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The role of digital technologies to unleash a green recovery: pathways and pitfalls to achieve the European Green Deal

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Abstract

Purpose – The article aims to concern identification and development of pathways for a green recovery process post pandemic taking into account the role of digital technologies for unleashing the policies planned within the European Green Deal (EGD).
Design/methodology/approach – The study is based on a systematic literature review (SLR). The electronic databases Scopus and Web of Science (WoS) were surveyed. The authors followed the SLR guidelines laid down by Tranfield *et al.* (2003) and the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) framework and 65 articles were found eligible after thorough reading and inclusion in the analysis.
Findings – The article presents an innovative framework containing the digital technologies and their roles in enabling the achievement of the EGD policies and the barriers to their adoption.
Originality/value – The proposed framework would guide organizations and policymakers' decisions to pursue a pathway in which a green recovery is possible, mainly after the consequences of the current pandemic, considering the pitfalls of the journey. The article is original as it provides an up-to-date guidance toward an emerging theme, which is a green recovery economy including a net-zero carbon worldwide target.

Keywords Industry 4.0, Smart technologies, Sustainability, Green recovery
Paper type Conceptual paper

1. Introduction

In recent years, the sustainability paradigm comprising a triple bottom line (TBL) integration between social, economic and environmental dimensions has gathered increasing attention among scholars and practitioners. The outbreak of the coronavirus disease 2019 (COVID-19) pandemic has, however, deviated attention from the aspiration to accomplish shared prosperity, laid down in the sustainable development goals (SDGs). Further, there is evidence that attention has been redirected toward recovering from the pandemic (Dupont *et al.*, 2020). This has transpired in the slow progress toward achieving SDGs (United Nations, 2020). Other studies have highlighted the critical negative effect of COVID-19 on SDGs (Berchin and

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de Andrade Guerra, 2020), thus generating the need to accelerate progress toward their achievement by 2030. In a wake to transform European Union (EU) into a resource-efficient and competitive economy, the [1] EGD is an integral part of the commission's strategy to implement United Nation's (UN) SDG Agenda 2030. The deal involves updating existing laws and introducing new regulations to combat climate change and environmental degradation. This study investigates the role of emerging technologies in offering solutions and transformations to a sustainable society for the achievement of SDGs and/or a green recovery (healthier lives, environmental protection, green working culture and better education).

Extant studies have established the significance of these advanced technologies in mitigating the social, environmental and economic issues through efficient use of green energy and utilization of green infrastructure, adoption of green vehicles and transportation (Valogianni *et al.*, 2020). This study focuses on the identification and development of pathways for a green recovery process concerning the role of digital technologies unleashing the policies planned within the EGD.

With this background, the present study attempts to examine the interaction between emerging technologies and TBL of sustainability as planned in the EGD. Here, the Industry 4.0 technologies have been taken as a combination of physical and digital technologies, such as artificial intelligence (AI), big data analytics (BDA), robots and cobots (RoCo), high-speed computing, augmented reality/virtual reality (AV/VR), blockchain technology (BCT) and other cognitive technologies (Haleem and Javaid, 2019; Ghobakhloo, 2018).

As this is one of the earliest studies investigating the role of enabling technologies in achieving SDG and EDG aims, there is a need for conducting an exhaustive SLR of the subject matter. Technology adoption has been widely recognized as a multi-faceted aspect; therefore, this study incorporates the technology-organization-environment (TOE) framework to recognize the implementation barriers for accomplishing EGD aims. This would enable an identification and evaluation of the existing studies and create ground for policy decision-making. Also, as COVID-19 is being increasingly narrated as a stress test for the achievement of these sustainability goals, there is a need to investigate the relevance of technological interventions in achieving EGD aims.

The study, therefore, intends to address the research questions as follows:

RQ1. How various Industry 4.0 technologies can lead to the green recovery process while leveraging the EGD elements?

RQ2. Which barriers may exist in the achievement of the EGD aims?

The study offers significant contributions to the existing studies on EGD. To begin with, the study investigates the key enabling technology (ies) for achieving EDG aims. As more sustainable strategies are needed to overcome and effectively manage the post-pandemic challenges, this article provides insights on integrating the most suitable technology with the relevant EDG aim/s, respectively. Existing studies have examined the influence of these technologies in meeting objectives of climate change, energy efficiency, smart transportation, etc. but there is no study addressing technology adoption for achieving EGD aims. The findings of this work contribute to the state of the art in the green recovery field by designing a framework to support organizations and policymakers to pursue a pathway toward the achievement of EGD while raising the awareness of the pitfalls of the green recovery journey.

2. Theoretical background

2.1 European Green Deal (EGD)

The EGD is an integral part of the commission's strategy to implement the United Nation's 2030 Agenda and the SDGs. "*The European Green Deal is a new growth strategy aspires to transform the EU into an enriched society, with a modern, resource-efficient and competitive* *economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use."* More specifically, the seven EGDs are means of accomplishing that European Commission strategy and they are as follows: *increasing the European Union's climate ambition for 2030 and 2050; supplying clean, affordable and secure energy; mobilizing industry for a clean and circular economy; building and renovating in an energy and resource-efficient way; accelerating the shift to sustainable and smart mobility; from "Farm to Fork": designing a fair, healthy and environmentally-friendly food system; preserving and restoring ecosystems and biodiversity and a zero pollution ambition for a toxic-free environment* (European Commission, 2019a).

2.2 Green recovery

The ambitious roadmap set by EGD is aimed at making the EU's economy sustainable. This involves the target of reducing carbon emissions by 50 and 100% by the years 2030 and 2050, respectively. It also entails a smooth and fair transition for labors working in the fossil fuel industry. Similarly, targets have been either revised or set afresh for attaining sustainable production and consumption processes, promoting a circular economy. The strategy as specified by European Commission intends to achieve climate neutrality by technological intervention, initiating action in economic sectors, empowering citizens and ensuring social fairness (European Commission, 2019a). This comprehensive approach focusing on healthier lives, environmental protection, green working culture and better education represents the EU's clean and green short-term resource recovery program, yielding a sustainable growth path in the long run.

2.3 Digital technologies

As Industry 4.0 is based on digitalization and integration of a firm's processes, several digital technologies would facilitate meeting this objective. Digital technologies reflect the technological opportunities in the information and communication technology (ICT) paradigm. The primary function of these technologies is to assure interoperability between different stakeholders and IT systems, minimize processing time and implementation cost. Accordingly, these technologies have been delineated into four characteristics-sensing (wearable and smart devices), communication (blockchain enabling peer-to-peer service delivery), processing [cloud computing (CC), machine learning and big data analysis] and actuation (3-D printing and robotics) (Aceto *et al.*, 2018). These technologies offer personalized solutions and can contribute toward co-production and co-creation.

The next section highlights the research methodology used in this study.

3. Research methodology: systematic literature review

The present study is based on a SLR approach to ensure replicability of research by highlighting transparent steps and procedures (Tranfield *et al.*, 2003). Therefore, as depicted in Figure 1, we followed the guidelines laid down by Tranfield *et al.* (2003) and recent SLR studies (see Bueno *et al.*, 2020; Gilek *et al.*, 2021; Zonta *et al.*, 2020), which served as operational and methodological guidelines for this research. The methodology comprises three stages, namely review planning, conducting the review and review reporting and dissemination. In the current section, the first two steps of the review methodology are described, and the third step is presented in Section 4.

3.1 Step I: review planning

The purpose of this review is to identify and develop pathways for a green recovery process about the role of digital technologies unleashing the policies planned within the EGD post-

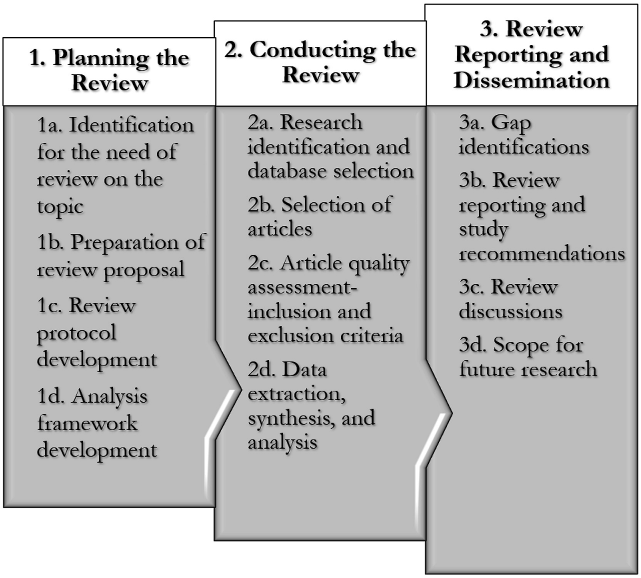


Figure. 1.
The SLR process based on guidelines laid down by Tranfield *et al.* (2003)

COVID-19. Therefore, after the identification of the research gaps, the first step was to identify how disruptive and emerging Industry 4.0 technologies can help transform the EUs economy for a sustainable future. Subsequently, constructs, keywords and search strings were developed. Therefore, an analytical framework was consolidated with two research questions. This framework set the tone for conducting Step, 2 i.e. conducting the review.

3.1.1 Analytical framework. While identifying the need for review on the current topic of research, we found limited management discipline-oriented studies that focused on the impact of Industry 4.0 technologies for a green recovery process, particularly focusing on the EGD elements.

As highlighted in Figure 2, the analytical framework depicts various theoretical points pertaining to sustainability barriers and challenges, Industry 4.0 technologies and the green recovery process. We used the framework as presented in Bueno *et al.* (2020) who studied smart production planning and control in the Industry 4.0 context as a reference point for our

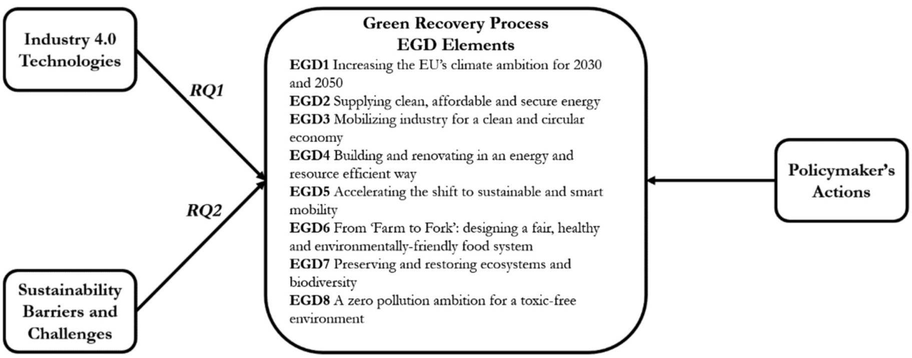


Figure 2.
Analytical framework

research. The primary purpose of this analytical framework is to establish the relationship reference between various Industry 4.0 technologies and the EGD elements. We also highlight which barriers may exist in the achievement of the EGD aims. Based on this, a policy framework has been suggested.

After replying to the two research questions, it is expected to propose actions that policymakers should consider based on the likely barriers involved in achieving the EGD aims.

3.2 Step II: conducting the review

In order to provide a solid foundation for any field of research, quality studies should be synthesized for the SLR process. The most important contributions are likely to be found in leading journals (Webster and Watson, 2002). Therefore, we followed the same logic as follows in the review studies undertaken by Bueno *et al.* (2020), Ghadge *et al.* (2012) and Maestrini *et al.* (2017), i.e. to include only refereed journal articles for the SLR.

The present review focused on the investigation and analysis of the articles about Industry 4.0 technologies and the green recovery process and included articles published from 2011 onwards. For the quality criteria of the selected studies, the researchers chose only the journals classified in the Australian Business Dean Council (ABDC) journal quality list 2021 and Q1 of the SCImago journal ranking (SJR). The timeline for the SLR was set from 2011 (beginning of Industry 4.0 era [2]) to January 2021.

In regard to the operational steps of the SLR, the following electronic databases such as Scopus and WoS were surveyed using the search strings as highlighted in Table 1. Eventually, Scopus was chosen, as it has a greater coverage in comparison to WoS (Mongeon and Paul-Hus, 2016). This was done for ensuring that no relevant studies were missed. For ensuring extensive coverage of papers citation chaining search was using both backward and forward approaches in the downloaded papers. The initial search returned 456 articles. The criteria for selecting the databases were based on the fact that these databases host journals with high-impact factors for the research subject.

A network visualization of the selected keywords is highlighted in Figure 1.

Following the database and keyword selection, in the next procedure, we made use of the PRISMA (Moher *et al.*, 2009) approach for executing the activities (see Figure 3) as follows: identification, screening, eligibility and inclusion. These steps from the PRISMA approach

Digital transformation construct	OR	Enabling technology construct	AND	Sustainability/sustainable development construct
"Digital Transformation" OR		"Blockchain" OR		"Sustainability" OR
"Digitalization" OR		"Artificial Intelligence" OR		"Sustainable Development" OR
		"Big Data" OR		"Climate Change" OR
		"Digital Twins" OR		"Carbon Neutral*" OR
		"Smart Grid" OR		"Environmental Challenges" OR
		"Smart Manufacturing" OR		"Sustainable Growth"
		"Smart Production" OR		
		"Smart Factory" OR		
		"Big Data Analytics" OR		
		"Internet of Things" OR		
		"Digital Factory" OR		
		"Additive Manufacturing"		

Table 1.
Keywords used in this research

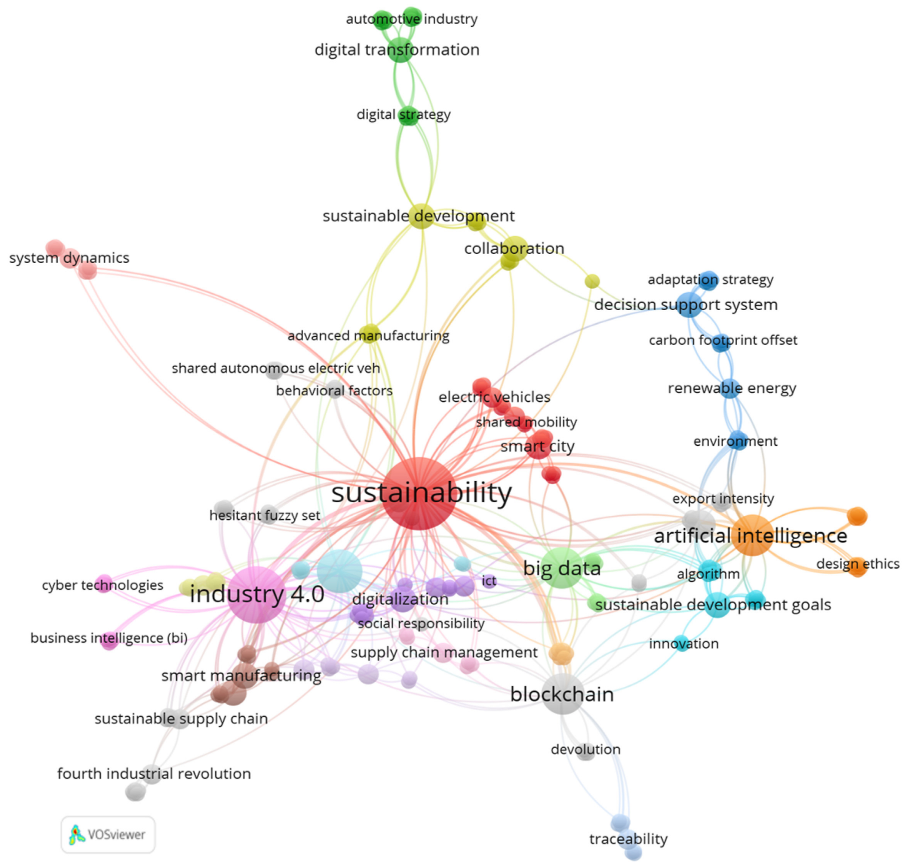


Figure 3.
Keyword visualization

reinforced the operationalization of the SLR activities as highlighted in Figure 2. In the identification phase, the database returned 456 articles. After the removal of duplicate articles, we were left with 271 articles (see Figure 4).

The inclusion and exclusion criteria as highlighted in Table 2 were applied to the remaining 271 identified articles. As a result, we excluded 206 articles. We were then left with the final 65 articles which were eligible for thorough reading and inclusion in the SLR.

3.3 Review reporting and dissemination

The last stage of an SLR's focuses on reporting and presentation of the theoretical and empirical findings regarding the two research questions. Besides, a content analysis showing an overview of the articles and the quantitative and qualitative analyses is highlighted in Section 4.

4. Review findings

4.1 Overview of the selected articles

As highlighted in Figure 5, there is an exponential growth in the articles that considered the term digital transformation, Industry 4.0 and sustainable development from the year 2019

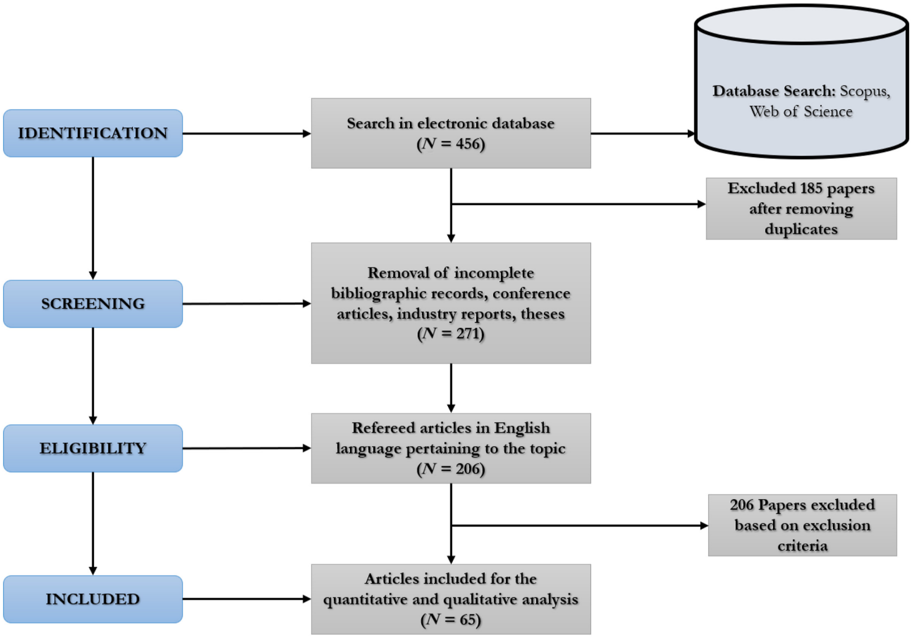


Figure 4.
PRISMA flowchart for the SLR

Table 2.
Inclusion and exclusion criteria

Criteria type	Criteria	Criteria details
Exclusion	Non-English language articles	Articles written in languages other than English
	Exclude studies on the basis of relevance	Studies that are similar but are not relevant to the research topic
	Exclude duplicate studies with matching titles and/or Digital Object Identifier (DOI)	Exclusion of duplicate studies
	Exclude industry reports, white papers, dissertation or theses and non-peer reviewed articles	Exclusion of industry reports, white papers and theses
	Exclude studies before 2011 as the topic of Industry 4.0 garnered research interest from 2011 onwards	Timeline-based selection of articles
Inclusion	Include journal articles only	Refereed articles only
	Include studies by applying a funneling process of selection based on title, abstract and keywords	PRISMA-based search
	Include studies by doing content analysis of full text	Article to fully address the subject of research
	Include studies on the basis of citation chaining search	Selection of closely related studies

onwards. It can be observed that nearly 52 articles were published in the years 2020 and 2021 alone. Regarding the research methods deployed, 28 studies are conceptual based (i.e. literature reviews, bibliographic surveys, essays and theoretical discussions), 16 are empirical studies, 15 are case studies and 6 have utilized modeling and simulation (Sim) (see Figure 6).

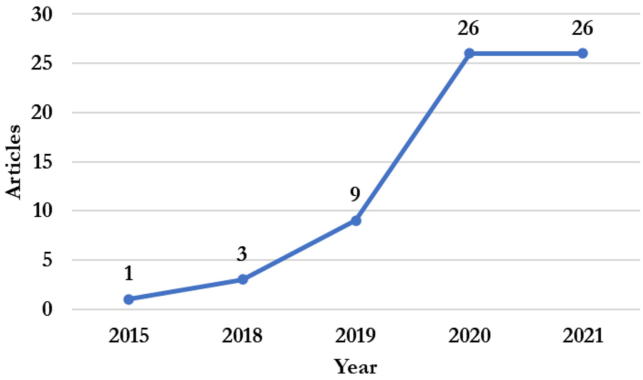


Figure 5.
Publication timeline

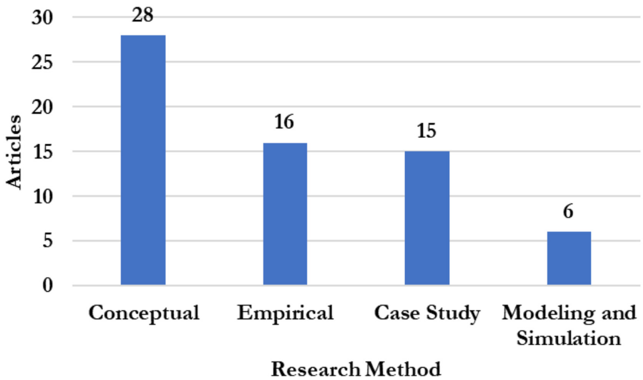


Figure 6.
Research methods used in the study

In case of the journals (Figure 7), *Journal of Cleaner Production* has the highest frequency of articles (26 articles), *Technological Forecasting and Social Change* (10 articles), *Journal of Business Research* (9 articles), *International Journal of Production Economics* (4 articles), *International Journal of Production Research* (4 articles), *Business Strategy and the Environment* (3 articles), *Production and Operations Management* (3 articles) and *Production Planning and Control* (2 articles). The other journals comprised one article each.

In the context of the Industry 4.0 perspective, Figure 8 highlights the Industry 4.0 technologies used in the studies. It can be observed that majority of the articles indicate BDA

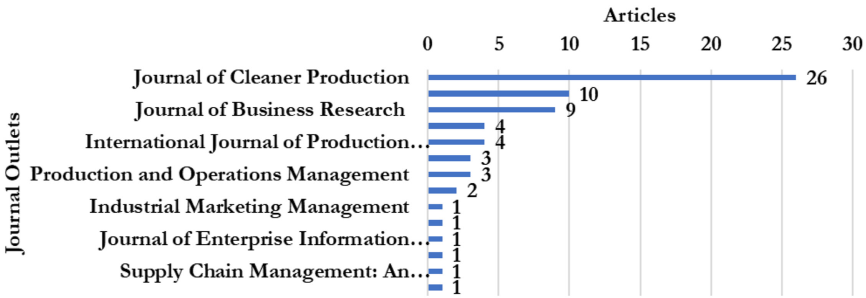
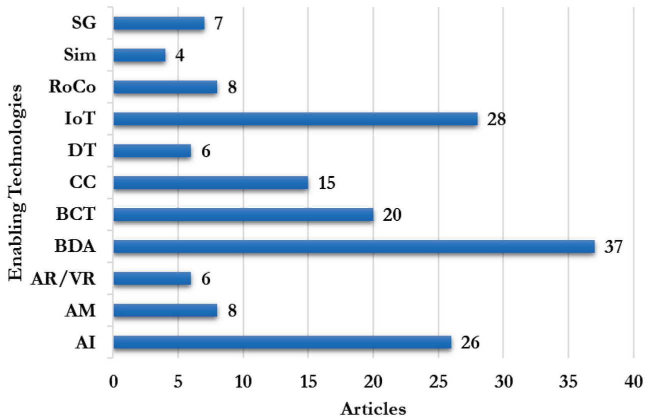


Figure 7.
Publication outlets



Note(s): Sim- simulation; RoCo- Robots and Cobots; IoT- of Things; DT- Digital Twin; CC- Coud Computing; BCT- Blockchain Technology; BDA- Big Data Analytics; AR/ VR- Augmented Reality/Virtual Reality; AM- Additive Manufacturing; AI- Artificial Intelligence

Figure 8. Industry 4.0 perspective

(22%), Internet of things (IoT) (17%), AI (16%), BCT (12), CC (9%), RoCo (5%), additive manufacturing (AM) (5%), digital twins (DT) (4%), AR/VR (4%), smart grid (SM) (4%) and Sim (2%).

4.2 Key findings from the analytical framework

In this sub-section, we discuss the results about the two RQs that we presented in the analytical framework. Using the content analysis technique, the results were extracted from the 65 articles selected for this review.

4.2.1 How various Industry 4.0 technologies can lead to the green recovery process while leveraging the European Green Deal (EGD) elements?. Majority of the studies in the past (Sharma *et al.*, 2020; Kamble *et al.*, 2018) have reported that the potential adoption of Industry 4.0 technologies leading to numerous benefits on the sustainability frontier. de Sousa Jabbour *et al.* (2018a) report that Industry 4.0 technologies and sustainability are critical for enhancing productivity and developing a sustainable organizational culture.

Although several challenges impede organizations from realizing their potential in developing a sustainable business environment, the Industry 4.0 technologies can help in overcoming these barriers and challenges. Table 3 highlights the prominent Industry 4.0 enabling technologies for achieving the policy-level goals of the EGD.

The following sub-sections will highlight the various sustainability challenges and barriers and how these can be overcome with various Industry 4.0 technologies.

4.2.2 Which barriers may exist in the achievement of the various EGD aims?. For analyzing the EGD aims implementation barriers, we organized the study based on the TOE theoretical framework (Tornatzky and Fleischer, 1990). As reported by Tornatzky and Fleischer (1990), the decision for adopting innovation at the organizational level is not only based upon technological factors, but organizational and environmental aspects as well. The TOE framework explores a firm on the three dimensions of technology, organization and the environment.

The technology dimension consists of all relevant technologies available outside and within the firm. The organization dimension incorporates the resources that might affect the

Policy-level goals of the European Green Deal (EGD)	Enabling technologies
Increasing the EU's climate ambition for 2030 and 2050	Big data analytics and Internet of things
Supplying clean, affordable and secure energy	Artificial intelligence, Big data analytics and Internet of things
Mobilizing industry for a clean and circular economy	Artificial intelligence and big data analytics
Building and renovating in an energy and resource-efficient way	Big data analytics and Internet of things
Accelerating the shift to sustainable and smart mobility	Big data analytics and Internet of things
From "Farm to Fork": designing a fair, healthy and environmentally friendly food system	Big data analytics and Internet of things
Preserving and restoring ecosystems and biodiversity	Artificial intelligence, big data analytics and cloud computing
A zero-pollution ambition for a toxic-free environment	Artificial intelligence, big data analytics and Internet of Things

Table 3.
EGD and technology mapping

ICT adoption process and includes firm size, organizational structure and decision-making functions. The environment dimension consists of factors such as industry structure, suppliers, regulatory environment and the customers.

We, therefore, segregated the sustainability challenges and barriers related to EGD aims into the three TOE dimensions, namely legal and governmental challenges, organizational challenges and technological challenges and modified the framework for including environmental/strategic/human challenges (see Table 4).

5. Discussion

5.1 Enabling technologies

The findings of our study reveal that BDA has the highest potential to contribute to the achievement of all the eight EGDs. However, it has emerged as the most favorable technology for subscribing to the objectives of EGD1, EGD4, EGD5 and EGD6. Our study has found BDA as the most conducive-enabling technology for the attainment of EGD2, EGD3, EGD7 and EGD8. Further, the findings of our study divulge that IoT is capable of promoting EGD1, EGD2, EGD4, EGD5, EGD6 and EGD8.

The findings of our research suggest that BDA and IoT can facilitate the achievement of EGD1. This is in line with the findings of Kong *et al.* (2020) and Elheddad *et al.* (2021) highlighting the potential of BDA in addressing urban environment, sustainability and reducing CO_2 emission for Organisation for Economic Co-operation and Development (OECD) countries, thus contributing to a lower pollution rate. Since climate change mitigation and adaptation strategies involve handling complex models and varied information, BDA would enable a systematic processing and evaluation of complex and heterogeneous data (Mavi and Mavi, 2021). Recent reports (WEF, 2021) and academic studies (Sharifi, 2019; Kahlen *et al.*, 2018; Sacchelli *et al.*, 2017; Pulselli *et al.*, 2019; Kohtamäki *et al.*, 2019; Marsal-Llacuna, 2020) have also underlined the importance of BDA in responding to disaster management, risk reduction and locating harmful emissions.

As presented in Table 3, the study establishes the benefits of AI, BDA and IoT for realizing EGD2. With the potential to contribute toward data handling, optimizing energy efficiency, preventing cyberattacks and predictive maintenance control, these technologies can transform the energy market (de Sousa Jabbour *et al.*, 2018a). Researchers (Haddadeh *et al.*, 2021; Valogianni *et al.*, 2020; Sharifi, 2019) have recognized the use of these digital technologies in energy demand and supply management controls, storage, grid operations and power failures. Ahmad *et al.* (2021) recognize AI's role in modeling, planning and Sim of

Challenges/barriers		Reference(s)	EGD impacted
Legal and governmental	Policy issues	Bag *et al.* (2021), Sihag and Sangwan (2020), Polemis and Spais (2020), Raven and Walrave (2020)	EGD1 and EGD3
	Cybersecurity	Upadhyay *et al.* (2021), Kouhizadeh *et al.* (2021), Planko *et al.* (2019)	EGD5
	Legal and contractual issues	Upadhyay *et al.* (2021), Elheddad *et al.* (2021), Coro and Trumpy (2020), Canhoto (2021), Braganza *et al.* (2021)	EGD3, EGD4, EGD5 and EGD8
Organizational	Financial constraints	Llopis-Albert *et al.* (2021)	EGD1, EGD2, EGD3, EGD4 and EGD5
	Infrastructural issues	Bai *et al.* (2020)	EGD4, EGD5 and EGD6
	Technological awareness	Bigerna *et al.* (2021), De and Singh (2021), Di Vaio *et al.* (2021)	EGD2, EGD3 and EGD4
	Lack of skilled workforce	Piwowar-Sulej (2021), Chiarini *et al.* (2020)	EGD3
Technological	Technology diffusion	Denicolai *et al.* (2021), Mavi and Mavi (2021), Awan *et al.* (2021), Smith and Beretta (2021), Camaréna (2020), Weerakkody *et al.* (2021), Tian *et al.* (2021), de Villiers *et al.* (2021), Kohtamäki *et al.* (2019)	EGD3 and EGD4
	Technology adoption	Denicolai *et al.* (2021), Frank *et al.* (2021), Saurabh and Dey (2021), Marsal-Llacuna (2020), Valogianni *et al.* (2020), Haddadeh *et al.* (2021), Dlugosch *et al.* (2020), Qi and Shen (2019)	EGD1, EGD2, EGD4 and EGD5
	Technology scaling	Denicolai *et al.* (2021), Li *et al.* (2021), Kouhizadeh *et al.* (2021), Dolgui *et al.* (2020), Pereira *et al.* (2020), Haftor and Climent (2021)	EGD4, EGD5 and EGD6
	Data interoperability	Ferrari *et al.* (2021), Li *et al.* (2021), Suman (2021), Kong *et al.* (2020), Köhler and Pizzol (2020), Feng *et al.* (2020), Kahlen *et al.* (2018), Sharifi (2019)	EGD2, EGD3 and EGD5
Environmental/strategic/human	Environmental issues	Birkel and Müller (2021), Diaz-Chao *et al.* (2021), Pizzi *et al.* (2021), Castro *et al.* (2021), Kristoffersen *et al.* (2020), Marsal-Llacuna (2020), Feng *et al.* (2020), Ghobakhloo (2020), Machado *et al.* (2020), Del Giudice *et al.* (2021), Kamble *et al.* (2018), Sharma *et al.* (2020), Sacchelli *et al.* (2017), Ukko *et al.* (2019)	EGD7 and EGD8
	Lack of economic and social benefits	Mota *et al.* (2015), de Sousa Jabbour *et al.* (2018a), Pulselli *et al.* (2019), Melander and Pazirandeh (2019), Jabbour *et al.* (2019), Allaoui *et al.* (2019)	EGD2, EGD3, EGD4, EGD5 and EGD6

Table 4.
Barriers and EGD mapping

energy systems; forecasting and optimizing maintenance schedules and strengthening energy infrastructure. These can significantly contribute toward enhancing firms' operational performance and efficiency, which is the need of the hour in increasingly competitive energy industry.

Based on the findings of our study, as compared to other enabling technologies, AI and BDA have emerged as enablers for realizing EGD3. Extant studies have shown that in the case of the circular economy paradigm, BDA and AI contribute toward reducing uncertainties, presenting prediction based results, integrating processes and sharing resources (Denicolai *et al.*, 2021; Birkel and Müller, 2021; Di Vaio *et al.*, 2021; Díaz-Chao *et al.*, 2021; Pizzi *et al.*, 2021; Castro *et al.*, 2021). This further supports reducing operational complexities (Gupta *et al.*, 2019), devising Circular Economy (CE) adoption strategies (de Sousa Jabbour *et al.*, 2018b), enhancing the effectiveness of decision-making (Gupta *et al.*, 2019) and achieving sustainable resource management as specified in the UN 2030 agenda (Di Vaio *et al.*, 2020).

Our findings disseminate that the accomplishment of EGD4 can be better realized through employing BDA and the IoT. Since these technologies work on real-time data, they provide smarter designs, lesser emissions, efficient performance monitoring, informed decision-making and faster delivery (Lu *et al.*, 2021; Lawal and Rafsanjani, 2021; Ferrari *et al.*, 2021; Allaoui *et al.*, 2019; de Villiers *et al.*, 2021; Birkel and Müller, 2021; Planko *et al.*, 2019). Studies also found a significant contribution of IoT toward analyzing the energy consumption of smart buildings (Sembroiz *et al.*, 2019) and extending safety and emergency response planning (Chen *et al.*, 2021). The findings of past studies also emphasize the immense potential of BDA toward reducing construction waste (Kumar *et al.*, 2021a, b).

Smart and sustainable mobility refers to the integration of digital technologies for improving accessibility and sustainability and ensuring safe transport systems. The findings of our study suggest that BDA and the IoT can contribute toward unleashing EGD5. These applications have the potential to provide benefits like real-time information, predictive maintenance, intelligent parking and traffic management, automated toll collection, improved surveillance, road safety and monitoring pollution levels (Zenkert *et al.*, 2018; Di Vaio *et al.*, 2020; Kristoffersen *et al.*, 2020; Marsal-Llacuna, 2020; de Villiers *et al.*, 2021; Haftor and Climent, 2021; Qi and Shen, 2019). BDA can play a key role in supporting the real-time detection of security threats like jamming and intrusion, which are posing security threats in urban transportation services in smart cities (Bangui and Buhnova, 2020).

The growing demand for agricultural products necessitates producers to improve productivity, reduce wastages in the supply chain and impart sustainability in the process. Our study emphasizes the crucial role of BDA and the IoT in realizing EGD6. These technologies provide relevant information on markets, inputs, prices, weather and best practices and thus facilitate improvements in agricultural management at the farmers' level (World Bank Group, 2017). Since these technologies impart precision and make information storage, processing and analyzing possible, researchers have shown the potential of these technologies in boosting agricultural supply chain efficiency (De and Singh, 2021; Haddadeh *et al.*, 2021; Sharma *et al.*, 2020; Allaoui *et al.*, 2019; Mota *et al.*, 2015).

The findings of this study highlight the suitability of AI, BDA and CC in achieving EGD7. The application of these technologies to biodiversity data can enable scientists to generate biological models and monitor events like environmental change and the spread of invasive species in near-real-time (Llopis-Albert *et al.*, 2021; Kong *et al.*, 2020; Sacchelli *et al.*, 2017). This leads to improved ecological forecasting, resulting in better decision-making (Ghobakhloo, 2020). Liu *et al.* (2021) found a significant role of these technologies in assessing the forest ecological environment.

As presented in Table 3, we found AI, BDA and IoT as the most impactful technologies for addressing EGD8. These technologies can enable researchers and practitioners to understand the current challenges while working on smaller data sets of pollutants and emissions. The networks of sensors used for the data collection on air pollution provide feasible solutions to climate researchers and businesses for identifying locations, potential causes and suggesting steps toward improving air quality (Li *et al.*, 2021; Frank, 2021; Di Vaio *et al.*, 2020; Marsal-Llacuna, 2020; Weerakkody *et al.*, 2021; de Villiers *et al.*, 2021; Braganza *et al.*, 2021; Ukko *et al.*, 2019; Sacchelli *et al.*, 2017).

Researchers have found significant challenges in aligning Industry 4.0 with sustainability in the manufacturing context (Sharma *et al.*, 2020; Hughes *et al.*, 2020), urban transportation (Dlugosch *et al.*, 2020), amidst barriers to digitalization and green innovation efforts (Melander and Pazirandeh, 2019) and presence of paradoxical tensions in adopting digital technologies (Smith and Beretta, 2021). This leads us to believe that the path to digital transformation for pursuing green recovery may not be smooth, and we would have to be mindful of the following challenges while going ahead with its widespread applications. Now we discuss the barriers (as presented in Table 4) impeding the achievement of EGD goals.

5.2 Barriers

5.2.1 Legal and governmental challenges. Government support and policy framework on compliance, intellectual property, usage of automatic systems along with human capital, consumer protection and related aspects can address uncertainties and hesitancy in technology adoption. Our study has found a gap in legislation and policy development on technology adoption and usage with hacking, illegal activities and loss of trust as consequent outcomes (Upadhyay *et al.*, 2021). This is in support of the findings of other studies (Bag *et al.*, 2021; Raven and Walrave, 2020; Polemis and Spais, 2020). Such *ad-hoc* policy interventions hinder the achievement of EGD1 and EGD3.

The realization of EGD3, EGD4, EGD5 and EGD8 is further constrained by the inadequate legal system and the resulting contractual issues, which generates confusion and creates a scope of pitfalls for technology diffusion (Upadhyay *et al.*, 2021; Elheddad *et al.*, 2021; Coro and Trumpy, 2020; Canhoto, 2021; Braganza *et al.*, 2021).

Our study identifies cybersecurity as a barrier to achieve EGD5. Cyber attackers may intend to get access to information and data, manipulate and modify the information for their interests, perform sabotage activities or induce participants to commit errors. The adverse consequences of these attacks can make the transportation ecosystem vulnerable to varied types of losses like monetary, privacy, integrity and trust (Upadhyay *et al.*, 2021; Kouhizadeh *et al.*, 2021; Planko *et al.*, 2019).

5.2.2 Organizational challenges. Our study identifies a set of organizational-specific challenges that impede the attainment of several EGD. We find inadequate availability of funds and the reluctance of firms to undertake capital investment in technology hindering the realization of EGD1, EGD2, EGD3, EGD4 and EGD5 (Llopis-Albert *et al.*, 2021). This may be attributable to the gap in payoff as in the current investment and future benefits, which may discourage companies to undertake substantial investments for securing a clean and circular economy, smart mobility, clean energy and climate. Also, there is a lack of analysis available in context to the return on investment for digital transformation by firms (Saurabh and Dey, 2021).

Our study also establishes that inadequate infrastructure may act as a constraint in the achievement of EGD4, EGD5, and EGD6. Extant studies have shown that building resilient infrastructure is capable of promoting sustainable industrialization, transportation and food management system (Bai *et al.*, 2020). Another factor inhibiting the achievement of EDG2, EGD3 and EGD4 is technological awareness. Lack of knowledge and information about technological mechanisms and consistent and precise information on technology usage requirements act as a hindrance in unlocking circular economy and generating resource efficiency (Bigerna *et al.*, 2021; De and Singh, 2021; Di Vaio *et al.*, 2021).

Our study further identifies the lack of a skilled workforce inhibiting the achievement of a circular economy (EGD3). Trained human resource and competence development for technology integration is crucial for technology implementation (Tortorella *et al.*, 2020; Piwowar-Sulej, 2021; Chiarini *et al.*, 2020).

5.2.3 Technological challenges. Technological context focuses on the salient characteristics of technology and the associated benefits in the form of improved efficiency, productivity and cost-saving. A review of extant studies has shown that there exist barriers to digitalization and green innovation efforts (Melander and Pazirandeh, 2019). The findings of our study reveal that technology diffusion can act as a barrier in achieving EGD3 and EGD4. This aspect of technology can impart an improvement in the existing models of resource-intensive linear value chains toward a circular economy and contribute to achieving a resource-efficient construction industry (Denicolai *et al.*, 2021; Mavi and Mavi, 2021; Awan *et al.*, 2021; Smith and Beretta, 2021; Camaréna, 2020; Weerakkody *et al.*, 2021; Tian *et al.*, 2021; de Villiers *et al.*, 2021; Kohtamäki *et al.*, 2019). This may also encourage new entrepreneurial activity, supporting opportunity-based ventures.

We also find several factors like technological feasibility, sophistication, knowledge, awareness and availability impacting technology adoption that impedes the attainment of EDG1, EGD2, E4 and EGD5. Though this holds for all the firms (Frank *et al.*, 2021; Saurabh and Dey, 2021; Marsal-Llacuna, 2020; Valogianni *et al.*, 2020; Haddadeh *et al.*, 2021; Dlugosch *et al.*, 2020; Qi and Shen, 2019), it is particularly true for smaller organizations where investment and capabilities in automation have not been developed fully (Denicolai *et al.*, 2021).

Our study has also identified technology scaling as a significant factor that can restrict the accomplishment of smart and sustainable energy, construction and food management system (i.e. EGD4, EGD5 and EGD6). Extant studies have supported this finding in the context of sectors like Small and Medium Enterprises (SMEs) (Polemis and Spais, 2020) and smart agriculture (Sacchelli *et al.*, 2017). Technology scaling leads to cost optimization and enables firms to reap benefits of economies of scale (Denicolai *et al.*, 2021; Li *et al.*, 2021; Kouhizadeh *et al.*, 2021; Dolgui *et al.*, 2020; Pereira *et al.*, 2020; Haftor and Climent, 2021).

Further, the critical requirement of data interoperability, which is the foremost requirement for the success of technology implementation, is vulnerable (Ferrari *et al.*, 2021), impeding the achievement of EGD2, EGD3 and EGD5. Studies have established that smooth communication between various partners using these digital technologies enhance efficiency and facilitate the move toward a circular economy, smart mobility and clean and secure energy (Ferrari *et al.*, 2021; Li *et al.*, 2021; Suman, 2021; Kong *et al.*, 2020; Köhler and Pizzol, 2020; Feng *et al.*, 2020; Kahlen *et al.*, 2018; Sharifi, 2019).

5.2.4 Environmental/strategic/human challenges. The findings of our study suggest that environmental issues act as obstacles in achieving EGD7 and EGD8. Proper resource planning, process optimization toward environmental targets, improved coordination of demand and capacities and an approach to provide consumer-specific products with no penalty being passed to the environment can contribute toward preserving ecosystems and striving for a toxic-free environment (Birkel and Müller, 2021; Diaz-Chao *et al.*, 2021; Pizzi *et al.*, 2021; Castro *et al.*, 2021; Kristoffersen *et al.*, 2020; Marsal-Llacuna, 2020; Feng *et al.*, 2020; Ghobakhloo, 2020; Machado *et al.*, 2020; Del Giudice *et al.*, 2021; Kamble *et al.*, 2020; Sharma *et al.*, 2020; Sacchelli *et al.*, 2017; Ukko *et al.*, 2019).

Our study also finds a lack of economic and social benefits as restricting the achievement of EGD2, EGD3, EGD4, EGD5 and EGD6. Studies have found the likely economic benefits such as cost reduction, reduced input prices; and likely social benefits such as strengthening communication between industry and society; better alignment between business, suppliers and customers and environment preservation and reduced waste generation as capable of mobilizing industry toward a circular economy, clean energy, construction, transportation and food management system (Mota *et al.*, 2015; de Sousa Jabbour *et al.*, 2018a; Pulselli *et al.*, 2019; Melander and Pazirandeh, 2019; Jabbour *et al.*, 2019; Allaoui *et al.*, 2019).

6. Proposed framework: policymakers' actions

A closer examination of Table 4 indicates that three EGDs aims are more likely to encounter barriers as compared to others aims. These are as follows: EGD3 (mobilizing industry for a clean and circular economy), EGD4 (building and renovating in an energy and resource-efficient way) and EGD5 (accelerating the shift to sustainable and smart mobility). Our study, therefore, suggests that policymakers should develop specific actions for helping organizations in addressing and overcoming the barriers related to these aims.

As presented in Table 3, enabling technologies such as BDA, AI and IoT can unleash the achievement of EGD3, EGD4 and EGD5, which are facing more barriers in comparison to other EGD aims. Concerning EGD3, BDA and AI contribute toward reducing uncertainties, presenting prediction-based results, integrating processes and sharing resources (Denicolai *et al.*, 2021; Birkel and Müller, 2021; Di Vaio *et al.*, 2021; Díaz-Chao *et al.*, 2021; Pizzi *et al.*, 2021; Castro *et al.*, 2021). Since BDA and IoT work on real-time data, provide smarter designs, lead to lesser emissions and enable efficient performance monitoring, informed decision-making and faster delivery (Lu *et al.*, 2021; Lawal and Rafsanjani, 2021; Ferrari *et al.*, 2021; Allaoui *et al.*, 2019; de Villiers *et al.*, 2021; Birkel and Müller, 2021; Planko *et al.*, 2019), our findings suggest that these technologies have the potential to achieve EGD4. Further, BDA and the IoT can contribute toward unleashing EGD5. This is attributable to the capabilities of these applications in extending benefits like real-time information, predictive maintenance, intelligent parking and traffic management, automated toll collection, improved surveillance, road safety and monitoring pollution levels (Zenkert *et al.*, 2018; Di Vaio *et al.*, 2020; Kristoffersen *et al.*, 2020; Marsal-Llacuna, 2020; de Villiers *et al.*, 2021; Haftor and Climent, 2021; Qi and Shen, 2019). Our study provides a framework of the enabling technology and how these technologies can facilitate the achievement of EDG aims. This would guide the policymakers in designing actions and policies for incentivizing the adoption of BDA, IT and IoT for achieving EGDs aims.

The findings of our study suggest that policymakers can contemplate specific policies to address the barriers emanating from financial constraints, technology adoption and lack of economic and social benefits (Table 4). Most of the extant studies have cited these barriers irrespective of the EGD aims. In this study, we have found a gap in payoff, in terms of the current investment and future benefits, disincentivizing the companies to undertake substantial investments for securing a clean and circular economy and smart mobility (Saurabh and Dey, 2021). Factors like technological feasibility, sophistication, knowledge, awareness and availability impacting technology adoption have been found to impede the attainment of EGD4 and EGD5, particularly for SMEs. Our study also finds a lack of economic and social benefits for organizations contemplating an integration of Industry 4.0 and sustainability as restricting the achievement of EGD3, EGD4 and EGD5.

Based on the identification of the most prominent barriers, and the role of enabling digital technologies for unleashing the EGD aims, this study proposes a framework for guiding the organizations and policymakers to pursue a pathway toward green recovery as described in the EU Green Deal.

The following framework (Figure 9) highlights that BDA, IoT and AI are the enabling technologies that can help organizations to pursue the achievement of EGD aims. In addition, given that the financial constraints, technology adoption and lack of economic and social benefits are the main pitfalls to succeed in achieving the EGD aims, policymakers should design specific policies to support organizations. Such policies should also take into account that there are substantial barriers to the achievement of EGD3, EGD4 and EGD5. Thus, we suggest that policymakers' actions should be designed around as follows:

(1) Creating tax incentives to invest in digital technologies, such as BDA, IoT and AI;

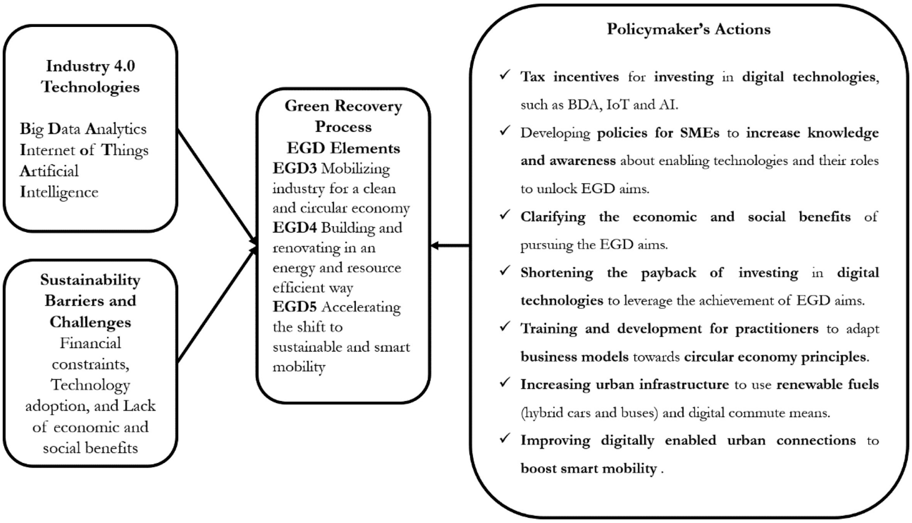


Figure 9. Final framework

(2) Developing policies targeting SMEs to raise the knowledge and awareness about enabling technologies and their roles to unlock EGD aims;

(3) Clarifying the economic and social benefits of pursuing the EGD aims;

(4) Helping to shorten the payback of investing in digital technologies to leverage the achievement of EGD aims;

(5) Providing training and executive courses to managers to learn about how to adapt business models toward circular economy principles;

(6) Increasing urban infrastructure to use renewable fuels (hybrid cars and buses) and digital commute means and

(7) Improving digitally enabled urban connections to boost smart mobility.

7. Conclusions

The article has investigated the interaction between digital technologies and sustainability as specified in the policies planned within the EGD. Through this review, we have sought to provide an intricate understanding of the challenges and barriers of technology adoption for pursuing a pathway toward green recovery. Our appraisal of extant studies in this field has revealed that while digital technologies have a strong potential to unlock EGD objectives, a cautious and judicious assessment of each technology before its adoption is warranted, as its influence on industry and EGD goal is distinct. Further, the findings of our study suggest that the path to digital transformation for pursuing green recovery may not be smooth. This requires mindfulness of the challenges associated with the widespread applications of technology implementation.

7.1 Academic contribution

The study conducts a SLR to identify the enabling technologies for the achievement of EGDs. Although extant studies have explored the role of disruptive technologies in achieving carbon emissions reduction, ensuring a toxic-free environment, driving a sustainable food production system, tackling climate change and decarbonizing the energy system, there is no published study that has examined the influence of these digital technologies in enabling the achievement of policies on EGD. This study is a first attempt to identify the appropriate enabling technology for each of the EDG aims, respectively, and thus contributes toward developing a pathway for the green recovery process. In this way, it contributes to the extant SLRs that have analyzed the impact of Industry 4.0 on sustainable development, albeit with a narrow glance.

From a theoretical perspective, the study provides an improved understanding of the key enabling technologies for investigating the achievement of policies planned in EGD. In particular, the study highlights the scope of BDA, IoT and AI as driving the EGD aims. The study contributes to the extant literature by providing insights on integrating the most appropriate technology for ensuing sustainability in alignment with the desired goal of EGD. For instance, firms aiming to achieve a clean and circular economy may find BDA, AI and IoT as the most suitable technologies (see Appendix Table A1).

7.2 Practical contributions

The article presents an innovative framework that guides organizations and policymakers' decisions to pursue a pathway in which a green recovery is possible, mainly after the consequences of the current pandemic, considering the pitfalls of the journey. The framework addresses specific actions to design policies targeting particular barriers to the achievement of EGD that are more likely to encounter difficulties in the green recovery journey, which are EGD 3, EGD4 and EGD5.

7.3 Future research and limitations

The findings of the present SLR are based purely on the findings of the articles obtained from the Scopus database. While carrying out this SLR, we used a particular set of keywords for searching the articles. Disagreements about inclusion and non-inclusion of specific articles or keywords were solved through discussions. Since the articles were selected from peer-reviewed journals, the list of articles considered for review is comprehensive, although not exhaustive. Further, there exists a possibility of some relevant research articles being not a part of this review because of their non-inclusion in the database.

Table 5 highlights the scope for future research pertaining to various policy-level goals of the EGD and which enabling technologies can help in addressing these gaps.

EGD goals	Scope for future research	Enabling technologies
Increasing the EU's climate ambition for 2030 and 2050	How investment in research and development related to Industry 4.0 technologies such as AI and BCT can help in improved forecasts for building climate neutral societies	AI, BCT, BDA and IoT
Supplying clean, affordable and secure energy	Further research on decarbonizing the existing energy systems for meeting the climate ambition targets. How innovative CE models can improve circularity in the systems. How energy poverty, equitable accessibility and environmental sustainability challenges can be resolved	BCT, IoT and AI

(*continued*)

Table 5.
Future research avenues on the policy-level goals of the EGD

EGD goals	Scope for future research	Enabling technologies
Mobilizing industry for a clean and circular economy	How product designs can be improved to address the sustainability challenges? How various innovative product-service systems can address the circularity gaps and improve the transition toward sustainability? How key product value chains can be improved through reduce, reuse and recycle principles? How customers can be empowered and actively participate in the sustainable product policy design and implementation?	BDA, AI and AR/VR
Building and renovating in an energy and resource-efficient way	How green buildings and infrastructure affects community health and well-being? Which clean energy alternatives can be used in the design of green buildings? How investment in climate resilient infrastructure can optimize resource and energy usage? How various CE models can be deployed for improving the circularity? How technologies such as digital twins and augmented reality can aid in design and construction of buildings? How BCT can be incorporated with the existing grid technologies for optimizing energy usage?	AR/VR, BCT, BDA, IoT and DT
Accelerating the shift to sustainable and smart mobility	How enabling technologies can help in reducing the carbon emissions and help in traffic decongestion? How various cleaner fuel alternatives can improve the current situation?	BDA and IoT
From "Farm to Fork": designing a fair, healthy and environmentally friendly food system	How CE principles can be implemented in the food value chains for improving the resource usage? How enabling technologies can improve the produce traceability across the food supply chains? How technologies can help in building resilient food systems? How enabling technologies can help in tackling food waste at consumer and retail levels? How enabling technologies can provide a smooth transition toward sustainable agricultural practices?	IoT, BCT and BDA
Preserving and restoring ecosystems and biodiversity	How enabling technologies address the environmental sustainability challenges? How enabling technologies can be leveraged for providing scalable ecology conservation practices?	BDA, CC and IoT
A zero-pollution ambition for a toxic-free environment	How enabling technologies can improve the pollution levels and help in creating a toxic-free environment?	BDA, IoT and AI

Table 5.

Notwithstanding the shortcomings mentioned above, the framework proposed as an outcome of this study is purely based on the articles reviewed in these papers and the learnings obtained from them.

However, this suggested framework has not been empirically tested. It is, therefore, recommended that future studies can empirically test this framework apart from providing other theoretical developments for achieving EDGs. Also, studies in future may validate these findings by conducting mixed methods and provide detailed insights associated with the phenomenon under consideration. Future studies can also explore the inter relationships between the TBLs of sustainability as an improved understanding of these elements may facilitate the achievement of EDG aims. Scholars can also validate the framework proposed in this study across different continents for assessing the impact of EGD.

Notes

1. The European Green Deal https://eurlex.europa.eu/legalcontent/EN/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2
2. The study by Kagermann *et al.* (2013) reported the beginning of Industry 4.0 era as the year 2011, as the Industry 4.0 concept was presented for the first time at the Hannover Fair in Germany (Hermann *et al.*, 2016).

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Appendix

Author(s)	Study type	Enabling technologies AI	AM	AR/VR	BDA	BCT	CC	DT	IoT	RoCo	Sim	SG	EGD policy-level aims E1	E2	E3	E4	E5	E6	E7	E8
Denicolai *et al.* (2021)	Empirical	☐	☐	☐											☐	☐				
Upadhyay *et al.* (2021)	Conceptual					☐									☐					
Bigerna *et al.* (2021)	Empirical					☐									☐					
Li *et al.* (2021)	Conceptual					☐			☐											☐
Ferrari *et al.* (2021)	Case study								☐							☐				
Frank (2021)	Empirical	☐	☐	☐																☐
Saurabh and Dey (2021)	Empirical					☐												☐		
Elheddad *et al.* (2021)	Empirical				☐	☐	☐	☐	☐				☐							
Di Vaio *et al.* (2021)	Conceptual				☐				☐						☐					
Díaz-Chao *et al.* (2021)	Empirical	☐	☐	☐	☐		☐	☐							☐					
Pizzi *et al.* (2021)	Case study	☐	☐	☐											☐					
Llopis-Albert *et al.* (2021)	Case study	☐	☐	☐	☐		☐	☐						☐					☐	
Mavi and Mavi (2021)	Empirical				☐								☐		☐	☐			☐	
Bag *et al.* (2021)	Empirical	☐	☐	☐					☐						☐					
Kouhizadeh *et al.* (2021)	Case study					☐									☐					
Smith and Beretta (2021)	Case study	☐	☐	☐	☐		☐	☐							☐					
Piwowar-Sulej (2021)	Empirical	☐	☐	☐											☐					
Haddadeh *et al.* (2021)	Empirical				☐									☐	☐			☐		

(continued)

Table A1.
Selected studies for the review

Table A1.

		Enabling technologies											EGD policy-level aims							
Author(s)	Study type	AI	AM	AR/ VR	BDA	BCT	CC	DT	IoT	RoCo	Sim	SG	E1	E2	E3	E4	E5	E6	E7	E8
Weerakkody *et al.* (2021)	Empirical				☐															☐
Canhoto (2021)	Case study	☐													☐					
Kamble *et al.* (2018)	Conceptual				☐	☐			☐									☐		
Tian *et al.* (2021)	Simulation					☐									☐		☐			
Sharma *et al.* (2020)	Conceptual	☐	☐	☐	☐	☐	☐	☐	☐	☐					☐			☐		
de Villiers *et al.* (2021)	Case study					☐			☐							☐	☐			
Braganza *et al.* (2021)	Empirical	☐															☐			☐
Haftor and Climent (2021)	Case study				☐				☐				☐		☐		☐			
Birkel and Müller (2021)	Conceptual	☐	☐	☐	☐		☐	☐							☐	☐				
De and Singh (2021)	Conceptual				☐				☐									☐		
Castro *et al.* (2021)	Conceptual	☐	☐	☐	☐										☐					
Awan *et al.* (2021)	Conceptual								☐						☐					
Suman (2021)	Conceptual	☐	☐	☐												☐				
Chiarini *et al.* (2020)	Empirical		☐	☐			☐	☐		☐	☐	☐			☐					
Di Vaio *et al.* (2020)	Conceptual	☐			☐								☐		☐		☐			☐
Sihag and Sangwan (2020)	Conceptual	☐														☐				
Kong *et al.* (2020)	Conceptual				☐								☐		☐		☐		☐	
Kristoffersen *et al.* (2020)	Conceptual				☐				☐						☐					
Bai *et al.* (2020)	Case study	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐			☐					
Camaréna (2020)	Conceptual	☐																☐		

(continued)

		Enabling technologies											EGD policy-level aims							
Author(s)	Study type	AI	AM	AR/ VR	BDA	BCT	CC	DT	IoT	RoCo	Sim	SG	E1	E2	E3	E4	E5	E6	E7	E8
Köhler and Pizzol (2020)	Case study					☐												☐		
Coro and Trumpy (2020)	Modeling and simulation	☐									☐			☐		☐				
Polemis and Spais (2020)	Empirical	☐												☐						☐
Marsal-Llacuna (2020)	Conceptual					☐			☐				☐		☐		☐			☐
Dolgui *et al.* (2020)	Conceptual		☐		☐			☐									☐			
Feng *et al.* (2020)	Conceptual					☐			☐								☐			
Valogianni *et al.* (2020)	Modeling								☐	☐		☐		☐		☐				
Pereira *et al.* (2020)	Modeling											☐				☐				
Ghobakhloo (2020)	Conceptual	☐	☐	☐	☐	☐	☐	☐	☐	☐									☐	
Raven and Walrave (2020)	Simulation	☐				☐											☐			
Machado *et al.* (2020)	Conceptual	☐	☐	☐	☐	☐	☐	☐	☐	☐			☐	☐					☐	☐
Hughes *et al.* (2020)	Conceptual	☐			☐				☐								☐			
Del Giudice *et al.* (2021)	Empirical				☐										☐					
Dlugosch *et al.* (2020)	Case study and simulation				☐				☐		☐	☐			☐	☐				
Ukko *et al.* (2019)	Empirical				☐		☐		☐				☐							☐
Kohtamäki *et al.* (2019)	Conceptual	☐	☐	☐	☐	☐	☐	☐	☐	☐			☐							☐
Sharifi (2019)	Conceptual				☐		☐		☐				☐	☐		☐				☐
Allaoui *et al.* (2019)	Conceptual				☐		☐		☐						☐	☐		☐		

(continued)

Table A1.

Table A1.

		Enabling technologies											EGD policy-level aims							
Author(s)	Study type	AI	AM	AR/ VR	BDA	BCT	CC	DT	IoT	RoCo	Sim	SG	E1	E2	E3	E4	E5	E6	E7	E8
Jabbour *et al.* (2019)	Conceptual				☐										☐					
Planko *et al.* (2019)	Case study				☐	☐			☐			☐				☐				
Melander and Pazirandeh (2019)	Case study				☐										☐	☐				
Qi and Shen (2019)	Conceptual				☐				☐			☐				☐	☐			
Pulselli *et al.* (2019)	Conceptual				☐						☐	☐	☐		☐	☐				
Kahlen *et al.* (2018)	Modeling				☐				☐		☐	☐	☐	☐						
de Sousa Jabbour *et al.* (2018a)	Conceptual	☐	☐	☐	☐	☐	☐	☐	☐	☐				☐	☐	☐	☐			
Sacchelli *et al.* (2017)	Case study				☐								☐					☐	☐	☐
Mota *et al.* (2015)	Case study				☐								☐		☐			☐		

Note(s): NB- Artificial intelligence (AI), blockchain technology (BCT), big data analytics (BDA), cloud computing (CC), additive manufacturing (AM), augmented reality/virtual reality (AR/VR), digital twins (DT), robots and cobots (RoCo), Internet of things (IoT), smart grids (SG) and Simulation (Sim)