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Review

Sustainability through digital transformation: EU practices

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Abstract: The significance of sustainability efforts has been reaffirmed by negative circumstances, such as the escalating visible consequences of climate change, floods resulting from erratic weather patterns in certain areas, and fires and extreme droughts in other regions. The logical rationale behind employing digital tools for sustainability purposes lies in the efficiency of digital transformation, supported by artificial intelligence, in improving remote access, control, and decision-making processes, as well as accomplishing tasks that are unachievable through human effort alone. Upon analyzing practices worldwide, it becomes apparent that the European Union (EU) is the singular entity that places utmost importance on digitalization as a means to ensure sustainability. Additionally, it provides comprehensive allocations for projects pertaining to this subject and supports the collective wisdom of its members through the established union. Hence, the purpose of this study is to examine the current literature in detail via a systematic review to extract the EU practices of sustainability through digitalization. Findings reveal the particular EU focuses and key themes on achieving sustainability with a visual representation of the results. Besides, the EU practices with other well-known countries on sustainability through digitalization efforts are compared and discussed. Thus, a practitioner can understand the findings of this research to use as the first step when generating research questions to start a new study.

Keywords: systematic review; sustainability; Industry 4.0; digital transformation; digitalization

1. Introduction

Industry 4.0 (viz., the Fourth Industrial Revolution) and sustainability goals are of paramount importance for the European Union (EU) owing to the numerous significant advantages in terms of economic competitiveness [1], new job fields' creation [2], market growth [3], environmental consciousness [4], natural resource usage efficiency [5], energy independence [6], and social inclusion [7]. Sustainability and Industry 4.0 are not mutually incompatible concepts [8]. Indeed, the EU is working extensively to merge these two agendas [9,10]. For example, in this context, smart/digitalized, and sustainable manufacturing techniques can assist the EU in meeting its climate targets by enabling real-time monitoring and resource usage optimization [11], thus, lowering the environmental effect. Furthermore, the EU has created policies and financial initiatives to help both Industry 4.0 and sustainability, proving its dedication to attaining these sustainable development goals [12,13].

The companies reach sustainability goals through Industry 4.0 by utilizing advanced digital technologies and data-driven approaches [14]. Efficient use of resources can be achieved through insights from data; hence, predictive maintenance and smart energy management can be fulfilled [15,16]. Besides, circular economy (CE) is another important part of reaching sustainability by monitoring the product lifecycle and having the ability to customize/personalize [17,18]. In a broader context, supply chain optimization can be attained by greener manufacturing implementations, and by higher supplier collaborations via real-time visibility [19,20]. As a result of doing so, traceability and transparency improve consumer engagement [21], Waste management can also be achieved in terms of both solid waste mitigation [22] and emission and energy use reduction [23].

The main technologies enabling Industry 4.0 are robotics, IoT/sensor technology [24,25], digital twins [26,27], big data [28,29], cloud computing [30,31], artificial intelligence (AI) [14,32,33], additive manufacturing [34,35], augmented reality [36,37], and cybersecurity [38]. The companies can facilitate these technologies in order to obtain Industry 4.0 benefits.

Therefore, the motivation of this study is based on this valuable background knowledge, emphasizing the importance of Industry 4.0 paving the way to sustainability. Moreover, according to worldwide industry reports, the USA, Germany, Japan, France, China, and South Korea are the most well-known countries leading to the industrial revolution [39]. However, although there are some particular countries preparing future plans and investing in cutting-edge technologies to have applications of Industry 4.0, like Italy [40], the EU falls behind within this competitive market environment. Indeed, there is also a gap in the literature focusing on the EU practices of Industry 4.0 in pursuit of sustainability (see Systematic Review section).

Hence, the purpose of this study is to extract the details of Industry 4.0 implementations in EU countries in order to achieve sustainability goals via a systematic review. Both the industrial reports and academic papers were included in the review to determine the mutual points adopted by the EU and to interfere with common application trends.

The following parts of this paper cover a systematic review, results, discussion, and conclusion.

2. Systematic review

In order to identify the triggering causal relation of Industry 4.0 (I4.0) to sustainability, the Scopus database, including well-known publishers such as Elsevier, Springer, Emerald, Sage, Wiley, Taylor & Francis, Routledge, etc., is searched with Industry 4.0/digital transformation/digitalization, sustainable/sustainability, and "European Union" keywords, and 174 document results were obtained in October 2023.

Accordingly, the number of "EU Industry 4.0 applications for sustainability (EU I4.0 Sustainability)" papers has been increasing since 2017 and has an increasing trend beginning this year. In comparison to the worldwide paper volume, although there are 9458 documents about that topic, only 174 of them are about EU applications. Therefore, it is obvious that despite the defined sustainability goals of the United Nations, the EU countries are falling back within this field of study in terms of publications. Moreover, EU I4.0 Sust papers include mainly articles (62%), conference papers (21%), reviews (6%), book chapters (6%), conference reviews (3%), notes (1%), and short surveys. Besides, social sciences (18%), computer science (14%), environmental science (13%), engineering (12%), energy science (9%), economics (9%), business and management (8%), and other disciplines contribute to the EU I4.0 Sust field of study. Furthermore, the major funding organizations are the

European Commission, Horizon Programme, European Regional Development Fund, Fundação para a Ciência e a Tecnologia, Javna Agencija za Raziskovalno Dejavnost RS, Ministry of Education and Science of Ukraine and Erasmus+. EU I4.0 Sust research is supported by Italy, Germany, Poland, Romania, Spain, Russia, Portugal, France, Greece, and the Netherlands.

EU-specific papers on I4.0 and sustainability are mainly eightfold: 1) sustainable development focus; 2) carbon-neutrality; 3) information and communication technology (ICT) use of individuals; 4) e-commerce/digital economy; 5) technology adoption and public policy making; 6) blue economy (referring to the industries relying on waterways/oceans to enhance tourism, transport, marine biotechnology, fishing, wind energy and agriculture); 7) digitalization affecting environmental sustainability, and agriculture. The following sub-sections entail EU I4.0 for sustainability research.

2.1. Sustainable development (SD) focus of the EU

The European Union (EU) prioritizes SD with a remarkable effort to address many factors that can be roughly classified as (i) economic; (ii) environmental, and (iii) social dimensions [41,42]. The economic dimension mainly covers resource-efficient economic growth, green technology investments, and green finance, while the environmental dimension addresses climate change, biodiversity and conservation, and the circular economy [43]. Thirdly, the social dimension emphasizes social inclusion, quality of life, and gender equality [44]. Here, the policy frameworks and regulations of governments are significant to monitor and report the industries in a transparent way [45,46]. Indeed, global cooperation like the Paris Agreement and the United Nations Sustainable Development Goals (SDGs) are paramount of importance to maintaining the SD [47].

The SD focus of the EU indicates that there is a strong link between digitalization and SD in EU countries [48]. Smart transportation [41], smart cities [49], smart mobility [50], smart organizations [51], smart agriculture [52], smart life cycle assessment [53], smart use of energy [54], smart waste management [45], smart recommendation systems [55], smart procurement and notification systems [56], smart food processing [57], smart process treatment/monitoring/controlling [58], smart tourism [59], smart finance [60], smart healthcare technologies [61], smart recycling [62], and cybersecurity [63] are the major implementation fields of EU academicians within EU I4.0 for sustainability research.

2.2. Carbon-neutrality (CN) focus of EU

The EU has established a high target of reaching CN by 2050, which entails balancing greenhouse gas emissions with reductions or cuts, ultimately attaining a net-zero carbon footprint [64]. There are significant factors to achieve CN such as controlling climate change, international cooperations/commitments [49], reducing air pollution/greenhouse gas emissions [65], mitigating the damages in natural habitats, protecting biodiversity [66], renewable energy use like wind and solar alternatives instead of fossil fuels [67], promoting waste management/circular economy/recycling/sustainable production and consumption [45], investing on cutting-edge technologies like carbon capture and storage [64], supporting electric vehicles in public transportation and individual mobility [50], suggesting energy use optimization in manufacturing industries [68], encouraging reforestation and sustainable farming [69], CN education to improve the awareness [70], government policies and regulations for CN [71].

2.3. Individuals' information and communication technology (ICT) focus of EU

The ICT use of individuals in the EU is affected by several elements, such as access through a digital infrastructure that is directly linked to internet availability and affordability [1], digital skills/literacy that can be improved by training/education to close the generation/age gaps, socioeconomic elements that can be shaped by income and employment status [44], digital inclusion strategies with governmental initiatives and accessibility standards [71], cultural elements with attitudes of people and social norms [72], digital privacy and cybersecurity [38], content relevance and local language [73], and regulations [74]. The aforementioned variables are interrelated and their influence on ICT use varies by EU member state. Authorities, politicians, and other parties in the EU are working on addressing these variables in order to encourage wider and more equal access to and usage of ICT across the area.

2.4. e-Commerce (eC) and digital economy (DE) focus of the EU

The eC focus enabling the DE has remarkable benefits, particularly the financial sustainability focus, however, there are some major concerns arising from the increasing logistics frequency and solid waste amounts [75]. eC and DE are affected by several factors in the EU, such as "Digital Single Market" strategy and "eC Directive" [76], protection of data/consumer/intellectual property [63], financial services/payment systems/fintech [3], cutting-edge technologies/5G/broadband access [77], global trade regulations/agreements/taxation [49], trust and preferences of customers [21], competitiveness [51], language problems for addresses [78], last-mile delivery/logistics [79], and digital literacy with training/education support.

2.5. Technology adoption (TA) and public policy making (PPM) focus of EU

The TA and PPM focus of the EU directly affects sustainability strategies in terms of innovation ecosystems and regulations. In other words, there is a significant background on how the technology is adopted by communities, how it is regulated, and what the result of this process is. This is a major concern of PPM in the EU. Within the context of laws and regulations, the standards for interoperability have an important role [56]. For the innovation ecosystem, research and development initiatives, startups and small and medium-sized enterprises are the fundamentals to foster the system [16]. Indeed, digital infrastructure [1], lifelong learning and workforce development through education [32], protection of data/privacy and cybersecurity [38], collaborations, funding mechanisms, public-private partnerships [80], competition in the market [51], digital inclusion with respect to accessibility and affordability [81], green technology and circular economy concern [79], public engagement and transparency [56] are all important factors affecting the TA and PPM in the EU.

2.6. Blue economy (BE) focus of EU

BE stands for the ocean/waterway's sustainable use by countries/authorities for financial welfare with both occupation opportunities and enhanced ecosystem protection, including several industries such as fishery, maritime transportation and biotechnology, tourism, aquaculture, and renewable energy [82]. BE depends on the coastal geography to access the sea [66], fisheries and aquaculture management, logistics infrastructure with the intermodality opportunity to enhance connectivity [79], recreation and coastal tourism [59], energy resources [54], training and workforce, regulations of EU [74], diplomacy for international cooperations [83], awareness of customers and entrepreneurship [11] to shape demand, ports, and shipyard infrastructure [84].

2.7. Digitalization effects on environmental sustainability (DEES) and agriculture (DEA) focus of EU

The DEES focus of the EU is twofold: positive and negative consequences. Energy efficiency via green information technology uses [68], renewable sources of energy usage [67], electronic management of wastes [45], smart mobility [50], remote working/sensing opportunities, traceability and transparency [66], digital document use instead of physical paper resources [76] are the positive consequences of digitalization on sustainability. However, storage/privacy/security/misuse/transfer of data consumes higher energy amounts [38], and solid electronic waste generation [45] has become a problem for EU countries.

With the introduction of digital technologies like IoT, digital twins, augmented reality, etc., the DEA's focus on the EU has gained momentum with the ability of remote control and monitoring [52], referring to "smart farming" or "precise/precision agriculture" or "agrifood 4.0/agriculture 4.0" [69]. 5G, broadband access, IoT/remote sensing, GPS use, and autonomous machinery are the main requirements of the digital infrastructure to enable connectivity [85]. Next, the gained data is analyzed to derive meaningful insights, for example, to optimize fertilizer/pesticide amounts, forecast the weather conditions/planting/harvesting times, manage the crops/livestock, etc. [86]. Here, resource conversation enables sustainable practices in agriculture. However, the existing farmers' resistance to change and to adopting new technologies is a common challenge that can be dealt with in training programs. Besides, mutual agriculture policies force these existing farmers to be a part of the change to achieve digitalization in agriculture. Moreover, the cost of these technologies is another issue for farmers. Indeed, consumer demands for more transparency through supply chain visibility encourage these farmers to keep up with new approaches [87].

The following section derives from this important background to provide meaningful results and compares the EU and worldwide approaches to achieving sustainability through digitalization.

3. Results and discussion

By examining the EU I4.0 for Sustainability systematic review in detail, one can infer that the sustainable development of the EU can be categorized as the financial, environmental, and social triple bottom line of sustainability (see **Figure 1**). Here, e-commerce/digital economy and blue economy practices directly affect financial sustainability, while carbon neutrality and blue economy practices have a direct impact on environmental sustainability. Moreover, social sustainability is supported by the privacy of the community, an enhanced workforce through community welfare, and the digital skills of people in terms of self-improvement. Besides, digitalization triggers both the digital economy and carbon neutrality practices by enabling real-time long-distance monitoring and controlling. However, individuals' ICT use and technology adoption are important to actualize digitalization, which fully depends on digital skills and public policies. In order to achieve this, there are three fundamental must-haves: (1) training/education, (2) laws and regulations, (3) privacy, data protection, and cyber security.

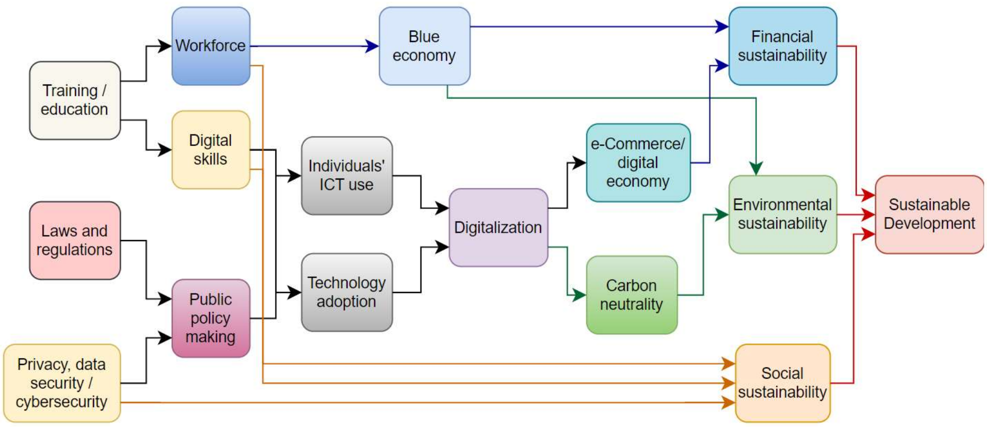

Figure 1. Causal relationship between EU I4.0 for sustainability research elements.

In order to compare the findings of this research with existing ones, an additional review is conducted. Accordingly, although the United States (US) has extended its digital infrastructure for sustainability, different states might have differentiated applications in terms of governmental policies. While EU countries have single mutual agreements like the "European Green Deal", the US implements public-private initiatives to achieve sustainability through digitalization. Furthermore, the EU supports the circular economy and smart city practices more, while the US seeks technology innovation, energy use optimization, and smart agriculture more [88–90].

China has again made efforts to monitor the environment and conduct green transportation solutions, however, the major difference between China and the EU is that the country's human population density is a challenge. Therefore, China has a focus on resource use minimization and efficiency through digitalization [91–93].

In addition, Japan is already familiar with the sustainability phenomenon, such as the "lean philosophy" that grounds "waste reduction" activities. Today's challenge for Japan is finding a workforce [94] in terms of social sustainability because they are shifting their workforce from China to Japan [95].

As another comparison, since Russia is prosperous in terms of natural resources, its focus is on smart enterprises to achieve digital transformation to point-to-point industrial systems by enhancing dynamic capabilities [96,97]. As a result, the systematic review indicates that the utmost efforts toward sustainability through digitalization are provided by the EU and the United Nations.

To highlight the scientific contribution of this research, the preliminary well-known and widely accepted conceptual frameworks of Kamble [98], Yadav [99], Birkel [100], Yadav [101], and Gupta [102] are all reviewed and adopted to generate this conceptual model. This study implements the mutual relationships of these frameworks in a parallel direction. A practitioner can understand by studying the [103–111] researchers to reach the details.

4. Conclusion

The European Union attributes paramount importance to Industry 4.0 and sustainability goals, as they offer significant advantages in terms of economic competitiveness, job creation, market growth, environmental consciousness, efficient use of natural resources, energy independence, and social inclusion. The concepts of sustainability and Industry 4.0 can be harmoniously integrated. The EU is actively engaged in merging these two agendas.

This study is motivated by valuable background knowledge that emphasizes the significance of Industry 4.0 as a pathway to sustainability. Furthermore, as indicated by global industry reports, the prominent nations that spearheaded the Industrial Revolution have been surpassed by certain countries that are strategically developing future plans and investing in cutting-edge technologies for the implementation of Industry 4.0, such as Italy. However, the European Union lags behind in this fiercely competitive market landscape. Furthermore, there is a noticeable lack of scholarly research that delves into the EU's practices in Industry 4.0 in the context of sustainability.

Thus, the aim of this study is to conduct a detailed examination of the current literature through a systematic review, with the goal of extracting and analyzing the European Union's sustainability practices in the context of digitalization.

The findings of this review reveal specific EU focuses and key themes on achieving sustainability in a visual format. Upon comprehensively analyzing the EU I4.0 for Sustainability systematic review, it becomes apparent that sustainable development can be divided into financial, environmental, and social aspects. A major influence on financial sustainability can be seen in e-commerce and digital economy practices, whereas a major impact on environmental sustainability can be observed in carbon neutrality and blue economy practices. In addition, a comparison and discussion of EU practices regarding digitalization and sustainability are also conducted.

Consequently, practitioners can use the findings of this research to generate new research questions for their own studies as a first step, which is also a theoretical contribution to scientific development. Many managerial implications can be derived by using the findings of this study in terms of decision-making, planning, and strategy-building by the authorities responsible for sustainability through digitalization in their institutions.

The research is limited to the EU practice literature; however, since the main idea of this research is to highlight the EU in detail, it might not be evaluated as a limitation. Besides, further studies might add more industry reports to emphasize EU practices, or more countries might be compared and discussed with EU practices.

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