n = 86$). This limitation must be considered when interpreting the results, but it is not assumed that there could be a significant distortion.

The mentioned aspects are related to the processes of data collection within the individual countries and their transfer to the international databases which are influenced by many factors. The processes of digital transformation and the more intensive CE introduction into the various sectors will create unique opportunities for further research. Above all, it is necessary to reevaluate the appropriateness of the metrics employed so far to evaluate the economic outputs from the CE use at the macroeconomic as well as at the microeconomic level. At the same time, it is necessary to look for possibilities of multi-dimensional evaluation of the impact of the ongoing transformation processes of enterprises and sectors on CE as well as at the end of the transformation processes. It is also important to develop optimal methods for comparing countries with the different levels of CE introduction and use from the point of view of sectoral and national differentiation. For this, the creation of an international database and the collaboration of international research teams are necessary to eliminate the shortcomings of the available databases which is also evidenced by this study. In future research, we will deal more intensively with the methodological and data aspects and test the optimal metrics for quantifying the regional disparities and discrepancies influenced by the Transforming Power of Research and Development and the socio-economic determinants.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Competing interests
The authors declare no competing interests.

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Informed consent
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