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REVIEW

Digitalization as an instrument in support of covering the circularity gap in the European Union economy

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Abstract
The primary objective of this paper is to underscore the multidisciplinary nature inherent in both the circular economy and the digital economy, placing particular emphasis on the backdrop of the COVID-19 pandemic. The global health crisis has brought to light a myriad of longstanding medical, social, economic, and environmental issues that have persisted for decades. The paper addresses the current challenges at the EU level, acknowledging the EU Green Deal as a somewhat satisfactory framework that aspires to achieve climate neutrality by 2050. However, the potential of smart technologies, particularly digitalization, in transitioning from a linear economy to a circular one is posited to be constrained by the limited imagination of decision-makers in both public and private sectors. Furthermore, this research seeks to delve into the capacity of digital economy indicators to elucidate the dynamics of circular economy indicators. It aims to construct a multi-linear regression model, utilizing the least squares method with panel data, to ascertain the interdependence between key circular aspects of the digital economy. The study's key finding suggests that while there is some evidence of beneficial connections between the two fields, there remains ample room for enhancing the adoption and utilization of digital components to achieve circular economy objectives. The novelty of this work lies in its demonstration of the multidisciplinary character of the economy amid contemporary challenges, with a specific focus on circular economy, environment, digitization, development, and sustainability. By emphasizing these multidisciplinary conceptual elements, the research contributes to the ongoing discourse and underscores their essential role in societal well-being.

Keywords Digitalization · EU · Transition to circularity · Circularity gap · Circular economy

1 Introduction

The COVID-19 has triggered comprehensive disturbances on the economy (Yue et al., 2020), and decision-makers' fearful perception on cross-borders business (Dong, 2022). Digitalization, as a critical and emerging trend, has shaped how people work, learn, shop and socialize safely during a pandemic and keep up with some normalcy.

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Digitalization is a global phenomenon that combines the current waves of the information society and technological breakouts (Valenduc & Vendramin, 2017), using big data and artificial intelligence (Crabbe et al., 2021). The development of digitization is rooted in a combination of economic, technological and social trends that underpin the way stakeholders perceive and engage with business (Popescu et al., 2022). Nowadays, a robust business infrastructure digitally-based is crucial to compete in markets, to foster the supply chain mechanisms, to boost the quality, and to expand in new directions. A robust digital system is not only important for the business environments, but also for the governmental bodies, which are the main actor of economies and they can stimulate their national competitiveness by being engaged with new strategies especially focusing of technology and digitalization. In private or in public, being the leader in engaging high tech and digitalization in pushing the economic growth and development underlines the concept of digital leadership (Petry, 2018). That is why the rapid move, in a specific way, the adaptation of technology and digitalization is with a high importance. In this regard, the knowledge in digital literacy is quite crucial and most of the private sectors are applying a lot of trainings that target the technological advancement and new tools supporting the emerging areas. The elements mentioned above have an impact on the economy in general and on the CE, which proposes that supply chain system, together with the waste generated during production stages can be considerably transformed (Li et al., 2018). Furthermore, many studies emphasize the connection between productivity and efficiency generally pushed by the technological innovation (Alfaro et al., 2019; Apostu et al., 2022; Berhani & Hysa, 2013; Hysa & Mansi, 2020).

Although digitization has now made significant progress, there are challenges at the country level in terms of generating strategic economic resources. Thus, the objective of this paper is to develop a multilinear regression model with panel data to perform an analysis that highlights the ability of digital technology indicators to connect with the dynamics of circular economy indicators.

The working hypotheses, presented synthetically, aim at: whether the elements that support the development of the CE (private investments, jobs and gross added value) also represent an impulse for the consolidation of the digital economy, and—whether the rate of circular use of materials and waste control can be improved by the evolution of the ICT sector, especially through the online ordering of products and the use of software solutions by businesses.

Though it is more like a beginning-of-the-road analysis, the research aims to be an opening for other empirical or theoretical papers dealing with the linking between the CE and the digital technology. The results highlight the need for a better adaptation of Eurostat's digitalization indicator system to the requirements of the circular economy. Recommendations for economic practices are provided afterwards.

2 Literature review

In European Commission (EC) Communication on the European Green Deal, the current ecological disaster is signaled to state in the new economic policy that targeting fairness, social prosperity, efficiency especially in resources management, helping the diminishing of emissions and economic profitability (COM (2019) 640, pp. 2). At the same time, the document mentions that preparedness and prevention are crucial for strengthening climate proofing, influencing investments (public or private) and sustaining the necessity of developing and integrating climate change instruments to the business risk management practices.

The document also points out that companies which are claiming that their products are green are required to justify these characteristics on the basis of a methodological standard to assess environmental impact, in accordance with existing standards at the European level, and the European Commission will make regulatory efforts to identify possible false environmental claims. In this sense, digitization can improve access to information about the characteristics of the products sold and give buyers the opportunity to compare and check green products before they come into their possession. Public authorities (such as government agencies) are also constrained by EU regulations to make green procurement, and the Commission's constant efforts to regulate green public procurement are in place. At the same time, digitalization also can facilitate the distance monitoring of water, soil, air and sound pollution, the number, health and conduct of earth animal species, human and natural disasters impact, or for monitoring and optimizing how natural resources and energy are used. In recent European Commission documents (EC, 2022a, 2022b), the need to ensure a safe and robust digital infrastructure for business continuity, making possible flexible working conditions, starting from the restructuring of the digital domain within the European institutions, is emphasized. Thus, one of the Commission's strategic objectives is to support an ecological, safe and resilient infrastructure.

There are a lot of circular economy (CE) and digital technology (DT) models in the economic literature, but they are studied separately as part of individual fields of research. For example, Cao et al. (2021) reviewed that due to green credit policy, the supply of funds in the market adjusts and affords higher finances for projects that help achieve a CE, emission deduction, efficiency in energy and environmental protection. Regarding the urbanization problems we face, Yigitcanlar et al. (2021) suggest that they can be mitigated using innovative digital technology. Supporting the initiatives settled by the EC, D'Amico et al. (2021) work generates perspectives on the practices comprising circularity within urban environments which are intersected with digitalization by examining some examples in different municipalities of the EU countries. The outcomes of this study offer a extensive range of models and technologies (monitoring stations, digital cameras, traffic tracking sensors, web platforms for sharing services and goods, etc.) that can improve the circular efficiency of urban metabolic flows. Ways have also been identified to put on circular methods to the ever-changing industrial system, as well as digital technologies with which to process the data provided by it. However, research to highlight the synergy and integrity between these two areas (EC-DT) is limited and limited.

Thus, regarding the integration of blockchain platforms, the results of the study by Basile et al. (2023) highlight the absence of a cutting-edge of technology presenting blockchain related innovation in CE structures.

In 1966, Boulding presented the concept of closed systems, envisioning a future economy that would operate by reproducing a limited stock of inputs and recycling waste production. This "closed" economic model ensures the maintenance of total capital and stands in sharp contrast to the "open" industrial economy depicted by linear model materials. The term "circular economy" found its first application in an economic model proposed in Pearce and Turner (1990). Grounded in the principle that "everything is a contribution to everything else," these authors conducted a critical analysis of the conventional linear economic system. They introduced a novel economic model, the circular economy, aligning with the laws of the Second Principle of Thermodynamics. Central to this model is the predominant consideration of the relationship between the economy and the environment, encompassing three key economic functions of the environment: resource provider, waste assimilator, and source of utility (Hysa et al., 2020). This perspective finds support in studies by Jiang et al. (2022) and Hysa et al. (2023).

Drawing upon the insights of Kenneth Boulding and other economists exploring the biophysical limits of the prevailing economic system rooted in consumption and a growing ecological deficit, Pearce and Turner defined the concept of the circular economy. Frosch and Gallopoulos (1989, p. 149) asserted that optimizing the entire system necessitates enhanced manufacturing processes "that minimize the generation of non-recyclable waste and minimize the permanent consumption of limited material and energy resources." They advocated for innovation in the manufacturing and design processes to redirect materials previously considered waste back into the production process.

In a regional context, the study by Usman et al. (2023) delves into Mercosur countries' dynamics from 1990 to 2018. It investigates the impact of technological innovations, economic growth, renewable energy, natural resources, and human capital on greenhouse gas (GHG) emissions. The authors propose that Mercosur economies should intensify their technological innovation activities and invest in human capital to foster rapid innovation by both new and established companies, contributing to sustainable development and improved quality of life (Apostu et al., 2023). Mounting concerns about climate change and finite resources have driven economies to seek strategies for sustainable development (Hysa & Çela, 2023; Khan et al., 2021; Panait & Gabriel, 2015; Petrescu et al., 2021).

Diverging from conventional sustainability concepts focused on mitigating the negative environmental impact of human activity, the circular economy, grounded in the Cradle-to-Cradle concept, aims to preserve and enhance the value, quality, and productivity of material resources (Ankrah et al., 2015). A significant contribution to research in this field, Ghisellini et al. (2015) comprehensively reviewed and summarized studies published over the last two decades, highlighting the benefits of implementing a circular economy.

In the paper "Can Re-distributed Manufacturing and Digital Intelligence Enable a Regenerative Economy? An Integrative Literature Review", (Moreno & Charnley, 2014), shows that advanced recycling technologies, tracking and return systems stimulate new opportunities for collecting, processing and reusing materials, leading to more interconnected markets. Digital intelligence can also be useful for efficient and fast collection of resource data, for supply chains, by optimizing operations, allowing the tracking and transfer of products from end users to the manufacturer or a third party and for tracking and controlling assets.

Exploring the intricate interconnections across various domains, the study conducted by Saqib, et al. (2023) scrutinizes the impact of technological innovation, financial inclusion, economic growth, and renewable energy on the ecological footprint of emerging economies spanning from 1990 to 2019. The findings suggest that technical innovation, climate technologies, and the adoption of renewable energy significantly diminish ecological footprint levels. Interestingly, the study notes that integrating innovative technology and renewable energy in emerging nations serves to alleviate the adverse effects of financial inclusion. This integration facilitates the adoption of creative technologies, ultimately leading to a reduction in ecological footprints.

Shifting the focus to the energy sector, the study by Usman and Radulescu (2022) employs econometric analysis to investigate the period from 1990 to 2019. This research assesses the influence of nuclear energy, technological innovations, renewable energy, non-renewable energy, and natural resources on the carbon footprint in countries with the highest nuclear energy production. The results indicate that both nuclear and renewable energy consumption significantly enhance environmental sustainability. Furthermore, the study underscores a bidirectional causality between technological innovations, renewables, non-renewables, and natural resources with the carbon footprint, providing valuable insights into the intricate dynamics of energy-related environmental impacts.

The topic of digitalization, digital skills, internet access and its impact on society has preoccupied researchers such as Manyika et al. (2015), who consider that the use of real-time data is very helpful for companies, which can thus monitor, make forecasts and prevent failures and, at the same time, collect products for their repair, recovery, reuse or reconditioning. Moreover, the digitization of the economies of the member states of the European Union is a global process in which all states are part of it. This increases the chances of success of joint ventures and building a sustainable European community based on the latest technologies (Brodny & Tutak, 2021). Therefore, it is considered necessary to redefine economic ownership, unlock creativity and use regenerative cycles in the digital age.

In their 2017 research, V. Salminen, H. Ruohomaa, and J. Kantola advocate for expediting the transition to the circular economy through innovative business models and digital technologies, emphasizing the judicious use of assets and flow management. They contend that digital technology serves as a key tool to overcome existing barriers, as highlighted by MacArthur (2016) and Antikainen et al. (2018).

Lieder and Rashid (2016) highlight a significant gap in circular economy assessments, pointing out the neglect of economic and business prospects in most analyses. This gap extends to the evaluation of digital technologies in the circular economy. While Pagoropoulos et al. (2017) and Antikainen et al. (2018) acknowledge the emerging role of digital technologies, they fail to identify the causes of the identified gap, attributing it to a limited technological perspective.

Territorial studies, exemplified by Bouillass et al. (2022) and Lameh et al. (2022), delve into the opportunities and challenges of introducing digitalization to promote the circular economy at a territorial level. Bouillass et al. make recommendations for public actors to address challenges, while Lameh et al. present models for developing a digitized territorial platform, emphasizing the need to understand specific needs.

De Wit et al. (2018) affirm the existence of a circularity gap in the implementation of the circular economy. They argue that integrating digital intelligence addresses this gap by distributing knowledge, optimizing material flows, and enabling circular business models. Çetin et al. (2022) provide empirical evidence from Dutch social housing organizations, showcasing how digital twins, artificial intelligence, and scanning technologies support circular strategies while identifying barriers to the adoption of digital technologies.

Rivza et al. (2019) emphasize the importance of a digital environment for digitized activities in the circular economy. They highlight the role of advanced technologies like the Internet of Things and cybernetic systems in improving circular economy performance. Kristoffersena et al. (2020) further stress the essential role of digital technologies, including the Internet of Things, big data, and data analytics, as enablers of the circular economy.

In conclusion, this research undertakes an integrated examination of the circular economy and digital technology, aligning with current trends and proposing future research directions.

2.1 Considerations about the indicators used in digital technology and in the circular economy

The current changes in the field of digital technology have brought many benefits both economically and societally. At the same time, these changes have given rise to new

Table 1 % of GDP allocated to ICT and NCSI indices in European Union. *Source*: Eurostat and NCSI data, 2020

The country	% of GDP allocated to ICT (%)—2018	% of GDP allocated to R and D—2018	NCSI 2020	DDL 2020	The difference (NCSI-DDL) 2020	Ranking NCSI 2020
UE 27	–	–	–	–	–	–
UE 28	4.2	–	–	–	–	–
Belgium	3.96	2.67	85.71	77.62	8.09	7
Bulgaria	6.1	0.76	51.95	63.59	– 11.64	52
Czech Republic	4.56	1.9	92.21	69.37	22.84	2
Denmark	4.56	2.97	81.82	83.55	– 1.73	12
Germany	4.4	3.12	80.52	91.95	– 1.43	14
Estonia	5.38	1.41	90.91	79.27	11.64	3
Ireland	11.6 (2014)	1.14	63.64	77.96	– 14.32	30
Greece	2.49	1.21	96.10	65.44	30.66	1
Spain	3.28	1.24	88.31	73.24	15.07	5
France	4.31	2.2	83.12	79.06	6.06	11
Croatia	4.45	0.97	83.12	66.91	16.21	10
Italy	3.29	1.42	76.62	66.63	9.99	19
Cyprus	–	0.62	41.56	71.71	– 30.15	72
Latvia	4.92	0.64	71.43	70.59	0.84	23
Lithuania	3.29	0.94	88.31	73.24	15.7	4
Luxemburg	–	1.17	62.34	83.06	– 20.72	32
Hungarian	5.95	1.51	64.94	66.08	– 1.14	27
Malta	8.04	0.6	50.65	73.59	– 22.94	55
Netherlands	4.50	2.14	81.82	83.88	– 2.06	13
Austria	3.58	3.14	68.83	78.67	– 9.84	26
Poland	3.59	1.21	87.01	66.59	20.42	6
Portugal	–	1.35	71.43	70.65	0.78	24
Romania	3.74	0.5	71.43	61.69	9.74	22
Slovenia	3.59	1.95	57.14	70.74	– 13.33	40
Slovakia	4.12	0.84	83.12	66.73	16.39	9
Finland	4.85	2.76	85.71	82.26	3.45	8
Sweden	5.94	3.32	57.14	83.48	– 26.34	42

types of challenges. One of these is related to the "creative destruction" triggered by the innovation in ICT that has created beyond advantages and vulnerabilities (Table 1).

A country must have adequate capacities for basic cyber security, incident management and the overall development of cyber security, with direct implications for sectors of activity in the economy.

Thus, the National Cyber Security Index (NCSI) measures how well countries are prepared for attacks in the online environment, especially in the field of online commerce. DDL (Digital Development Level) shows, the level of digital development, and the difference, insofar as it presents a positive result highlight that the development of cyber security of the country is in accordance with or before its digital development, and if it is a negative result, reveals that cyber security is under the digital development of the national society.

Table 2 Classification of countries at EU level, according to the digital intelligence index. *Source*: Digital planet, digital intelligence index, own processing

The country	2014	2017	2020
Belgium	Stall out	Stall out	Stall out
Bulgaria	–	Breakout	Breakout
Czech Republic	Watch out	Standout	Standout
Denmark	Stall out	Stall out	Stall out
Germany	Stall out	Standout	Standout
Estonia	Standout	Standout	Standout
Ireland	Standout	Stall out	Stall out
Greece	Watch out	Watch out	Watch out
Spain	Watch out	Watch out	Stall out
France	Stall out	Stall out	Stall out
Croatia	–		Watch out
Italy	Watch out	Breakout	Watch out
Cyprus	–	–	–
Latvia	–	–	–
Lithuania	–	–	Standout
Luxemburg	–	Standout	BreakOut
Hungarian	–	–	–
Malta	Watch out	Watch out	Watch out
Netherlands	Stall out	Stall out	Stall out
Austria	Stall out	Stall out	Stall out
Poland	Watch out	Breakout	Breakout
Portugal	Watch out	Standout	Stall out
Romania	–	–	Watch out
Slovenia	Watch out	Watch out	Stall out
Slovakia	Watch out	Watch out	Watch out
Finland	Stall out	Standout	Stall out
Sweden	Standout	Stall out	Stall out
UK	Stall out	Standout	Stall out

In 2020, Greece, with 96.1 points, occupies the best position in terms of the NCSI index, both at EU and global level. It also has a cyber security training of 30.66 points, being above the digital development of the national society, although the % of GDP allocated to ICT is 2.49%, the lowest in the Union and only 1.21% allocation to research and development.

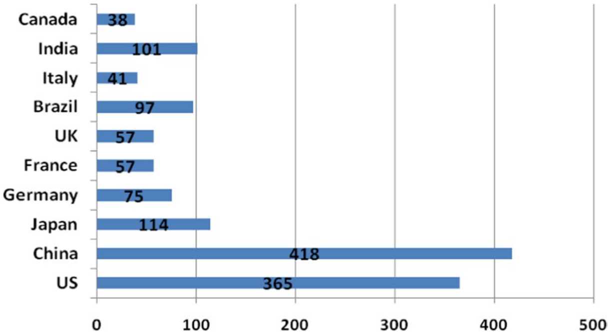
Cyprus is on the last position, at EU28 level and on position 72 in the total ranking, out of the 160 countries analyzed, with 41.6 points and a negative record of −30.15 points of cyber security training.

Romania is on the 18th place in the group and it ranks 22nd in the world and has a positive cyber security training of 9.74 points.

In Table 2, we see a general picture of challenges faced in digital capacities and capabilities and also the possibilities to develop in the future.

In this context, the Fletcher School at Tufts University, in partnership with Mastercard, has reached the third edition of "Digital Evolution" which can be observed in all EU countries, both in terms of the development of digitization and the pace of development. Countries such as Slovakia, Hungary and Greece remain at the top of the rankings, facing real

Fig. 1 The effect of a 10-point increases in digital density on GDP levels in 2020 (billion USD). *Source*: Macchi et al. (2021), Accenture Strategy, Digital Density Index (upgrade work since 2015)



challenges and major shortcomings both in terms of the current level of development and the possibility of evolution. Bulgaria, Poland and Latvia are at the level of 2020, with a low level of digital development, but with a huge growth potential, which if they manage to take advantage of, they can occupy a place in the "Stand out" category in the coming years. The Czech Republic, Estonia Germany, and Lithuania are at the top of the EU rankings, registering high levels of digitalization, but also potentially increased in terms of momentum. Belgium, Denmark, the Netherlands, Austria and France are economies that fall into the "Stall out" category, since 2014 and until now, which reveals the achievement of digital maturity, but a small boost in terms of future growth.

If in the 1990s, countries were pursuing the transition to market economy from a socialist economy, with the fundamental objectives of restoring democratic structures and the market economy,[1] at the level of 2021, the concerns are completely different.

In the joint Digital Density Index study in 2021, both, Oxford Economics and Accenture Strategy, proved that digitalization and high tech in digital tools improve the productivity and growth and development. For instance, for an increase of 10-points on the digital density, can increase of up to $ 1.36 trillion in GDP in the world's top 10 economies (Fig. 1).

The highest GDP growth is expected in China, where increased use of digital technologies could lead to 418 billion USD growth by 2020, followed by the US (365 billion USD) and Japan (114 billion USD). The British economy could expect a growth of 57 billion dollars, and Canada, the last ranked in this top, at 38 billion USD.

To achieve this increased use of digital and GDP, the index also identifies specific areas for improvement and collaboration between companies and governments, which can lead to greater digital efficiency for businesses boost digital growth at the national level.

Thus, (Macchi et al. 2021) consider the creation of digital markets, the digital management of enterprises, more efficient sources of supply and the stimulation of facilities.

A country's digital readiness score generally reflects its economic development. Early and mid-stage digital development is characteristic of emerging economies in Africa. Countries with strong digital development generally have developed economies and are located in North America, Europe and Asia–Pacific (Table 3).

As we observe in the data provided in Table 3, most of the countries have enhanced tools and support toward digitalization and its' maturity, but yet no country has achieved a perfect score for any component and only Singapore has achieved a score higher than 20

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[1] Albu, L., L.; The transition of the economy or the transition of economic science?, Expert Publishing House, IRLI, Bucharest, 1998; IPE Library.

Table 3 Scores and stages of digital training at EU level, 2019. *Source*: Cisco, digital readiness index 2019

The country	Score	Steps	Global position
Belgium	16.22	Amplification	24
Bulgaria	13.72	Acceleration	44
Czech Republic	15.78	Acceleration	25
Denmark	18.98	Amplification	4
Germany	17.25	Amplification	14
Estonia	17.14	Amplification	19
Ireland	10.01	Amplification	20
Greece	13.77	Acceleration	42
Spain	15.74	Acceleration	26
France	16.25	Amplification	23
Croatia	14.20	Acceleration	40
Italy	14.87	Acceleration	35
Cyprus	15.37	Acceleration	29
Latvia	15.54	Acceleration	27
Lithuania	14.78	Acceleration	36
Luxemburg	15.00	Acceleration	31
Hungarian	19.54	Amplification	2
Malta	14.13	Acceleration	39
Netherlands	18.66	Amplification	6
Austria	17.25	Amplification	18
Poland	14.94	Acceleration	33
Portugal	14.96	Acceleration	32
Romania	13.24	Acceleration	52
Slovenia	15.51	Acceleration	28
Slovakia	14.44	Acceleration	37
Finland	17.98	Amplification	11
Sweden	18.42	Amplification	7

out of a possible maximum score of 25. At the opposite pole Chad occupies the last position with a score of 4.32. At the EU level, the average is 15.91 and Luxembourg ranks best with a score of 19.54 and Romania least well with 13.24.

3 Research methodology

In light of the significant interplay between the Circular Economy (CE) and Digitalization (DE), the objective of this study is to elucidate the correlations between various indicators of the CE and those of the DE. The selected indicators encompass Private investments, jobs, and gross value added associated with circular economy sectors (termed as Privinvce), Circular material use rate (Circmur), Generation of municipal waste per capita (Gmwpcapita), Recycling rate of municipal waste (Rrmw) (considered as dependent variables). Concurrently, independent variables include % of the ICT sector in GDP (ICTinGDP), % of the ICT personnel in total employment (ICTpersinTE), Enterprises utilizing software solutions, such as CRM, to analyze client information for marketing purposes (EusslCRM), and Individuals utilizing the internet for ordering goods or services (Induifogs). This study seeks to uncover and comprehend the intricate relationships and dependencies between these variables, shedding light on the nuanced dynamics at the intersection of Circular Economy and Digitalization.

Considering that circular economy (EC) indicators are closely correlated with economic growth, and as CE indicators on growth and development of economy was among the frequent studies examined in many researches, there are still few references regarding the impact of digitalization on EC. Given the European Commission's interest in transposing digitization as an enabler of the CE, we formulate our research questions and statistical hypotheses. Thus, our first hypothesis is if private investments, jobs and gross value added related to circular economy sectors (Privinvce) manifest some characteristically rather complementary in relation to some elements of the digital economy, suggesting rather the need for public investment to unblock this connection. The second hypothesis is if Circular material use rate (Circmur) can be stimulated especially by the ICT sector evolution in GDP and the capacity of individuals of using internet for ordering; the behavior of the consumers could strengthen the link between digital economy (DE) and circular economy (CE). The third hypothesis is that Municipal Waste Generation per capita (Gmwpcapita) does not produce an important slowdown for digitization factors. The last hypothesis tested is whether the Municipal Waste Recycling Rate (Rrmw) could have a strong boost from businesses using software solutions (EusslCRM) and individuals ordering online (Induifogs).

To verify the raised hypotheses, this study employed a panel data model and the method of least squares (LS) by using the Eurostat database for the period 2009–2021.

The data are systematized in the form of a panel, and where they are missing, we used interpolation and proxy methods, based on data from countries with similar economic development. To extend the series, where necessary, we used extrapolation methods. Specifically, we applied Pearson correlation matrix, LM Breusch-Godfrey test, Breusch-Pagan-Godfrey Heteroskedasticity test, and ADF test and a Granger causality test (Table 4).

4 Results

To go through the results, in the very beginning we investigate the indicators specifications such as statistical descriptive measure included in Table 5. Accordingly, we observed that except Privinvce, all the other measures, like mean and median, are found to be similar to each other, hence we concluded that the data are normally distributed (Hozo et al., 2005).

To measure the direction and the strength of a relation, the Pearson correlation matrix is used, but for multicollinearity in the study of Dabholkar et al. (2000) it is recommended that the independent variables to be smaller than 0.30, and to avoid potential case of multicollinearity under the 0.75 (Berman) so based on the results in Table 6 we sum up that there are moderate multicollinearity issues between the variables proposed for the model.

Thus, before we use any method of investigation for test the hypothesis we should examine if there exist some correlations of the residuals. For this reason, we performed a serial Correlation LM Test, more exactly a Breusch-Godfrey serial correlation LM test. Accordingly, the null hypothesis corresponds to "no serial correlation in the residuals" (RESID), in our case 2 (see "Appendix").

Next, a unit root test is been applied to adjust the model. As seen also in Table 7, the output reject the null hypothesis of unit roots. This result is valid for all variables in level forms since t-statistic is found to be more than t-critical value. The null hypothesis was

Table 4 Variables and notations used. *Source*: Systematization of authors based on the Eurostat primary source

Used statistical variable	Abbreviation	Measurement unit	Source
Private investments, jobs and gross value added related to circular economy sectors	Privinvce	Million euro	Eurostat
Circular material use rate	Circmur	%	Eurostat
Generation of municipal waste per capita	Gmwpcapita	Kilograms per capita	Eurostat
Recycling rate of municipal waste	Rrmw	%	Eurostat
% of the ICT sector in GDP	ICTinGDP	%	Eurostat
% of the ICT personnel in total employment	ICTpersinTE	%	Eurostat
Enterprises using software solutions, like CRM to analyze information about clients for marketing purposes	EusslCRM	% of enterprises	Eurostat
Individuals using the internet for ordering goods or services	Induifogs	% of individuals	Eurostat

Table 5 Descriptive statistics of the model. *Source*: Authors' processing in EViews 11; Eurostat data

Observations: 351	Privinvce	Circmur	Gmwpcapita	Rrmw	ICTinGDP	ICTpersinTE	EusslCRM	Induifogs
Mean	6251.389	8.758	496.595	34.447	4.302	2.980	18.572	46.245
Median	2301.300	7.000	486.000	34.600	4.150	2.825	18.000	46.000
Maximum	43,464.90	31.900	961.500	70.850	8.890	9.120	31.000	90.000
Minimum	142.800	0.600	247.000	1.1000	1.9600	1.230	6.000	2.000
Std. Dev	8530.276	6.585	134.089	15.953	1.141	0.922	5.832	21.104
Skewness	1.748	1.246	0.659	0.068	0.946	1.644	0.062	−0.052
Kurtosis	5.403	4.215	3.479	2.092	4.465	9.874	2.034	1.958
Jarque–Bera	263.285	112.531	28.785	12.317	83.789	849.483	13.861	16.201
Probability	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
Sum	2,194,237	3074.100	174,305.0	12,091.05	1510.250	1046.297	6519.000	16,232.00
Sum Sq.Dev	2.55E+10	15,178.12	6,292,988	89,083.38	456.393	297.776	11,908.01	155,883.9

Table 6 Pearson correlation matrix. *Source*: Authors' processing in EViews 11; Eurostat data

	Privinvce	Circmur	Gmwpcapita	Rrmw	ICTinGDP	ICTpersinTE	EusslCRM	Induifogs
Privinvce	1							
Circmur	0.294	1						
Gmwpcapita	0.253	0.168	1					
Rrmw	0.387	0.555	0.411	1				
ICTinGDP	−0.011	−0.033	0.144	–0.055	1			
ICTpersinTE	0.023	0.273	0.207	0.215	0.704	1		
EusslCRM	0.261	0.252	0.454	0.464	0.023	0.266	1	
Induifogs	0.319	0.501	0.480	0.673	0.273	0.593	0.556	1

Table 7 Unit root test results (Augmented dickey—fuller). *Source*: Authors' packing the regression results of the processing data in EViews12; Eurostat data

Series	Level		Critical value		First diference		Critical value	
	Constant & trend		5%	1%	Constant		5%	1%
Privinvce	t-statistic	−3.814	−3.423	−3.986	t-statistic	−11.912	−2.870	−3.450
	Prob.*	0.017			Prob.*	0.000		
Circmur	t-statistic	−5.110	−3.423	−3.984	t-statistic	−19.196	−2.870	−3.449
	Prob.*	0.000			Prob.*	0.000		
Gmwpcapita	t-statistic	−5.272	−3.423	−3.984	t-statistic	−18.625	−2.870	−3.449
	Prob.*	0.000			Prob.*	0.000		
Rrmw	t-statistic	−5.120	−3.423	−3.984	t-statistic	−19.197	−2.870	−3.449
	Prob.*	0.000			Prob.*	0.000		
ICTinGDP	t-statistic	−3.766	−3.423	−3.984	t-statistic	−18.386	−2.870	−3.449
	Prob.*	0.020			Prob.*	0.000		
ICTpersinTE	t-statistic	−5.557	−3.423	−3.984	t-statistic	−6.224	−2.870	−3.450
	Prob.*	0.000			Prob.*	0.000		
EusslCRM	t-statistic	−5.011	−3.423	−3.984	t-statistic	−18.657	−2.870	−3.449
	Prob.*	0.000			Prob.*	0.000		
Induifogs	t-statistic	−4.274	−3.423	−3.986	t-statistic	−4.327	−2.870	−3.450
	Prob.*	0.004			Prob.*	0.001		

also rejected while we use ADF test since the p value was well under 0.05. Thus, we can conclude that all the variables are stationary at level, indicating that they are order zero integrated I(0).

This study performed a multiple regression model, specifically the LS model, and the computations were performed by the EViews 11.0 software. This model was employed to estimate the impact of the DE indicators on the CE indicators in EU countries through 2009–2021. For the multiple linear regression, the endogenous variable (Y) is private investments related to circular economy (Privinvce), or Circular material use rate

Table 8 Results for panel regression equation for EU27 countries. *Source*: Authors' packing the regression results of the processing data in EViews 12; Eurostat data; marked in gray only the variables that are validated for the model with a *p* value below 0.05

Method: Least squares and 351 included observations				Coefficient	t-Statistic	Prob.
Dependent variable	PRIVINCE	Independent variable	C	1106.1760	0.5224	0.6018
R-squared	0.1563		ICTINGDP	784.4753	1.4481	0.1485
Adjusted R-squared	0.1465		ICTPERSINTE	−3086.0520	−3.8856	0.0001
F-statistic	16.0211		EUSSLCRM	160.6686	1.8252	0.0688
Prob(F-statistic)	0.0000		INDUIFOGS	172.6678	5.9101	0.0000
Dependent variable	CIRCMUR	Independent variable	C	6.4820	4.3642	0.0000
R-squared	0.3036		ICTINGDP	−1.9011	−5.0034	0.0000
Adjusted R-squared	0.2955		ICTPERSINTE	1.6518	2.9653	0.0032
F-statistic	37.7023		EUSSLCRM	−0.0887	−1.4399	0.1519
Prob(F-statistic)	0.0000		INDUIFOGS	0.1552	7.5757	0.0000
Dependent variable	GMWPCAPITA	Independent variable	C	260.0613	8.6243	0.0000
R-squared	0.3076		ICTINGDP	24.6557	3.1961	0.0015
Adjusted R-squared	0.2996		ICTPERSINTE	−38.8371	−3.4340	0.0007
F-statistic	38.4327		EUSSLCRM	6.5739	5.2444	0.0000
Prob(F-statistic)	0.0000		INDUIFOGS	2.6840	6.4516	0.0000
Dependent variable	RRMW	Independent variable	C	16.5246	5.7262	0.0000
			CIRCMUR	0.6558	6.4486	0.0000
R-squared	0.5766		ICTINGDP	−1.0791	−1.4498	0.1480
Adjusted R-squared	0.5705		ICTPERSINTE	−3.4298	−3.2143	0.0014
S.E. of regression	10.4554		EUSSLCRM	0.2977	2.5411	0.0115
Durbin-Watson stat	0.3309		INDUIFOGS	0.4653	11.1176	0.0000

(Circmur) or Generation of municipal waste per capita (Gmwpcapita) determined by a set of four exogenous indicators, i.e., % of the ICT sector in GDP—ICTINGDP (X1), ICT personnel in total employment—ICTPERSINTE (X2), Enterprises using software solutions, like CRM to analyze information about clients for marketing purposes—EUSSLCRM (X3), Individuals using the internet for ordering goods or services—INDUIFOGS (X4), as independent variables. For rate of municipal waste (Rrmw) the independent variables are: Circular material use rate (Circmur) (X1), ICTINGDP (X2), ICTPERSINTE (X3), EUSSLCRM (X4) and INDUIFOGS (X5). To analyze the private investment related to circular economy between EU member states between 2009 and 2021 according to the explanatory variables, the output of the regression model is revealed in Table 8.

The most reliable explanatory variable for CE indicators conducts seems to be Individuals which were identified as user of internet for online orders of goods or services (Induifogs). Also, since the value of R-squared is quite modest under 0. 50 for almost all equations (except

Table 9 Granger causality test results. *Source*: Authors' processing data in EViews 12; Eurostat data, note: only results with a probability below 0.05 are presented

Pairwise granger causality tests		
Sample: 1351		
Lags: 2 Obs. 349		
Null hypothesis:	F-Statistic	Probability
INSUIFOGS does not granger cause GMWPCAPITA	5.53727	0.0043
EUSSLCRM does not granger cause RRMW	3.88783	0.0214
ICTINGDP does not granger cause ICTPERSINTE	4.73100	0.0094
EUSSLCRM does not granger cause INDUIFOGS	3.38232	0.0351

RRMW), we emphasize that only a modest part of the variability of the endogenous variable is determined by the exogenous factors of the model, and conclude that the important part of the model needs other factors to explain the gross part of the variability of the dependent variable that are not yet included in the analysis (Table 9).

At the same time, the results should be regarded with cautions on the fact that the series needed interpolation and proxies, and the series could have been more reliable with extensive set of data.

Examining Table 10 results, we confirm that the four hypothesis are found valid. Analyzing the results of the Granger causality test we can see that: INDUIFOGS causes Granger the GMWPCAPITA, EUSSLCRM Granger cause RRMW, ICTINGDP Granger causes ICTPERSINTE and EUSSLCRM Granger causes INDUIFOGS.

Thus, the indicator Individuals that order goods and/or services through internet (Induifogs) can contribute to the improvement of the indicator Generation of municipal waste per capita (Gmwpcapita) through the way of ordering products, paying for services, reducing packaging, reducing the time and stress of purchase for the customer etc. At the same time, as the Granger test shows, the Indicator Enterprises that is in use of software solutions, such as CRM (EUSSLCRM) can contribute to improving the prediction of the future values of the indicator Recycling rate of municipal waste (Rrmw) emphasizing, along with the result of above, that digitization has and will have an increasingly important role in the intelligent management of ordering, production, distribution and recycling of goods and improving the services offered.

The result regarding the Granger causality between the indicator % of the ICT sector in GDP (ICTinGDP) and the future evolution of the indicator % of the ICT personnel in total employment (ICTpersinTE) reveals that with the development of the ICT sector and its increasingly substantial contribution to GDP formation and the number of employees in this field will feel substantial influences. The aspect must also be viewed in a negative sense, that is, when there will be imbalances in the ICT field also the number of employees in this field will experience adjustments in the following periods.

Based on the above findings (Table 10), the four raised hypothesis are tested and found to be valid. The results are in line with the literature review findings highlighting the robust role of digital economy in the CE.

Table 10 Statistical hypotheses validation. *Source*: Authors' results

Hypothesis		Valid (Yes/No)
Hypothesis 1	Private investments, jobs and gross value added related to circular economy sectors (Privinvce) manifest some characteristically rather complementary in relation to some elements of the digital economy	Yes
Hypothesis 2	Circular material use rate (Circmur) can be stimulated especially by the ICT sector evolution in GDP and the capacity of individuals of using internet for ordering	Yes
Hypothesis 3	Generation of municipal waste per capita (Gmwpcapita) is possible not to be importantly slowdown for the digitalization factors; all the ICT indicators selected for the model explain quite well the evolution of the municipal waste indicator	Yes
Hypothesis 4	Recycling rate of municipal waste (Rrmw) could have a strong boost by enterprises conduct in using software solutions (EusslCRM), by circular material use rate (Circmur), by ICT personnel in total employment (Ictpersinte) and individuals ordering online (Induifogs)	Yes

5 Conclusion

Through the econometric investigation, this study highlighted the robust impact of exogenous indicators included in the raised hypotheses, determining factors of the DE on the CE selected indicators. The results even they are not quite impressive may show ways of connecting better the digital economy and the circular economy.

The digital economy and the economy based on environmental protection sometimes go in the same direction, but there are also areas where they diverge. The environment is the bases of human life and activity sustaining better use for digitalization, providing the main resources for producing technology but at the same time absorbs all the negative residuals of human activity. At the same time, by sometimes extremely sensitive touch of digitalization, the negative human (especially industrial) impact on the environment can be constantly reduced and kept considerably under control.

When the Covid-19 virus appeared, we don't know how many of us had the problem of a situation with a magnitude at the level where, instead, one thing is certain, the pandemic forced changes around the world. From the business side, customers needed to use services that require as little contact as possible, using remote operations or at least limited operations when it comes to proximity. In response, businesses, institutions and educational institutions have been engaged with remotely activities through the internet. Accordingly, they used different collaboration platforms and applications to stay connected to each other (Avram & Hysa, 2022).

Pandemic was a key factor of pushing most of the businesses toward digitalization. However, some of the businesses have even experienced before the digitalization and online works. Due to these changes, businesses are experienced huge transformation in their structures, organization, and managing systems. Given that many physical business locations have been and still are closed, consumers have shifted to online activities to meet their needs, even those a considerable number of customers were not so unenthusiastic to do so.

Parallel to drastic changes in digitalization area, the transition to EC has been accelerated too and the circularity gap has been reduced, by innovating products and creating their visibility, providing coordinates about their condition, location and availability in real time. Institutions and organizations of all kinds are trying digital platforms to stay afloat during the pandemic. These transformations happed in most of the sectors. Equally, much of the health care system has had to adapt. Telemedicine and remote diagnosis help patients receive medical advice and online diagnoses was crucial to them.

Finally, as many studies have suggested, the circular and digital economy can be considered a model of the response to the economic crisis, so we suggest that Romania's economy should focus on digital economy innovation and circular. From the econometric study, starting from the basic assumptions, we conclude that the indicators of the circular economy can be better stimulated by the implementation of more advanced technologies and digitalization. Thus, the best explained is the indicator regarding the generation of municipal waste, which has a significant connection with all the digitalization indicators proposed by model. Also, the weakest field explained by the proposed digitalization variables is related to private investments in the sectors of the circular economy. Therefore, more and more, private and public, investments are needed to transform the sectors of the circular economy into increasingly digital ones, and the highly digitized sectors should increasingly respect the environment, using more and more the recycling process of their precious components. Regarding the limitations of the research, we can specify that the series of data can be extended and can be proposed other explanatory variables, also a national/sub-regional level analysis could develop with a reasonable time series, aspects that are still unexplored. Other limitations of the study are related to the fact that it does not insist in a comparison between countries at different levels of digitalization and does not cover a specific industry in countries with different levels of digitalization.

Appendix

Breusch-Godfrey Serial Correlation LM Test and Breusch–Pagan–Godfrey heteroskedasticity Test for the connection of provinces with selected DE indicators

Breusch-Godfrey Serial Correlation LM Test:			
Null hypothesis: No serial correlation at up to 2 lags			
F-statistic	571.2249	Prob. F (2.344)	0.0000
Obs*R-squared	269.7702	Prob. Chi-Square (2)	0.0000
Heteroskedasticity Test: Breusch-Pagan-Godfrey			
Null hypothesis: Homoskedasticity			
F-statistic	14.6260	Prob. F(4.346)	0.0000
Obs*R-squared	50.7658	Prob. Chi-Square (4)	0.0000
Scaled explained SS	75.8494	Prob. Chi-Square (4)	0.0000

Source: Authors' packing the regression results of the processing data in EViews 12; Eurostat data

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References

Alfaro, E., Yu, F., Rehman, N. U., Hysa, E., & Kabeya, P. K. (2019). Strategic management of innovation. In J. Chen, A. Brem, E. Viardot, P. K. Wong (Eds.), *The routledge companion to innovation management* (pp. 107–168). Routledge: Oxfordshire.

Ankrah, N. A., Manu, E., & Booth, C. (2015). Cradle to cradle implementation in business sites and the perspectives of tenant stakeholders. *Energy Procedia, 83*, 31–40.

Antikainen, M., Uusitalo, T., & Kivikytö-Reponen, P. (2018). Digitalization as an enabler of circular economy. *Procedia CIRP, 73*, 45–49.

Apostu, S. A., Gigauri, I., Panait, M., & Martín-Cervantes, P. A. (2023). Is Europe on the way to sustainable development? Compatibility of green environment, economic growth, and circular economy issues. *International Journal of Environmental Research and Public Health, 20*(2), 1078.

Apostu, S. A., Mukli, L., Panait, M., Gigauri, I., & Hysa, E. (2022). Economic growth through the lenses of education, entrepreneurship, and innovation. *Administrative Sciences, 12*(3), 74.

Avram, G., & Hysa, E. (2022). Education, Knowledge and data in the context of the sharing economy. *The sharing economy in Europe: Developments, practices, and contradictions* (pp. 181–206). Springer International Publishing.

Basile, D., D'Adamo, I., Goretti, V., & Rosa, P. (2023). Digitalizing circular economy through blockchains: The blockchain circular economy index. *Journal of Industrial and Production Engineering, 40*(4), 233–245.

Berhani, R., & Hysa, E. (2013). The economy of albania today and then: The drivers to growth. In *Proceedings of the 4th International Conference on European Studies, Tirana, Albania* (p. 598).

Bouillass, G., Saidani, M., Lameh, J., & Yannou, B. (2022). Digital technologies to advance circular economy at territorial level: Challenges and solutions. In *2022 IEEE 28th International conference on engineering, technology and innovation (ICE/ITMC) and 31st international association for management of technology (IAMOT) joint conference* (pp. 1–9). IEEE.

Brodny, J., & Tutak, M. (2021). Assessing the level of digitalization and robotization in the enterprises of the European Union Member States. *PLOS ONE Journal*. https://doi.org/10.1371/journal.pone.0254993,page1

Cao, Y., Zhang, Y., Yang, L., Li, R. Y. M., & Crabbe, M. J. C. (2021). Green credit policy and maturity mismatch risk in polluting and non-polluting companies. *Sustainability, 13*(7), 3615.

Çetin, S., Gruis, V., & Straub, A. (2022). Digitalization for a circular economy in the building industry: Multiple-case study of Dutch social housing organizations. *Resources, Conservation and Recycling Advances, 15*, 200110.

Crabbe, M. J. C., Li, R. Y. M., Dong, R. K., Manta, O., & Comite, U. (2021). Editorial: Recent advances in 2020 2nd international symposium on big data and artificial intelligence.

Dabholkar, P. A., Shepherd, C. D., & Thorpe, D. I. (2000). A comprehensive framework for service quality: An investigation of critical conceptual and measurement issues through a longitudinal study. *Journal Retail, 76*, 139–173.

D'Amico, G., Arbolino, R., Shi, L., Yigitcanlar, T., & Ioppolo, G. (2021). Digital technologies for urban metabolism efficiency: Lessons from urban agenda partnership on circular economy. *Sustainability, 13*(11), 6043.

de Wit, M., Hoogzaad, J., Ramkumar, S., Friedl, H., & Douma, A. (2018). The circularity gap report. An analysis of the circular state of the global economy. Technical Report. https://www.circularity-gap.world/

Dong, R. K. (2022). Emotion and international business: Theorizing fear of failure in the internationalization. *Frontiers in Psychology-Organizational Psychology*. https://doi.org/10.3389/fpsyg.2022.850816

European Commission. (2022a). Brussels, 30.6.2022, C (2022) 4388 final communication to the commission european commission digital strategy next generation digital commission.

European Commission. (2022b). Brussels, 2.3.2022 COM (2022) 83 final communication from the commission to the european parliament, the european council, the council, the european economic and social committee and the committee of the regions towards a green, digital and resilient economy: Our European Growth Model.

Eurostat. Employed ICT specialists—total. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=isoc_sks_itspt&lang=en

Eurostat. Households—level of internet access. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=isoc_ci_in_h&lang=en

Frosch, R. A., & Gallopoulos, N. E. (1989). Strategies for manufacturing. *Scientific American, 261*(3), 144–153.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2015). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production, 114*, 11–32.

Hozo, S. P., Djulbegovic, B., & Hozo, I. (2005). Estimating the mean and variance from the median, range, and the size of a sample. *BMC Medical Research Methodology, 5*, 13.

Hysa, E., & Çela, A. (2023). Circularity environment and sustainable development. In *Reference module in social sciences*. Elsevier, ISBN 9780443157851. https://doi.org/10.1016/B978-0-44-313776-1.00096-9

Hysa, E., Akbar, M., Akbar, A., Banda, I., & Apostu, S. A. (2023). Renewable energy through the lenses of financial development and technological innovation: The case of CEE countries. *LUMEN Proceedings, 19*, 82–96.

Hysa, E., Kruja, A., Rehman, N. U., & Laurenti, R. (2020). Circular economy innovation and environmental sustainability impact on economic growth: An integrated model for sustainable development. *Sustainability, 12*(12), 4831.

Hysa, E., & Mansi, M. E. (2020). The entrepreneurs' role in innovation: developed versus developing countries. In *IBANESS congress series on economics, business and management* Plovdiv, Bulgaria (pp. 6–7).

Jiang, X., Akbar, A., Hysa, E., & Akbar, M. (2022). Environmental protection investment and enterprise innovation: Evidence from Chinese listed companies. *Kybernetes, 52*(2), 708–727.

Khan, S. A. R., Yu, Z., Panait, M., Janjua, L. R., & Shah, A. (Eds.). (2021). Global corporate social responsibility initiatives for reluctant businesses. IGI Global.

Kristoffersena, E., Blomsmab, F., Mikalefa, P., & Lia, J. (2020). The smart circular economy: A digital-enabled circular strategies framework for manufacturing companies. *Journal of Business Research, 120*, 241–261.

Lameh, J., Bouillass, G., Saidani, M., & Yannou, B. (2022). Digitalisation for a territorial circular economy: Towards an integrated platform. In CONFERE22: 29ème colloque des sciences de la conception et de l'innovation.

Li, R. Y. M., Meng, L., Leung, T. H., Zuo, J., Tang, B., & Wang, Y. (2018). Unmaking waste in construction in the EU and Asian circular economy. In: R. Crocker, C. Saint, G. Chen, & Y. Tong (Eds.), *Unmaking waste in production and consumption: Toward the circular economy*. Emerald.

Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *Journal of Cleaner Production, 115*, 36–51.

MacArthur, E. (2016). Intelligent assets: Unlocking the circular economy potential. Foundation Ellen MacArthur Foundation.

Macchi, M., Berthon, B., & Robinson, M. (2021). Accenture strategy, digital density index (upgrade work since 2015).

Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J., & Aharon, D. (2015). The internet of things mapping the value beyond the hype. Mckinsey and Company.

Moreno, M., & Charnley, F. (2014). Can re-distributed manufacturing and digital intelligence enable a regenerative economy? An integrative literature review, pp. 563–575.

Pagoropoulos, A., Pigosso, D. C., & McAloone, T. C. (2017). The emergent role of digital technologies in the circular economy: A review. *Procedia CIRP, 64*, 19–24.

Panait, M., & Gabriel, P. M. (2015). Quality management and social responsibility in the context of sustainable development. *Industrija, 43*(4), 175–189.

Pearce, D. W., Turner, R. K., & Turner, R. K. (1990). *Economics of natural resources and the environment*. Baltimore: Johns Hopkins University Press.

Petrescu, M. G., Panait, M., & Fu, H. (2021). Integrated management systems under the banner of sustainable development: Risks and opportunities. In *Sustainable management for managers and engineers* (pp.157–187).

Petry, T. (2018). Digital leadership. In K. North, R. Maier, & O. Haas (Eds.), *Knowledge management in digital change* (pp. 209–218). Cham, Switzerland: Springer. ISBN 9783319735467.

Popescu, C., Hysa, E., Kruja, A., & Mansi, E. (2022). Social innovation, circularity and energy transition for environmental, social and governance (ESG) practices—A comprehensive review. *Energies, 15*(23), 9028.

Rivza, B., Kruzmetra, M., Gudele, I., & Foris, D. (2019). Digitalization as an essential growth factor contributing in SME development (experience of Latvia and Romania). https://agronomy.emu.ee/wp-content/uploads/2019/04/BSE2019_319_Rivza.pdf

Saqib, N., Ozturk, I., & Usman, M. (2023). Investigating the implications of technological innovations, financial inclusion, and renewable energy in diminishing ecological footprints levels in emerging economies. *Geoscience Frontiers, 14*(6), 101667.

Usman, M., Balsalobre-Lorente, D., Jahanger, A., & Ahmad, P. (2023). Are Mercosur economies going green or going away? An empirical investigation of the association between technological innovations, energy use, natural resources and GHG emissions. *Gondwana Research, 113*, 53–70.

Usman, M., & Radulescu, M. (2022). Examining the role of nuclear and renewable energy in reducing carbon footprint: Does the role of technological innovation really create some difference? *Science of the Total Environment, 841*, 156662.

Valenduc, G., & Vendramin, P. (2017). Digitalization, between disruption and evolution. *Transfer: European Review of Labor Research Policy, 23*(2), 121–134.

Yigitcanlar, T., Corchado, J. M., Mehmood, R., Li, R. Y. M., Mossberger, K., & Desouza, K. (2021). Responsible urban innovation with local government artificial intelligence: A conceptual framework and research agenda. *Journal of Open Innovation: Technology, Market, and Complexity, 7*(1), 71.

Yue, X.-G., Shao, X.-F., Li, R. Y. M., Crabbe, M. J. C., Mi, L., Hu, S., & Dong, K. (2020). Risk prediction and assessment: Duration, infections, and death toll of the COVID-19 and its impact on China's economy. *Journal of Risk Financial Management, 13*(4), 66.

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