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Industry 4.0 technologies as enablers of sustainability risk management

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Abstract

Motivation: Companies operate in a volatile, uncertain, complex, and ambiguous (VUCA) business environment, as evidenced by massive collapses in commodity prices, acts of terrorism, cyber security threats, natural disasters, technological failures, and pandemics. Numerous reports indicate that the top risks with the highest probability of occurrence in the next decade include extreme weather events, failure of climate protection measures, and man-made environmental damage (*The Global Risk Report 2021* of the World Economic Forum, The World Business Council for Sustainable Development report and many others). The UN Sustainable Development Goals (SDGs) cover the above challenges and define the agenda for solving them to 2030. The intensification of environmental and social risks reinforces the need to deepen research and explore new ways of managing

sustainability risks (SRs). At the same time, businesses are undergoing the technology transformation (Industry 4.0) accelerated by the COVID-19 pandemic. It became necessary to shift some investment to this business area, which also needs to be supported by additional capital. The technology-driven transformation can significantly support companies in managing SRs.

Aim: The aim of the study is to diagnose the importance of investments in Industry 4.0 technologies (T4.0) as potential enablers supporting sustainability risk management from the perspective of supply chains.

Results: SRs represent one of the critical risk areas of the 21st century. Despite the well-recognized potential of the T4.0 implementation for sustainable supply chain management, the research studies concentrated on their potential role within SR management in international supply chains are limited and fragmented. The diagnosis of the growing importance of T4.0 supporting risk management at strategic and operational levels of business activities implies the recommendation to integrate their use in this area into the technological transformation, and then consistently into planning and financing of development and implementation projects. Companies may attempt to address these challenges through Environmental, Social, and Governance (ESG) initiatives.

Keywords: risk management; sustainability risk; corporate investment; Industry 4.0 technologies; supply chain

JEL: G320; L210; M160; O390

1. Introduction

Operating in a Volatile, Uncertain, Complex, Ambiguous (VUCA) business environment is a challenge for all business participants at both local and global levels. The manifestations of the pervasive and increasing intensity of VUCA conditions can be seen in many dimensions — the massive collapse of commodity prices, acts of terrorism, cyber security threats, natural disasters, technological failures, and pandemics. The World Economic Forum (WEF, 2021, p. 12; Turek & Rogowski, 2021) identified the most important global risks in five categories: economic, environmental, geopolitical, social, and technological. The risks with the highest probability of occurrence over the next ten years include extreme weather events, failure of climate action, and man-made environmental damage as well as the concentration of digital power, digital inequality, and cybersecurity failure. Among the risks with the greatest impact over the next decade, infectious diseases rank first, followed by failure of climate action and other environmental risks, the proliferation of weapons of mass destruction, livelihood crises, debt crises, and IT infrastructure failures. There is a need for a flexible, integrated risk management (RM) system, both at the company level and by national governments and, at the international level. There is a need to pay attention to and find more effective ways of identifying, categorizing, quantifying, mitigating, and communicating new risks to decision-makers, including sustainability risks (SRs). The WEF has identified sustainability risk management (SRM) as a key imperative for the transformation of economies,

societies, and ecosystems at the macro level, as well as business models, processes, and relationships at the micro level.

A supply chain management (SCM) perspective is the key to transforming business models, processes, and relationships through the lens of SRM in the 21st-century global network economy. The competition between supply chains (SCs) in the VUCA business environment plays out in the field of RM excellence, which is the art of exploiting opportunities and neutralizing threats by configuring and reconfiguring structures, processes, and relationships. The challenges for risk managers become greater with the more complex structures and multi-level linkages between the entities in international SCs as well as with various stakeholders. In the continuum of efforts to meet sustainability requirements, SCM strategies and models are evolving. On the one hand, the achievements of the discipline of management and quality science in terms of research on sustainable, green, closed, or circular SCM concepts are significant, providing above all conclusions on their essence, elements, and effects. On the other hand, it deals only marginally with the design, implementation, and improvement of a flexible, integrated SRM system in international SCs for the challenges of the 21st century.

Furthermore, the intensification of external environmental and social risks reinforces the need to deepen research and explore new ways of managing SRs. The conditions of the COVID-19 pandemic verify the ability of companies to manage risks in international SCs, providing a kind of "litmus test" of the effectiveness of assumptions and standards in this area. Researchers on the issue of SRM emphasize the continuation of its rise to prominence after the pandemic. The recommendation of greater attention to SRM in the activities of enterprises comes in the era of digital transformation of SCs, currently determined by the Industry 4.0 technologies (T4.0) (in the future Industry 5.0) as well as regulations at the European level resulting from The European Green Deal (European Commission, 2021) and concerning nonfinancial reporting. Based on the literature review, a high potential of T4.0 for use in SRM in the perspective of SCs was diagnosed, but at the same time, the level of adaptation of these technologies in business practice and their impact on this area of management has not been sufficiently recognized by researchers so far.

In view of the above, the main aim of the article is to diagnose the importance of investments in Industry 4.0 technologies as potential enablers supporting sustainability risk management from the perspective of supply chains. To achieve this goal, the authors applied the research procedure covering four phases and used the following methods: literature review, pilot survey, semi-structured individual in-depth interview and survey research based on CATI method. However, the article content is mainly focused on the results and conclusions on the basis of the survey research carried out among 120 trade and manufacturing enterprises listed in the WIG index on the Warsaw Stock Exchange. The scope of the research study refers to the main technologies of Industry 4.0, such as additive manufacturing, artificial intelligence, block-

chain, Big Data analytics, cloud computing, the Internet of Things, and technology platforms. Considering sustainability risk, the following types of risk are considered: economic, social and environmental referring to the sustainable development, and internal (endogenous) or external (exogenous) because of the origin — within the supply chain or in its business environment.

The article is structured as follows. Section 2 provides a theoretical background regarding sustainability risk definition and its types, the significance, stages, and strategies of SRM as well as the contemporary technology-driven transformation of this business area. Section 3 presents the research procedure conducted by the article authors as a part of the statutory research in the Collegium of Business Administration at SGH Warsaw School of Economics in 2020–2021. Next, section 4 is focused on the research results in order to investigate the types and extent of the T4.0 application in supply chain sustainability risk management (SCSRM). Finally, section 5 presents the key conclusions and implications.

2. Literature review

There are several definitions of sustainability risk functioning among business practitioners and scholars as well. The Federation of European Risk Management Associations (FERMA, 2021) defines sustainability risk as "Uncertain social or environmental event or condition that, if it occurs, can cause a significant negative impact on the company. It also includes the opportunity that may be available to an organization because of changing social or environmental factors". Another definition proposed by Swiss Reinsurance Company (2012) characterizes sustainability risks as "ethical concerns related to environmental and socio-economic impacts of our business transactions and the reputational risks they may entail". There are also definitions of sustainability risk focusing on its negative aspect solely (Palousis et al., 2010; Tang et al., 2018). Based on the results of the literature review, the authors of the article identified and categorized sustainability risk types considering the source of the risk and the dimensions of the Triple Bottom Line concept: economic, social, and environmental. These three categories of sustainability risk may have an internal (endogenous) origin — with its source within the SC and an external (exogenous) origin — with its source in the SC environment. The adopted classification of risk types in the context of sustainable development is in line with the categorizations proposed in the literature, e.g. by Busse et al. (2017), Giannakis and Papadopoulos (2016), and Xu et al. (2019). In this regard, the authors of the article define sustainability risk as the possibility of deviation from the economic, social and environmental value expected by stakeholders.

Scientific publications address the issue of SRM mainly in relation to sustainable SC development (Giannakis & Papadopoulos, 2016; Ocicka & Turek, 2021; Sutrisno & Kumar, 2022), product development process (Palousis et al., 2010), or project management process (Bai et al., 2017). The currently avail-

able literature, therefore, does not cover many relevant issues, i.e. the adoption of T4.0 (additive manufacturing, artificial intelligence, Big Data analytics, Blockchain, cloud computing, digital platforms, Internet of Things) in the SRM process. The literature is dominated by exploratory research on the potential of using T4.0, primarily in the general context of SC management, and by the research on sustainability risk in adopting the Industry 4.0 concept (Beier et al., 2017; Nowicka, 2020; Pasi et al., 2022; Witkowski, 2017). At the same time, the existing body of work in the social sciences is very limited regarding the issue of recognizing the impact of T4.0 application on SRM.

The RM function is currently undergoing an evolutionary process toward digitization, in line with the requirements of Industry 4.0, towards sustainability, and towards the Enterprise Risk Management (ERM) concept. Companies are in the process of transforming RM function from silo-based towards integrated, holistic, disciplined, and top-down approach (Abdul Razak et al., 2020; Johnston & Soileau, 2020) based on the four fundamental stages: risk identification, risk analysis, risk strategies and implementation, risk monitoring (COSO, 2004; Lachapelle & Hundozi, 2015) and the idea of dual nature of risk (positive and negative risk) (Shaheen et al., 2020). Additionally, considering the opportunities offered by digital transformation, T4.0 may help companies to implement RM strategies (i.e. reducing the probability of risk, reducing the impact of risks, risk sharing or transfer, risk avoidance, risk acceptance, or ignoring the risk) more effectively and accurately resulting in more informed decisions (FERMA, 2019).

Understanding the evolution of the RM process requires a multi-level approach: a macro perspective (e.g. the emergence of new sources of risk on a global scale, such as climate change), a mezo perspective (development of modern technologies, the transformation of societies towards sustainable development) and a micro perspective (e.g. the need to maintain competitiveness) (Schulte et al., 2020). The SRM process is a response to the described evolutionary process and to new challenges emerging from a constantly changing environment (Schulte & Hallstedt, 2017). Various economic, environmental, geopolitical, social, and technological disasters and crises are expected to become more frequent in the future, with increasingly severe economic, social and medical consequences (WEF, 2021). For example, the materialization of the risk of a pandemic has created profound uncertainty in human health and economic health around the world.

Multiple challenges regarding sustainable development are emerging, including above-mentioned COVID-19 pandemic. They not only reveal the lack of business operations resilience but also the imbalance between short-term and long-term business profitability (Høgevold et al., 2014; Schulte & Hallstedt, 2017). Enterprises need to develop the capacity to systematically identify and strategically manage the risk to adapt to frequently changing conditions. At the same time, society undergoes a transformation towards sustainability, and it requires a transformation of companies on many levels, including the in-

tegration of sustainability aspects into the RM process (Schulte & Hallstedt, 2017). By integrating sustainability into RM, enterprises address also the direct interests of many stakeholders lowering the potential of conflict (Lenssen et al., 2014). The support of T4.0 within the SRM process will help companies to adjust business operations and achieve long-term objectives (Lenssen et al., 2014).

3. Methods

In order to develop high-quality research, the authors of the article used a methodological triangulation: a literature review, a quantitative survey, and an individual in-depth interview. The research procedure included the four stages presented in Scheme 1 and was conducted in the period from December 2020 to October 2021. In phase 1, the literature review covered the following topics: (1) technologies 4.0 (T4.0), specifically blockchain, Big Data analytics, internet of things, cloud computing, artificial intelligence, additive manufacturing (3D printing) and technology platforms, (2) use of T4.0 in risk management, (3) sustainable supply chain. The conclusions carried out from the literature review made it possible to move on to phase 2. The purpose of the pilot survey was to investigate the extent to which T4.0 might be implemented and how it may affect SCSRM. The pilot study contributed to the development of knowledge and provided valuable lessons for the survey carried out in phase 4. In phase 3, the authors conducted a semi-structured individual in-depth interview (IDI) with a senior SC manager representing a global company competing in the life science industry. The IDI was conducted in January 2021. Based on the findings, a qualitative case study was developed to analyse the role of T4.0, especially technological platforms, for SCSRM in detail (Ocicka & Turek, 2021). The authors gained access to unique information and data consistent with the research topic. This in-depth interview (IDI) helped the authors to formulate the questions for the purpose of the quantitative research survey carried out in the last phase.

The phase 4 of the research procedure was conducted in September and October 2021. The Authors commissioned the study to be carried out by an external entity — the CBM Indicator in Warsaw. The research sample included 120 enterprises listed in the WIG index on the Warsaw Stock Exchange, operating in manufacturing as well as distribution sectors and meeting the following two criteria: 1) international SCs management and 2) implementation of T4.0 supporting risk management during the last 5 years. The CATI (Computer-Assisted Telephone Interviewing) research technique was used for the purpose of the study. This method was selected mainly to provide remote contact for conducting interviews with high-level managers in a flexible and safe manner during the COVID-19 pandemic. The survey questionnaire included 2 filter questions consistent with the above-mentioned criteria for purposive selection of companies, 16 specific questions related to the scope of application and impact of T4.0 on SCSRM, and 14 questions in a metric on the respondents' pro-

fessional profile, type of core business activity and role of companies in SCs, as well as their financial performance. The respondents represented the following groups of professionals: chairman, board member, managing director of the company, director/manager/management level employee in risk management, finance management or SC management. The main results of phase 4 are presented in the next section of the article.

4. Research results on the T4.0 application in SCSRM

The surveyed enterprises have implemented cloud computing (61.7%), Big Data analytics (21.7%), 3D printing (21.7%), the Internet of Things (13.3%), artificial intelligence (9.2%), technology platforms (6.7%) and Blockchain (4.2%) in the last five years (Table 1). The results of the empirical research revealed the strategic importance of T4.0 in the activity of enterprises, as evidenced by the summed percentages of respondents' answers "I agree" or "I strongly agree" to the statements about achieving strategic goals (81.6%) and building competitive advantage (82.5%) as the final effects of their implementation. Respondents also positively assessed the importance of technology in the operational activities of enterprises. The vast majority declared that the implementation of T4.0 was successful (88.4%), bringing benefits to enterprises (89.2%) and providing a rationale for investment in development and further technological improvement (60.9%).

In the survey, 85% of respondents confirmed that the T4.0 implementation enhanced supply chain risk management capacity. The dominant rating of the extent to which T4.0 supported the management of sustainability risk is a rating of 4 — at the ‚high' level on a scale of 1 to 5. The dominant rating remains at the same level in the evaluation of the impact of T4.0 on the management of internal and external economic, social and environmental risks (Table 2). Furthermore, based on the percentage of "agree" and "strongly agree" responses, it was also confirmed that the implementation of T4.0 to support sustainable risk management in the SC increased the ability of the surveyed companies to manage operational (90.9%), reputational (90.9%), financial (93.4%), investment (90%) and market (90%) risks.

The results of the empirical study confirmed the potential of different T4.0 applications in SCSRM and the possibility of continuing research on their implementation projects and effects from the SC management perspective. Respondents in the survey indicated that additive manufacturing, artificial intelligence, Blockchain, Big Data analytics, cloud computing, the Internet of Things, and technology platforms support the different stages of SRM in the SC to a high or very high degree (Table 3).

The results of the study also allow investigation that T4.0 predominantly support the implementation of SRM strategies in the SC to a high degree, with no significant differences noted for their respective types (Table 4).

More than 70% of the respondents declared that T4.0 implementation has become one of the priorities in the COVID-19 pandemic. Respondents' assessment of the importance of the role of T4.0 for increasing supply chain disruption risk management capacity during the COVID-19 pandemic was not consistent, namely, 22.5% of the respondents expressed "disagree", 63.3% "agree" or "strongly agree", 14.2% had no opinion. Based on the results of the survey, the assessment of the impact of the COVID-19 pandemic on increasing investment in T4.0 implementation projects was not clearly resolved, with 48.3% of respondents confirming this impact and 51.7% not confirming this impact. It can be concluded that numerous of the surveyed entities had previously planned investments in cutting-edge technologies and the COVID-19 pandemic crisis triggered changes in the prioritization of their deployment objectives, increasing the importance of risk management.

The companies participating in the study, considering their place in the supply chain, are primarily producers of finished products (38%), first-tier suppliers (32%), 2nd or further-tier suppliers (13%), distributors–wholesalers (10%), distributor–retailers (8%). Taking into account the type of activity, the research sample is dominated by enterprises operating in Section C of the PKD (Polish Classification of Activities) — industrial processing and they constitute 66.7% of the surveyed entities. 22.5% are enterprises from Section G of the PKD — wholesale and retail. The remaining enterprises account for 10.8% of entities in the research sample. During statistical analyzes, no similarities were identified in groups of enterprises with the same profile of activity at the level of statistical tendency.

5. Conclusions and implications

Industry 4.0 technologies are becoming an integral element in the management of enterprises at strategic and operational levels, gradually gaining importance as a factor increasingly influencing their competitive advantage. The research findings reflect that the enterprise risk management function is undergoing an evolutionary process toward digitization and the level of investment in the technological transformation of SCSRM is now increasing in business practice. All T4.0 were identified by the majority of respondents as technologies that supported to a high or very high degree the management of economic, social and environmental risks both within and around the supply chain. In conclusion, the results of the empirical study reinforced the theoretical and cognitive needs in the social sciences, in particular the disciplines of management and quality sciences, economics and finance, in terms of developing sustainable risk management strategies and concepts to meet the challenges of the 21st century, considering the importance of technological transformation. Further research is also required on SRM reporting.

Moreover, the results of the conducted research have practical implications. Technologies 4.0 represent the required potential for the development of flex-

ible and integrated SRM, but their adaptation to the needs of this area in Polish enterprises and their supply chains is still at an early stage of application. Industry 4.0 technologies as the foundation of the technology megatrend, are changing the nature of enterprise operations and supply chain management in the VUCA business environment in the 2nd and 3rd decades of the 21st century. The diagnosis of the growing importance of T4.0 in risk management at strategic and operational levels of business activities implies the recommendation to integrate their use in this area, and then consistently into the planning and financing of development and implementation projects. The significant potential is represented by individual 4.0 technologies, and the desired synergy effects are created by both the integration of various technologies and the cooperation of enterprises in their implementations. An integrated and relational approach to the exploitation of 4.0. technologies potential in risk management is therefore postulated.

The diagnosis of the high importance of T4.0 in the context of sustainable development and in the implementation of sustainability risk management strategies determines the postulate for the development of performance reporting in this area of management. Reporting on meeting environmental, social, and corporate governance (ESG) criteria are currently used by companies included in the WIG-ESG index on the Warsaw Stock Exchange. It is worth emphasizing that in view of megatrends in a volatile, uncertain, complex, and ambiguous business environment, it is desirable to focus reporting more on risk management. The increasing role of SRM determines the necessity to develop managerial competencies responding to the challenge of exploiting opportunities and neutralizing threats in companies' activities in this area.

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Appendix

Table 1.
Implementation of technologies 4.0 in supply chain management

Technology	Indications		Percentage (N=120)
	Number	Percentage	
additive manufacturing	26	15.7	21.7
artificial intelligence	11	6.6	9.2
blockchain	5	3.0	4.2
big data analytics	26	15.7	21.7
cloud computing	74	44.6	61.7
internet of things	16	9.6	13.3
technology platforms	8	4.8	6.7
total	166	100.0	138.5*

Note:

* The value exceeds 100%, because the respondent could choose more than one technology.

Source: Own preparation.

Table 2.
Assessment of the importance of T4.0 in SCSRM depending on the type of risk

Type of risk	Percentage of indications*				
	1	2	3	4	5
internal economic risk	0.0	0.0	10.0	69.2	20.8
external economic risk	0.0	0.0	10.8	72.5	16.7
internal social risk	0.0	0.0	9.2	76.6	14.2
external social risk	0.0	0.0	10.0	70.0	20.0
internal environmental risk	0.0	0.8	11.7	67.5	20.0
external environmental risk	0.0	0.8	10.0	70.9	18.3

Note:

* Likert scale: 1 — neutral, 2 — low, 3 — moderate, 4 — high, 5 — very high.

Source: Own preparation.

Table 3.
Assessment of the impact of T4.0 on the stages of SCSRM

Stage of SCSRM	Percentage of indications*				
	1	2	3	4	5
risk identification	0.0	0.8	14.2	71.7	13.3
risk measurement and assessment	0.0	0.8	19.2	65.0	15.0
selection of the risk control method (strategy) and its implementation	0.0	0.8	16.7	71.7	10.8
monitoring and evaluation of the effectiveness of the method used	0.0	0.0	15.8	74.2	10.0

Note:

* Likert scale: 1 — very low, 2 — low, 3 — moderate, 4 — high, 5 — very high.

Source: Own preparation.

Table 4.
Assessment of the T4.0 importance in the implementation of SCSRM strategies

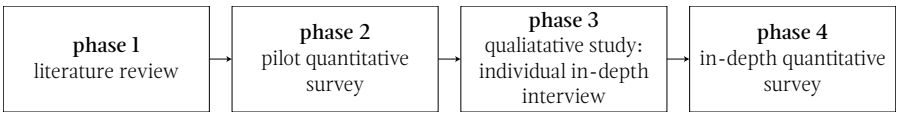
Type of risk	Percentage of indications*				
	1	2	3	4	5
internal economic risk	0.0	0.0	10.0	69.2	20.8
external economic risk	0.0	0.0	10.8	72.5	16.7
internal social risk	0.0	0.0	9.2	76.6	14.2
external social risk	0.0	0.0	10.0	70.0	20.0
internal environmental risk	0.0	0.8	11.7	67.5	20.0
external environmental risk	0.0	0.8	10.0	70.9	18.3

Note:

* Likert scale: 1 — neutral, 2 — low, 3 — moderate, 4 — high, 5 — very high.

Source: Own preparation.

Scheme 1.
Phases of the research procedure



Source: Own preparation.