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INDUSTRY 4.0: DIGITALIZATION AND SUSTAINABILITY OPPORTUNITIES

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ABSTRACT

The fourth industrial revolution and the underlying digital transformation, known as Industry 4.0, is progressing exponentially. The digital revolution is reshaping the way individuals live and work fundamentally, and the public remains optimistic regarding the opportunities Industry 4.0 may offer for sustainability. The present study contributes to the sustainability literature by systematically identifying the sustainability functions of Industry 4.0. In doing so, the study first reviews the fundamental design principles and technology trends of Industry 4.0 and introduces the architectural design of Industry 4.0. The study further draws on the interpretive structural modeling technique to model the contextual relationships among the Industry 4.0 sustainability functions. Results indicate that sophisticated precedence relationships exist among various sustainability functions of Industry 4.0. 'Matrice d'Impacts Croisés Multiplication Appliquée àun Classement' (MICMAC) analysis reveals that economic sustainability functions such as production efficiency and business model innovation tend to be the more immediate outcome of Industry 4.0, which pays the way for development of more remote socio environmental sustainability functions of Industry 4 together with energy sustainability, harmful emission reduction, and social welfare improvement. This take a look at can serve industry 4.0 stakeholders – leaders within the public and private sectors, industrialists, and academicians – to better apprehend the possibilities that the digital revolution may additionally offer for sustainability, and paintings together extra closely to ensure that enterprise four.0 delivers the intended sustainability functions round the world as efficaciously, equally, and fairly as possible.

Keywords: Industry 4.0; Smart Manufacturing; Digitization; Sustainability; Environmentalism; Industrial Internet.

I. INTRODUCTION

At the dawn of the 21st century, the world is witnessing the fourth industrial revolution and the digital transformation of the business world, which is commonly referred to as Industry 4.0. The fourth industrial revolution is a hit rather than hype (Ardito et al., 2019; Buer et al., 2018; Schroeder et al., 2019). Since the publicisation of the term "Industrie 4.0" in 2011, the digital transformation necessitated by Industry 4.0 immediately captured the attention of industrialists and governments worldwide (Ghobakhloo, 2018; Nascimento et al., 2019). Since the first industrial revolution in 18th century, the world has been dealing with the challenge of producing more goods from limited and depleting natural resources to meet the ever-growing consumption demand while limiting negative environmental and social impacts (Beier et al., 2018; Müller et al., 2018a).

Consistently, the sustainability impacts of Industry 4.0 and the way it can contribute to the sustainable economic, environmental, and social development is increasingly gaining attention. Sustainability is a broad concept addressing most aspects of the human world (Beier et al., 2017). Sustainability is not limited to the environmentalism, as it also involves preserving economic and social resources (Choi and Ng, 2011; Ford and Despeisse, 2016). United Nations defines sustainability as a movement for ensuring a better and more sustainable wellbeing for all, including the future generations, which aims to address the everlasting global issues of injustice, inequality, peace, climate change, pollution, and environmental degradation. Although sustainability is a relatively new concept, however, its roots are in the enduring movements such as conservationism or socio-economic justice (Caradonna, 2014). Sustainability has a rich literature, and academia has made a significant contribution to the conceptualization and materialization of its three underlying pillars of environmental, economic, and social sustainability (Ford and Despeisse, 2016; Kamble et al., 2018; Khuntia et al., 2018). Environmental sustainability is mainly concerned with maintaining the earth's environmental systems equilibrium, the balance of natural resources consumption and replenishment, and ecological integrity (Glavič and Lukman, 2007). Economic sustainability concerns long-term economic growth while preserving environmental and social resources. Viewed from this perspective, the growth of economic capital should not be at the expense of the decrease in natural or social capital. Thus, economic growth should not ignore the balance in natural resources, ecosystems, social welfare, and distribution of wealth (Choi and Ng, 2011). Social sustainability is the process of recognizing and managing the positive and negative business, environmental, economic, and technological impacts on people. Social sustainability ultimate goal is the creation of healthy and liveable communities where everyone is protected from discrimination and has access to universal human rights and basic amenities such as security or healthcare (Dempsey et al., 2011). Sustainability is indispensable because of a simple reason; Earth's ecosystems and the desired quality of humankind's life cannot be maintained without human beings embracing sustainability (Caradonna, 2014; Glavič and Lukman, 2007). Consistently, the sustainability impacts of Industry 4.0 merit the full attention of academia given preceding industrial revolutions resulted in dramatic and somewhat unexpected economic, environmental, and social changes. Despite being in its infancy, the unforeseen or unintended consequences of Industry 4.0 and digital transformation on triple bottom line sustainability are expected to be consequential (Jabbour et al., 2018a; Kamble et al., 2018).

In the Industry 4.0 environment, the interconnected computers, smart materials, and intelligent machines communicate with one another, interact with the environment, and eventually make decisions with minimal human involvement (Gilchrist, 2016). The digital connectedness and information development and sharing, as the true power of Industry 4.0, may have contradictory impacts on triple bottom line (economic, environmental, and social) sustainability (Jabbour et al., 2018 a, b; Kamble et al., 2019; Müller et al., 2018b). Digitizing manufacturing and business processes and deploying smarter machines and devices may offer numerous advantages such as manufacturing productivity, resource efficiency, and waste reduction (Tortorella and Fettermann, 2018). In contrast, an increased rate of production thanks to industrial automation would be associated with higher resource and energy consumption as well as elevated pollution concerns (Beier et al., 2017; Liu and Bae, 2018). Viewed from the social development perspective, digital transformation and the restructuring of the industry are expected to disrupt the labour market severely. Experts believe digitization and the emergence of labour-saving technologies (e.g., intelligent robots, autonomous vehicles, and cloud solutions) will eliminate the majority of lower-skilled jobs while creating countless job opportunities in various areas such as automation engineering control system design, machine learning, and software engineering (Brougham and Haar, 2018; Frey and Osborne,2017).

The research on the sustainability impact of the fourth industrial revolution is in its nascence, and the sustainability implications of Industry 4.0 in terms of economic, environmental, and social impacts of manufacturing digitization requires further exploration. The present study addresses this issue by modelling the process through which Industry 4.0 - characterized by its underlying digital technologies and design principles – can positively contribute to sustainable economic, environmental, and social development. Therefore, the study first offers a concise discussion on the concept of Industry 4.0 phenomenon and its functionalities. The study further employs Interpretive Structural Modelling (ISM) to identify Industry 4.0 functions for sustainability. In doing so, the study first performs a state-of-the-art content-driven review and analysis of the literature to identify the critical sustainability functions of Industry 4.0.

How is Industry 4.0 Technology Impacting the Manufacturing Industry?

In manufacturing, Industry 4.0 has widespread repercussions. It's used to leverage operational efficiency, refine demand forecasting, break down data silos, engage in predictive maintenance, offer workers boosts to safety and virtual training, and more. Industry 4.0, as part of a wider concept termed digital transformation, spans manufacturing from planning to delivery, with solutions for deep analytics, shop floor data sensors, smart warehouses, simulated changes, plus product and asset tracking.

For manufacturers, Industry 4.0 technologies help to bridge the gap between what were once separate processes to a more transparent, visible view across the entire organization, with plenty of actionable insights.

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Real-World Industry 4.0 Technologies

Below are the top digital transformations technologies brought about by Industry 4.0. Big Data & Analytics

- Autonomous Robots
- Simulation/Digital Twins
- Horizontal and Vertical Systems
- Industrial IoT (IIoT)
- Cybersecurity Technology
- The Cloud
- Additive Manufacturing
- Artificial Intelligence
- Augmented Reality

II. LITERATURE SURVEY

The research conducted was intended to throw light on the ambiguity of the I4.0 impact on CI. As explained by Saunders et al. (2019), an exploratory research design is especially useful when it aims to clarify and deepen understanding an issue, event or problem; especially if the nature of the research topic akucaci (Saunders, et al., 2019, p. 186). Therefore, due to the newness of the title and also because I4.0 called the key to its achievement, studies aimed at investigating the impact of I4.0 acquisition on it management processes can only check as opposed to descriptive or descriptive. Kumongo for this study, the test status is highlighted in the study questions, R1, R2 and R3 (section 1.3) and the selected Delphi research data collection method as well which includes open-ended questions. In addition, the theme data analysis strategy has been received when processing data collected. This means that categories and themes existed identified during the processing of collected quality data. Theme analysis is both systematic and flexible and helps to identify themes and patterns for continuity to check; is particularly useful in the development of theoretical research (Saunders, et al., 2019, p. 651).

III. METHODOLOGY

Using the Delphi method, respondents responded to several rounds of questioners and group responses each round is compiled and a response to each respondent before answering the following round of the questioner. Respondents were carefully selected based on their expert knowledge study area. The intended result is that the group effect is more accurate in comparison a pure collection of individual ideas. Julsrud and Priya Uteng echo this sentiment: ―The process can be he said they have a basis for the idea that several brains are better than one, especially in areas with high level of difficulty and uncertainty ‖(Julsrud & Priya Uteng, 2015).

IV. DATA COLLECTION

The data has been collected through Delphi survey method, as described in the previous section. The survey consisted of three open-ended questions for the first iteration and three open-ended questions for the second iteration. The first three questions have been designed as to encourage participants to reason around both the potential positive and negative aspects of I4.0 impact on CI.

1.	Create three open questions for the first multiplication survey with three participants
2.	Identify relevant stakeholders in the four different categories described in section 3.2.1.
3.	Create an email template that you use to share with the interviewer
4.	Identify at least four participants for the survey
5.	Share the first recurring question with the four participants above
6.	Prepare survey questions and email template based on feedback from the survey
7.	Share the first repetition of a query as a word file attached to a full email sample people and allow a one-week response time limit
8.	Send a reminder to non-respondents within two days and after four days

9.	Review and compile the answers provided, analyzing the collected data by reference themes in accordance with the procedure described in paragraph 3.4.
10.	Review and update the question with processed data from the first iteration with three follow-up questions (Appendix D)
11.	Share integrated responses from initial repetitions with people and second repeated questions (Appendix E)
12.	Send reminders to unresponsive people within two days and after four days
13.	Review and integrate the answers provided, analyzing the collected data by reference spaces and themes
14.	Decide based on the answer if a third cycle is needed or if there is another depth interview required by anyone
15.	Move into analysis and discussion phase

In order to establish a high content validity, i.e., an adequate coverage of the research questions through the Delphi survey, careful formulation of the survey questions have been made using feedback from three stakeholders with experience from CI and I4.0. Moreover, the survey was piloted by four participants to identify and correct any unclarities.

V. RESULTS AND DISCUSSION

The survey data in the form of text-strings containing participants' key points and arguments are presented in addition to the survey response information.

For the first iteration, the survey has been shared with 33 individuals resulting in 20 responses which corresponds to a response rate of 61%. Details can be seen in Table below.

	Sent	Received	Rate
GKH	12	7	58%
Volvo	12	6	50%
Light house	5	4	80%
Academics	4	3	75%
Total	33	20	50%

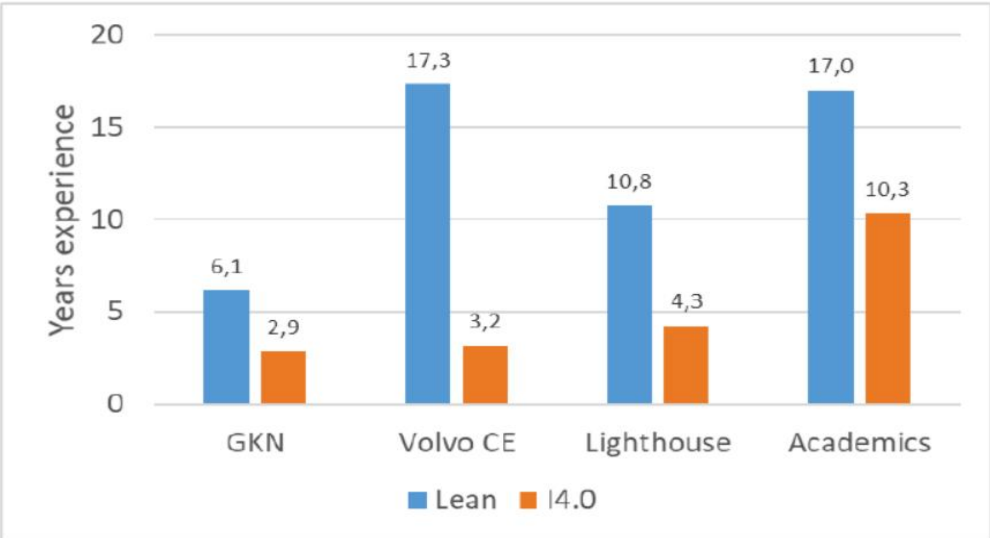

Figure 11: Number of years of experience of participants per organization.

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Below Figure shows the number of text-strings found containing the participants' positive and negative arguments for the Connectivity value driver's impact on the conditions for CI. As can be observed, 69% of the answers were identified as positive (Possibilities) and 31% as negative (Challenges and Risks). This is indicative of an overall positively weighted attitude towards the implementation of Connectivity and its impact on CI in the manufacturing environment. In total, 54 arguments have been found, 37 as positive and 17 as negative.

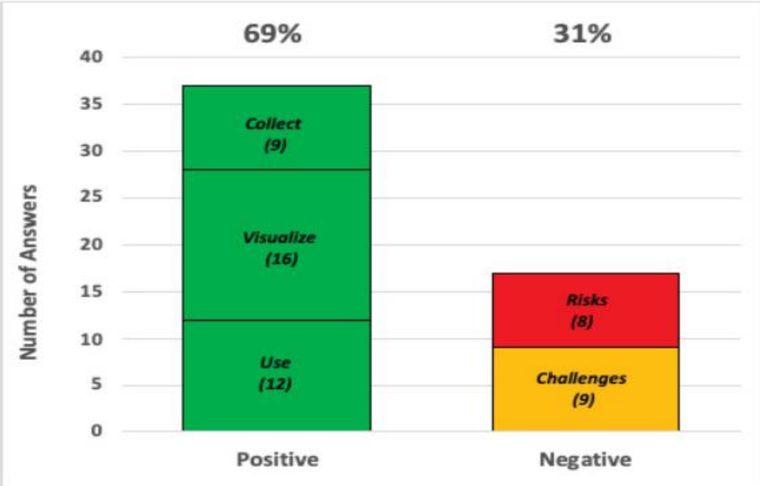

Figure 12: Summary of positive and negative input on the impact of Connectivity on CI.

For the second iteration, a second survey has been shared with the respondents of the first iteration, i.e., a total of 20 individuals. The survey can be seen in Appendix D. Responses have been received from 10 individuals resulting in a response rate of 50%

	Sent	Received	Rate
GKN	7	2	29%
Volvo CE	6	5	83%
Lighthouse	4	2	50%
Academics	3	1	33%
Total	20	10	50%

The main purpose of the second iteration has been to share the summary of the results of the first iteration.

VI. ANALYSIS AND DISCUSSION

The research questions have provided a basis for the analysis, and the findings have been compared and elaborated on in relation to the theoretical framework. The analysis and discussion are reflective of the authors own knowledge and perspective of the research findings. Therefore, the discussion should be viewed as the authors' subjective generalizations of the participants' findings concerning I4.0's Possibilities, Challenges, Risks as well as success factors. Moreover, instead of critically reviewing the content of each text-string the discussion has served as to clarify and to reason around them.

Most of the answers provided for all value drivers have been positive, 69% for Connectivity, 61% for Intelligence and 63% for Flexible automation; indicative of an overall positively weighted belief of the impacts of I4.0 on the conditions for CI. While the results are arguably a reflection of the current I4.0 hype, they also highlight the overall difficulty in critically assessing the potential impacts from technologies that have not yet made their way into manufacturing (at least not beyond the piloting scale into large-scale rollout). Moreover, in combination with I4.0's generally vague definition and its announcement before its realization, industry and academia tend to customize its definition as to constitute a salvation from the current limitations and problems associated with today's manufacturing systems, which further adds to the I4.0 hype.

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	Connectivity		Intelligence		Flexible automation	
Possibilities	69%	• Collect data • Visualize data • Use data	61 %	• Transparency • Decision support • Autonomy	63 %	• Flexibility • Automation
Challenges	17%	• Value adding • Engagement & Change	17 %	Trust & Understanding Education & Training	21 %	• Knowledge • Strategy & Standards
Risks	14%	• Digital waste • Rigidity	22 %	• Data quality & Application • Ownership & Participation	16 %	Excessive solutions • Rigidity

Summary of themes of Possibilities, Challenges and Risks derived from the value drivers' impact on the conditions for CI.

VII. CONCLUSION

This study has merely touched the surface of the numerous Possibilities, Challenges and Risks that companies can encounter on their I4.0 transformation journey in relation to CI. Future research should aim at further substantiate the findings in this study. More specifically, future research should aim at reaching a higher degree of data saturation, particularly focusing on clarifying the potential downsides of the I4.0 implementation on CI, i.e., the Challenges and Risks. Moreover, as I4.0 technologies are more widely adopted, researcher should try to quantify the Risks impact by conducting quantitative studies. The studies should preferably be longitudinal in order to capture the potential differences in CI-rates, pre and post implementation. This could be done from a more general perspective by studying the impacts from each individual I4.0 value driver, or from a more detailed perspective, e.g., on a case-to-case basis by assessing specific technologies separately or jointly.

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