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Information Technology and Digital Sufficiency for Building the Sustainable Circular Economy

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Abstract: Information technologies possess the significant potential to improve the efficiency of resources and optimize energy usage, as well as make a significant contribution to the sustainable circular economy (CE). The concept of digital sufficiency provides a framework for understanding how information technology can be part of significant achievements in the circular economy, especially when embraced by business companies. Moreover, the possibility of the implementation of closed-loop resources has become possible with the development of digital manufacturing technologies. However, the research of establishing the CE in SMEs, especially in fossil-energy-abundant countries, such as the Russian Federation, is quite limited. Our paper fills in this gap by studying the adoption of CE practices as well as the investments for promoting CE in Russian SMEs through such factors as the existence of R&D, bank loans, and access to grants at the national and international level. It achieves this based on the data sample of 314 managers of Russian SMEs. Our results demonstrate that the investment or existence of R&D in SMEs and knowledge of CE as well the governmental funding and access to wider markets all together tend to have a significant and positive effect on implementing and investing into CE in SMEs, while the administrative barriers yield a small but negative effect. These results might be helpful for the relevant stakeholders in order to identify factors catalyzing attention from both the SMEs engaged in CE transitions, as well as help the decision makers wishing to foster the transformation of the SMEs to a circular economy. We can conclude that supporting SMEs (both financially and via increasing their public awareness) to make their own transitions towards CE has a societal effect that can speed up a greener transition and significantly contribute to increasing energy efficiency.

Keywords: information technology; digitalization; circular economy; Internet of Things; SMEs; energy efficiency

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1. Introduction

In the post-COVID world, information technology and digital sufficiency are gaining an increasingly indispensable role in the transition to a greener future ruled by Industry 4.0, where energy efficiency and optimization would help in building a sustainable circular economy (CE) [1–3]. In a way, CE represents a closed-loop material flow that can go throughout the whole economy [4,5].

The circular economy model that helps to capture value swaps out the traditional "take-make-waste" approach for one that keeps materials in use, reduces waste, and prioritizes the regeneration of the natural ecosystem [6,7]. Figure 1 reveals how the CE differs from

the traditional economy (TE) (also known as the "linear economy"). While the inputs in TE go through the traditional production and utilization to generate a considerable amount of waste, CE offers a solution to minimizing this waste through recycling, reusing, repairing, and returning the materials and spare parts back to production and further down to reusing.

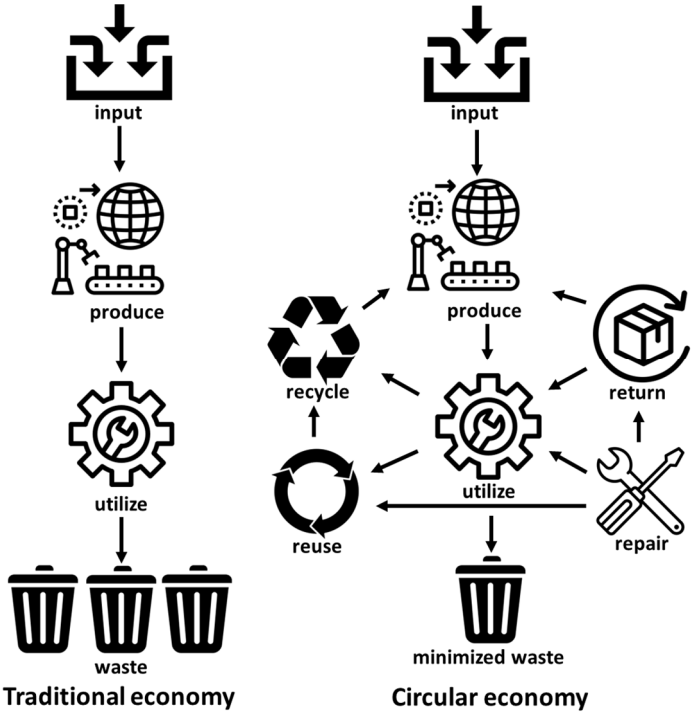

Figure 1. The difference between the traditional economy (TE) and the circular economy (CE). Source: Own results.

All of the above is achieved through designing products and materials to remain in use for as long as possible with their highest qualities and applying novel and innovative business models [8]. A good example are the two "fast fashion" companies—the Swedish H&M and the Spanish Zara—that encourage their customers to help recycle clothing and use these inputs for producing and recreating new fashion goods and products. Furthermore, tech giants such as Toshiba or Dell are also working on reusing their products, such as TV sets, laptops, or personal computers, with the aim of reusing electronic parts and reducing packaging to achieve higher energy efficiency [9,10].

For some technology companies, improving their products' circularity creates new value and supports their plans for becoming more sustainable [11,12]. Circularity is emerging as a need and the tech hardware companies build greater resiliency into their supply chains and reap greater profits from the green premiums and second- and third-use revenue streams [13–15]. Within those new business models, emerging digital technologies can strengthen a shift towards CE by collecting and analyzing as well as consolidating data. As a management impact, an agenda of CE transition can be proposed using Industry 4.0 technologies across organizational staff at operational, tactical, and strategic levels and as a potential use strategy within particular domains of research, such as supply chain management and the manufacturing of products in general [16,17]. Highly developed technologies could offer manufacturing organizations competitive advantages in developing economies, considering the fact that Industry 4.0 solutions contribute to the transition from the linear economy towards the CE and Sustainable Development Goals (SDGs) [18]. These technological features can enhance material re-use, upcycling, circularity, and recycling programs, and the performance management of the circular supply chain allowing for higher energy efficiency and saving [19,20]. This is due to the fact that Industry 4.0 tends to support cleaner manufacturing practices which are likely to drive potential for innovation,

welfare, and employment. Leveraging technologies also frees time and resources that companies can utilize for focused sustainability product development and education for customers [21–23]. Similarly, the Internet of Things (IoT) solutions can be used to prolong product usage, helping maintain it detecting faults and improving the delivery of technical support, as well as maximizing resources [24,25]. As a result, these resources are not just supporting CE but are also driving new opportunities for social businesses.

This paper studies the role of information technology and digital sufficiency for building the sustainable CE. In doing so, it offers some research novelty by focusing on a case study of 314 small and medium enterprises (SMEs) from Russia facing the challenges generated by the circular economy and exploring the opportunities created by the circular economy in this country abundant in natural resources (mostly fossil fuels and natural gas). It also highlights the digital sufficiency policy which is crucial for building the advanced circular economy of the 21st century based on energy efficiency and renewable energy deployment. It appears important to identify the relevance of digital technologies as the drivers of the circular economy business model, particularly in the current scenario of the post-pandemic world.

The paper is structured as follows: Section 2 provides a literature overview that discusses the role of the circular economy and explains the role of SMEs in it. Section 3 offers a brief introduction of the empirical model and the overview of the data. Section 4 outlines the results of the empirical model. Section 5 features the discussion of the results. Finally, Section 6 closes the paper with overall conclusions and key implications, as well as the pathways for further research.

2. Literature Overview

2.1. Role and Provisions of CE

It is obvious that CE greatly benefits from digitalization that has been further fostered by the COVID-19 pandemic and the digital surge in business, economics, and the social life it has brought about [26,27]. The IoT technologies are already changing the practices of the circular economy and existing business models, by enabling businesses and organizations across a wide variety of industrial sectors to eradicate waste and recirculate materials, as well as to restore nature [28–30]. Some studies have identified the emerging opportunities in the digital and circular economy for supply chain productivity [31–33].

In general terms, CE offers organizations and business companies improved supply chain visibility, brings greater opportunities for R&D and innovation, and allows them to meet complex requirements in a supply chain based on the principles of reversal logistics [34–36]. Reverse logistics supply chains are dedicated to a flow of products and materials backwards, with a focus on refurbishing, reusing, repairing, recycling, or natural systems regeneration [37,38]. Based on AI and blockchain solutions, this technology enables the illumination of the supply chain, creating transparency not only between all layers of suppliers but also between the physical materials which are a part of the production process. The inputs for products in the cutting-edge technologies come from many different sources and improving circularity requires an intimate knowledge of material flows prior, during, and after a product's useful lifetime [39–41].

The CE represents a step forward for environmentally and socially responsible practices but also brings new complexities to supply chain management and supervision [42–44]. Some recent studies reported respondents making changes in their supply chains, including the integration of CE products in planning processes, adding new capabilities at existing manufacturing sites, or adding new sites for repairing/remanufacturing and waste management, all owned by the business [45–48]. Advanced digital technologies like AI, smart sensors, and blockchain, just to name the well-known ones, are helping generate the real-time data, analytics, and business intelligence that builds resiliency, as well as providing organizations with the basis for managing carbon emissions [49,50].

Some previous research has also identified opportunities in the digital and circular economy for improving supply chain efficiency [51–53]. In order to reach circularity,

modern business companies need to shift from linear supply models towards a complex ecosystem, which has multiple dependencies and feedback loops, including solutions at the end of their lifetime [54–57]. For building this type of economy, a circular value chain needs to exist, where every actor is advocating for circularity [58]. In the traditional linear economy, once the raw materials have reached their end of life, producers may be able to leverage digital technologies to assess if a product has reached enough intrinsic value that it should be returned to them [59]. When raw material selection is locked into a project phase, this may make it difficult to manage end-of-life products and conduct repairments [60–62].

In addition, it becomes apparent that the "digital twins" technologies might also represent one of the viable solutions that companies can adopt for a more CE approach to their business practices [63,64]. These technologies allow companies to better anticipate when, where, and how replacements may need to occur for any given product [65,66]. This can contribute to improving the response strategies and transforming the supply chains for sustainability, resilience, and energy efficiency [67,68]. As organizations continue to look for ways to eradicate waste throughout operations and adopt the circular economy, technology solutions such as enterprise resource planning and supporting business applications can play an important role in accomplishing these goals [69–71].

As the CE model is replacing the traditional approach, the value chains get shortened, emissions are lowered, local economies become stronger, and the energy efficiency rises [72,73]. In addition, it appears that the decentralized approach for the circular economy, including renewable energy generation, would help local regions and small businesses to become more self-reliant in terms of commodities, resources, and energy usage [74,75]. By integrating circular thinking into basic strategies, business companies might contribute to powerful new perspectives, along with levers to improve efficiency and creating new value [76,77]. Companies (in particular SMEs) which use digitalization to adopt the concept of the circular economy would reap the rewards in deeper customer relationships and loyalty. They can do so by breaking the supply chain and collaborating with the product teams to evaluate opportunities for building points of value as they transition into the circular economy [78–80].

Even though the global COVID-19 pandemic has upended raw material flows and prices as well as final products, the CE model helps to create supply chain resiliency when faced with this kind of disruption. The flexibility associated with different aspects of production, such as quality, cost, speed, and processing innovations, helps organizations gain a competitive edge and develop sustainable supply chains. In broad terms, flexibility in the sustainable supply chains is highly related with a firms' ability to effectively utilize green technologies, design eco-friendly supplies and products, and ultimately minimize resource consumption [81]. The evaluation of their effectiveness uses broader metrics that do not automatically suggest integrating circularity [82]. All of that applies to the small and medium enterprises that need to be aware of the CE provisions and promote their own innovations as well as research and development (R&D) to the CE.

2.2. SMEs and the Circular Economy

SMEs that often constitute a backbone of the economy in many developed countries need to recognize their key role in transforming into a greener, global CE and need to manage their transformation processes aggressively [83–85]. As a result, the findings from, for example, Europe reveal that European SMEs are suffering from an inherent inadequacy with respect to addressing the shift towards circularity coherently and therefore need to be provided with concrete supports (e.g., government funds or increasing the knowledge of CE practices) which could promote redesigning their business in a circular way [86–88]. Less research has highlighted ways of implementing circular approaches within SMEs in a time of CE transformation [89,90]. Our evaluation of SMEs in various countries showed that companies with foreign equity as well as access to more markets (e.g., international rather than just local ones) were more likely to have business strategies and a strategic planning process for the transition to CE practices [91,92]. One recent study with a sample

of Dutch-based SMEs tested a model offering insights on organizational attributes that may help firms implement circularity into their business strategies [93].

Since the adoption of circular economy practices is promoted through the support process for lowering environmental impacts, the SME managers believe that if this new transformation is motivated by the business' interests it would self-organize to each of the economic stakeholders' groups [94,95]. Before discussing what barriers and facilitators are considered as the most important factors in SMEs that are moving from the traditional linear economy to CE, their current activities need to be along with their technical concerns about achieving better management of resources [96]. At the same time, it appears that the CE activities need to be actively promoted by the relevant stakeholders (policymakers and governments) since the adoption of green closed-loop technologies or efficient energy tools needs to gain wide public support and knowledge before the entrepreneurs would start taking them seriously and consider implementing them into their daily business routine [97].

Many studies demonstrate the challenges SMEs are facing in their transition towards the circular economy, such as the lack of technical expertise, limited access to funding, or administrative barriers [98,99]. Their smaller scale means they face unique challenges on their journey towards closing the loops and improving their resource efficiency. Furthermore, other studies also demonstrated how a circular economy could be a real business opportunity for companies, particularly mid-sized and smaller ones [100,101].

All in all, in order to make a successful transition from a linear to a circular economic model, we need to redefine the process of value creation, designing new business models capable of capturing all these elements with an integrated, systems-based approach. The main obstacle to the adoption of that by SMEs is a lack of a suitable context to implement the circular business models that would also mean effectiveness and energy efficiency, as well as the optimization required for the CE principles to work properly [102].

Given all the above, an empirical model can be built for assessing how SMEs can implement CE processes or invest into the CE practices using various forms of their own innovations and/or external support. The model is presented in Section 3.

3. Empirical Model and Data

The empirical model that is outlined in this part of our paper was designed to determine the ways of implementation of circular economy practices in Russian SMEs as well as assess the volume of investments by SMEs in promoting CE through such factors as R&D, bank loans, and the possibility to receive grants from regional and central governmental authorities, as well as having access to national and international markets. The model employs our own data collected using online surveys with 314 managers and owners of Russian SMEs located in the Moscow and Yekaterinburg regions.

The formal empirical model can be presented in the form of a multilevel mixed-effect probit model that follows:

$$Pr(CE_{ij} = 1 \mid x_{ij}, c_{ij}, \varepsilon_j) = \Phi(x_{ij}\beta + c_{ij}\gamma + z_{ij}\varepsilon_j) \quad (1)$$

where:

CE—is a binary dependent variable (either an ordered categorical variable with the values 0 = no investment in CE, 1 = 1–5% investment in CE, 2 = 5–10% investment in CE, and 3 = >10% investment in CE as well as the dummy variable which equals to 1 = implementing CE and 0 = otherwise) that shows the investments in CE and the implementation of the CE of the SME i in case of the technology/innovation j;
x—is a vector denoting investment into R&D, obtaining information, as well as local and international funds;
c—is a matrix with constant as well as control variables of the model;
ε—is the random intercept term yielding the random effect.

The data obtained for testing our empirical model that is presented above was collected by the research team of authors using quasi-random sampling with elements of the snowball technique assisted by the opportunity sampling technique via our contact points. An online Google Docs survey was accompanied by a personalized e-mail message or phone call from our own contact points (the so-called "gatekeepers"). Our selection of the respondents and the reliability of local gatekeepers was possible using the extensive graduate student networks in the two regions involved into our research. The graduate students recruited in these respective regions were taught how to deal with eventual difficulties and arising issues. To ensure the ethical norms and standards that are typical for this type of survey, written informed consents were obtained from all the subjects prior to the study via a simple online form which was a part of the questionnaire survey.

In spite of the fact that the way our respondents have been selected and how the sampling has been arranged constitute a certain limitation of this study, our results can be nevertheless perceived as meaningful and helpful in studying the implementation of CE in SMEs in general and in Russian SMEs in particular. We also must mention that we selected this approach due to the opportunity to reach the Internet-based population, which otherwise would not be reachable [103,104] and enables communication with people who might not have time to meet face-to-face [105].

A total of 314 respondents (aged 25–73 years; 13.3% females and 86.7% males) represented by the managers of SMEs from the two Russian regions (Moscow region and Yekaterinburg region) completed a questionnaire voluntarily and anonymously between June 2022 and November 2022. Table 1 reports the data and the demographic profiles of the SME managers involved in our survey.

Table 1. Statistics of the respondents from a survey of SME managers. Source: Own results.

		No.	**%**
Age	25–35 years	64	20.3
	36–55 years	178	56.7
	56–70 years	70	22.4
	>70 years	2	0.6
Gender	Female	42	13.3
	Male	272	86.7
Years in the company	<5 years	52	16.5
	5–10 years	78	25.0
	10–15 years	158	50.2
	>15 years	26	8.3
Position in the company	Director and owner	67	21.3
	Director	125	40.0
	CFO	77	24.5
	Logistics manager	30	9.5
	ICT manager	15	4.7
Industry	Building and construction	49	15.6
	Textile and clothing	86	27.4
	Chemical industry	45	14.3
	Metal industry	74	23.7
	Paper and plastic	32	10.2
	Electronics	28	8.8
Total: 314			

It can be seen that our sample is dominated by middle-aged males with the majority working for their respective SMEs for more than 10 years, which might constitute another limitation of our sample but otherwise reflects the composition of SME managers and owners in the business companies in Russia.

Moreover, it needs to be mentioned that the selection of the SMEs from the two particular regions for this study was not accidental: both Moscow and Yekaterinburg region represent major industrial hubs in Russia with a wide range of both massive industrial enterprises as well as SMEs operating in multiple sectors. With the ongoing modernization of the Russian energy system, the perspectives of its transition to sustainable energy in some near future, or in the face of the unprecedented economic sanctions imposed by Western countries on the Russian economy, the possibility of implementing the elements of circular economy is becoming less distant and more desirable given the possibilities it can provide for Russian SMEs.

4. Empirical Model Estimation

Our empirical model specified in Equation (1) in the previous section (Section 3) is similar to the ones used in other related research projects focused on assessing the preferences or attitudes of users and consumers for the new technologies and setting as shown, for example, in the publications of Kashintseva et al., which deal with consumer acceptance of industrial CO_2 capture and storage [106], or Shouran et al., which focus on users' attitudes towards the privacy and security of IoT in smart homes [107]).

Table 2 below reports the results of the two mixed probit regression models: one for determining the investment into circular economy and the other one studying the implementation of the circular economy in the Russian SMEs from the Moscow and Yekaterinburg regions.

Table 2. Investment and implementation of circular economy (mixed probit regression). Source: Own results.

	CE Investment			**CE Implementation**	
	Estimate	**SE**		**Estimate**	**SE**
R&D in energy and environment	0.330 ***	0.063	R&D in energy and environment	0.317 ***	0.089
CE awareness	0.400 ***	0.061	CE awareness	0.486 ***	0.051
Regional funding	0.521 **	0.361	Government programs	0.457 ***	0.056
Government funding	0.404 **	0.364	Finances	0.048 ***	0.024
Bank loans	0.566 ***	0.078	Adminstrative barriers	−0.063 ***	0.027
Adminstrative barriers	−0.029 *	0.011	Company size	0.491 *	0.344
Company size	0.070	0.254	Company age	−0.036	0.056
Company age	0.063	0.064	Local markets	0.279 *	0.051
Local markets	0.051 *	0.065	National markets	0.155 **	0.078
National markets	0.034 **	0.033	International markets	0.199 **	0.062
R&D	0.641 ***	0.067	R&D_1	0.407 ***	0.074
Localization	−0.009	0.007	R&D_2	0.205 ***	0.076
Energy prices	−0.029	0.059	R&D_3	0.539 ***	0.078
Inverse Mills ratio	−0.779 ***	0.275	R&D_4	0.402 ***	0.084
Cutpoint 1	−0.108	1.345	Energy price	0.042	0.026
Cutpoint 2	1.744	1.345	Materials	−0.005	0.042
Cutpoint 3	2.332 *	1.342	Constant	−1.535	0.755
N = 314					

Note: *** Significant at the 0.01 level; ** Significant at the 0.05 level; * Significant at the 0.1 level.

The first model features the natural logarithm of the binary dependent variable (ordered categorical variable) showing the investments into CE (represented by the clusters between 1–5%, 5–10%, and above 10% of the net profit) as well as such independent variables as awareness and information about the CE principles and rules, regional or central governmental funding, possibility to obtain bank loans, the existence of administrative barriers, company size, company age, the company's access to local and national markets, the existence of R&D (a dummy with a value 1 = R&D is present in the company and 0 = otherwise), localization, and energy prices (energy costs for the company).

The second model features the natural logarithm of the binary dependent variable indicating the implementation of CE as well as the independent variables represented by the awareness about the principles and rules of CE, the existence of the government programs aimed at supporting CE in companies, access to finance, the existence of administrative barriers, company size, company, age, the access to local, national, or international markets, R&D in the company (1–5%, 5–10%, 10–20%, and above 20% of the net profits), energy prices, and the prices of materials (inputs) used by the company.

Our results reveal that R&D in energy and environment has a positive and significant effect on the likelihood of Russian SMEs to invest into CE and to implement it in their operation. The awareness (knowledge) of the CE and what it represents also have a positive and significant effect on the investment into CE and implementation of CE in SMEs. Such variables as regional (local administrations and authorities) and governmental funding also have a positive effect which provides a support for the government initiatives aimed to financially support CE. At the same time, administrative barriers have a small but negative effect on the implementation of CE and investing into CE.

The age and size of the company did not come through as significant for CE-related activities but the fact whether the SMEs sell their products on the local, national, or, even better, international markets contributes to setting up the CE principles in their functioning.

The investment or existence of R&D in the companies also came through as positive and significant. Conversely, the energy prices did not have any significant impact on CE in our sample of Russian SMEs, perhaps due to the fact that energy prices in Russia are lower in comparison with Western countries and very few SMEs are preoccupied with this factor in Russia at the moment while doing their daily business.

5. Discussion of Results

We have already shown that SMEs are a backbone of the economy and can become the key players in steering it towards the more circular models. Our study focused on the case study of Russian SMEs in order to characterize the tools, opportunities, and challenges that influence successful transitions to CE and ensures its full support and development.

Within this context, special emphasis should be placed on energy efficiency whenever the circular economy is implemented. Increasing the energy efficiency using sustainable energy resources is crucial for the sustainable development of economies worldwide. Renewable energy resources are more efficient and cost-effective, particularly when it comes to increasing energy prices and greenhouse effects. SMEs can also tackle at least half of the world's greenhouse gas emissions by changing how they manufacture and use products. They can optimize their products and solution designs for greater energy efficiency and lower emissions, as well as reducing their packaging footprint—transitioning to a circular economy is at the heart of this effort.

Circular business models are proven to be a smart corporate strategy that promotes access to new markets, drives innovation solutions, and reduces manufacturing costs. In addition, they clarify the rationale for how organizations create, offer, and deliver value, minimizing environmental and social costs. In can be seen that CE developed the core elements framework which includes the enabling elements and practical examples to assist interventions at every level in creating conditions and eliminating barriers for circular transformation. Thence, intense research efforts must focus on balancing resource use, the integration of renewable energy systems, effective energy conversion technologies, effective integration of processes, and efficient technologies for the implementation of the circular economy structure. Using digital, online platforms and technologies that offer insights for monitoring and optimizing resource usage, strengthening connections among actors in the supply chain, and enabling implementation of circular models might be of a great help. Smart grid systems that improve electricity distribution efficiency while considering energy resource degradation and modern communications technology can also play an important role in enhancing CE activities. More efficient communications may

result in significant savings in resources and help SMEs in the implementation of CE for their business activities.

The CE criteria should include the environmental and social footprint, and security of the supply of resources with an emphasis on energy. The conventional approaches for the evaluation of energy efficiency programs for electricity utilities and for the smart grid, and the agent-based end-use modelling strategy which addresses several shortcomings of the earlier methods, need to be reviewed. Evaluations from a CE perspective may yield valuable insights for the SMEs to evaluate adopted technologies in terms of their circularity and to better manage their resources. This would have important implications for the energy management and process optimization as well as the innovative solutions and technologies leading to the increased efficiency and resilience in industrial systems. In addition to reducing waste, the CE innovations can optimize the use of resources and enhance public health as well as promote well-being in the long run.

6. Conclusions and Implications

All in all, our paper offers some interesting research findings on the relationships found between smart technologies, circular economy practices, and organizational effectiveness and innovativeness in Russian SMEs during the turbulent post-COVID era marked by the upheaval of the energy markets and issues with the global supply chains.

Our results reveal that investments into R&D, either using companies' own profits or obtaining grants from the regional or central governments, can significantly foster the proficiency in CE activities and lead to the better use of materials and energy. Combined with the ongoing increasing awareness of CE principles and SDGs, the circular economy could assist the energy and utilities sectors to efficiently address the chronic challenges associated with improving efficiency and decreasing demand for scarce, untapped resources not only in Russia but also all around the world.

In addition, it becomes clear that relevant stakeholders and policymakers must ensure that they are fully aware of recent developments in the digital world and its novel approaches to production and recycling, such as the CE approach in SMEs. As explored throughout this paper, it is impossible to predict with confidence how specific digital technologies will interplay with particular applications in the energy system, particularly in complex real-world situations involving multiple policy objectives and uncertain feedbacks. Novel digital technologies are needed to be integrated with human staff, processes, and governance infrastructures, but they will also affect the ways each production process should be redesigned. Solutions should incorporate features that help to digitize an entire production process, and this is where digital technologies can be leveraged to maximize effectiveness. Digital transformation of the supply chain within the CE allows for better communication using digital technologies such as production portals. This is because digital supply chain management benefits from increased visibility, better communications, stronger analytics, and better relationships–all things that can help manufacturers and supply chain partners get things done more efficiently. By helping with digital economics and digital industrial transformation, they enhance network effects for communications services, which benefits energy systems and increases energy efficiency in SMEs. Network infrastructure, the development of communications services, development of information technology industries, and innovations in digital technologies all positively contribute in different degrees towards energy efficiency. Our findings revealed that investing into R&D and implementing the digital and information technologies had a number of positive impacts in developing CE practices in SMEs. Digitization may bring about transformative changes in SMEs aspiring to operate on the principles of CE and the growth of digital economy is beneficial for upgrading industrial structures which are responsible for nurturing new technologies, new forms of businesses, new models, and new industries for improving energy efficiency.

Therefore, we argue that business companies run the risk of digitalizing current processes, instead of radically changing supply chain operations, by adopting the new

technologies without making changes in the operational systems, thinking, and managerial infrastructure. This can ensure the unobstructed flow of information throughout value chains, with insights that drive faster decisions. Moreover, SMEs (in Russia and beyond) need to become more open to business competition and new markets if they want to realize the potential of the services they are sharing through digital transformation. In their turn, the governments should aim to ensure that policies and platforms aimed at the delivery of digital energy are available (for instance, regarding the role of smart meters or other energy management systems) so that different companies can compete to come up with new business models and serve consumers better.

Our findings suggest that the digital transformation of SMEs with an aim to implement the CE is a major constituent for improving the resilience of supply chains, as well as a major pathway to improving their resilience suggesting the adoption of digital technologies in manufacturing enterprises for improving risk-response capacity and the resilience of supply chains. Nevertheless, even though an enterprise's R&D intensity might be low, and the R&D spending might be insufficient, achieving higher supply chain resilience can occur for large companies that have a relatively high level of digital transformation. Here is where the potential or benefits of digital twins lies.

As far as the policy implications of our study are concerned, we think that the stakeholders interested in the creation of the green transition and CE in SMEs should promote sharing the experiences of effective approaches for supporting a circular supply chain and finding practical solutions and investment policies. Most importantly, they can create some international platforms for fostering international collaboration for developing CE projects thereby contributing to the circular global value chains. Sharing the experience (e.g., through mutual learning programs (MLPs)) on how CE activities can be supported in SMEs and how to better select those SMEs who would become the champions in CE implementation also constitutes a useful initiative that can bear some fruit.

When it comes to the pathways for further research, it might be interesting to compare our results with those from the EU and the United States using the same methodology and SMEs from similar industries. It might be that some other factors (such as energy prices or the relevance of energy saving and energy efficiency) would emerge in those SMEs. In addition, it might be interesting to further explore the possibilities of financing SME activities in the field of CE via private sources, such as, for example, crowdfunding platforms. It would also be interesting to explore whether the CE activities would be implemented at all if the governmental funds were lacking. In the face of the rising economic uncertainties and energy prices in the world, CE faces some serious challenges that need to be properly tackled by the relevant players on the market.

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