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Applicability of Industry 4.0 Technologies in the Adoption of Global Reporting Initiative Standards for Achieving Sustainability

Abstract

Global reporting initiative (GRI) is the global standard of sustainability. It epitomizes the global best practice of triple bottom line, i.e., economic, environmental, and social impacts. This research is an expert-based analysis of 132 industry leaders and policymakers from 36 industries to evaluate the significance of Industry 4.0 (I4.0) technologies on GRI adoption. In the first phase, the influence of I4.0 on GRI standards is analysed using basic descriptive statistics and analysis of variance. In the second phase, the significance of the GRI standards in the context of I4.0 is evaluated using the Fuzzy Analytical Hierarchy Process (AHP). The findings indicate that 85% of environmental, 65% economic, and 50% societal GRI standards are influenced by I4.0. It is also found that the influence on economic performance, indirect economic impacts, energy, and emissions are significantly high. Findings ratify that the social aspect, which is often overlooked, needs more focus in manufacturing. Most of the contemporary research on evaluating the impact of I4.0 on sustainability is conceptual, lacks comprehensiveness, and rigor by thorough testing and validation. This study is one of the pioneering works offering a conceptual framework that aids in integrating I4.0 with GRI.

Keywords: Industry 4.0; Sustainability; Government policy; Global reporting initiative; Digitisation; Industrial internet of things.

1. Introduction

Industry 4.0 coupled with sustainability are trending themes in business and scientific research nowadays (Müller, 2020; Beier et al., 2020). The concurrent advances in the field of industrial internet of things (IIoT), advanced robotics, quantum computing, augmented reality, additive manufacturing, and nanotechnology are fashioning new-fangled business models (Morrar et al., 2017). However, there is some apprehension about whether these swift advances in technological development and digitalization positively impact society (Beier et al., 2020). I4.0 and its associated technology-dissemination movement are projected to grow significantly in terms of technological change and socio-economic influence (Kiel et al., 2017; Birkel et al., 2019).

I4.0 is exemplified by the extraordinary progression in digital technology-empowered platforms (Ghobakhloo, 2020). However, this transformation has unsettled the prevailing engineering arrangements (Dev et al., 2020). The transition to I4.0 has been complicated and multifaceted as organizations struggle to shift towards evolving technologies while clutching on to sustainability (Bag et al., 2018). So far, literature associated with I4.0 has primarily focused on technological aspects (Kiel et al., 2017). At the same time, numerous scholars have found that enhancing the environmental and social aspects of engineering value formation while ensuring economic viability is a challenging undertaking (Birkel et al., 2019; Machado et al., 2020).

Sustainability standards are a broad term that focuses on defining, monitoring, and reporting the economic, ecological, and societal aspects of organizations (Blasco and King, 2017; Calabrese et al., 2019). This can be successfully achieved by adopting various standards such as GRI, sustainability accounting standards board, carbon disclosure project, and Dow jones sustainability index (Calabrese et al., 2019). Prominent scholars have highlighted that more than 300 standards exist to measure and report sustainability (Buchholz et al., 2019; Calabrese et al., 2019).

In this study, the GRI framework of sustainability is chosen due to three reasons. First, the GRI framework is being used extensively worldwide for reporting sustainability initiatives (Marimon et al., 2012). Second, the GRI framework has been established to epitomize the best available choice for sustainability reporting by being rooted in the fundamentals of economic, ecological, and societal aspects (Simmons et al., 2018). Third, researchers have identified that the GRI framework represents a harmonized, comprehensible, standardized, and objective report for all firms worldwide (Marimon et al., 2012).

There seem to be numerous possibilities and instances of I4.0 that conflict with one or more of the triple bottom line's three facets, i.e., economic, ecological, and societal characteristics (Müller and Voigt, 2018; Bag et al., 2018; Birkel et al., 2019). Specifically, empirical investigations into I4.0, in conjunction with environmental, economic, and social facets of sustainability, are limited (Birkel et al., 2019; Kiel et al., 2017). Hence, an interdisciplinary and integrative examination of I4.0 with sustainability is required to harmonize and conjoin environmental and societal benefits with business success (Müller and Voigt, 2018). The contemporary research investigating the impact of I4.0 on sustainability is at the theoretic level and lacks rigor and comprehensiveness. The motivation for this work comes from the major research gaps, i.e., lack of empirical study investigating the impact of I4.0 on GRI standards. The swift leap of change is challenging the entire community of industry leaders, policymakers, and academia to an extraordinary degree. Thus, it is imperative to view industrial modernizations from a societal viewpoint (Birkel et al., 2019; Müller, 2020).

Industry leaders can no longer focus on expansions and trends in their sectors alone; they need to examine transformations and disruptions in the entire ecosystem of business, keeping sustainability in mind (Simmons et al., 2018; Calabrese et al., 2019). Furthermore, prominent scholars have identified the need for carrying out empirical research on the integration of sustainability with digital technologies (De Sousa et al., 2018; Kamble et al., 2018; Birkel et al., 2019; Machado et al., 2020; Beier et al., 2020). Thus, this research aims to address these issues by answering the following research questions:

RQ1. What is the impact of I4.0 technologies on the adoption of GRI standards?

RQ2. What is the significance of GRI standards in the context of I4.0?

To address the above research questions, the following are the research objectives set by the authors:

- To investigate the impact of I4.0 technologies on GRI triple-bottom-line standards.
- To determine the significance of GRI standards in the context of I4.0.

This research work is categorized as follows. The subsequent section literature review offers an overview of I4.0 technologies, sustainability, and integration between the two, to capture the research gap and finalize research objectives. This section is followed by an explanation of research methodology, expert survey, analysis of findings by ANOVA, Fuzzy AHP, and conceptual framework for assessing the impact of I4.0 on GRI and discussion. The last section summarises the conclusion of the findings and the direction for future research.

2. Literature review

This section provides a comprehensive review of the I4.0, its technologies, GRI framework, relationship between sustainability and digital technologies.

2.1 Industry 4.0 (I4.0) and its technologies

The transition to I4.0 technologies offers numerous opportunities to reinvent worldwide supply chains with sustainability in mind (Ghobakhloo, 2020; Müller, 2020). As a concept, I4.0 seamlessly connects physical assets and advanced digital technologies, involving nine digital technologies, i.e., advanced robots, IIoT, big data analytics, additive manufacturing, cloud manufacturing, augmented reality (AR), simulation, horizontal and vertical integration, and cybersecurity (Kiel et al., 2017; Birkel et al., 2019). I4.0 technologies focus on end-to-end digitization of all value chain aspects (Kiel et al., 2017). Yet, in a supply chain aspect, I4.0 technologies offer an opportunity to significantly improve supply chain processes and then achieving strategic outcomes (Büyüközkan and Göçer, 2018). This digitization drive has become the mainstay of engineering organizations, regardless of their size or scale (De Sousa et al., 2018).

Implementing I4.0 technologies will aid organizations to realize sustainable growth and generate higher top and bottom-line values through faster design and development, innovative products, lower risk, and eradication of wastage (Ghobakhloo, 2020). However, the speed, breadth, and complexity of I4.0 technologies are compelling to reconsider how nations advance and how businesses generate value (Müller, 2020). Digital technology is more than just technology-driven transformation. It facilitates an opportunity to support everybody, including industry leaders, policymakers, and individuals from all income groups and countries, and creating a human-centered society (Morrar et al., 2017; Fukuyama, 2018).

2.2 GRI framework and the standards

GRI is an autonomous organization and the first standardized methodology for sustainability reporting (Simmons et al., 2018). GRI institutionalized the sustainable development framework to benchmark sustainability (Simmons et al., 2018). GRI sustainability report of an organization provides information and facts about its financial, environmental, societal, and governance performance (Simmons et al., 2018). In 2017, 63% of the biggest 100 corporations and 75% of the Fortune 250 companies had stated the application of GRI standards in respective organizations (Blasco and King, 2017). Some of the key GRI standards include economic performance, indirect economic impacts, child labor, emissions, anti-corruption drives, employment, and training and education (Piecyk and Björklund, 2015; Blasco and King, 2017). Empirical research has also shown that organizations that implement a reporting standard like GRI tend to be more devoted to sustainability (Piecyk and Björklund, 2015). Guided by the GRI's principle and management approach, reporting is done around a triple bottom line, i.e., environmental, economic, and societal (Blasco and King, 2017). The GRI framework, its principles, and standards have been collated and presented in Figure 1.

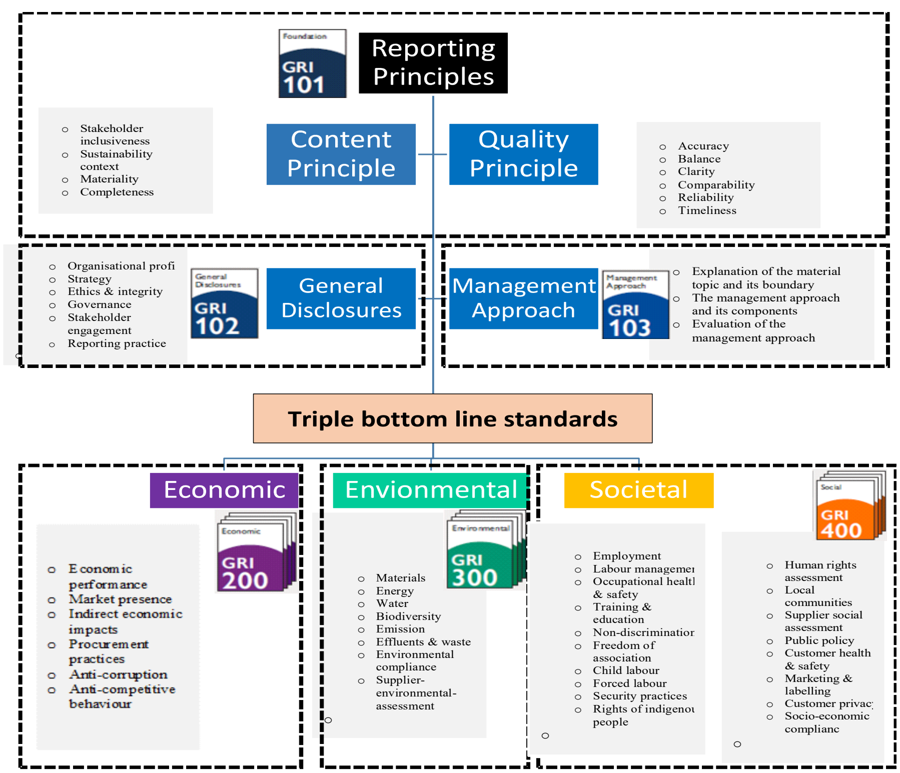

Figure1. GRI framework including triple bottom line standards

2.3 Link between sustainability and digital technologies

The societal viewpoint reveals that technological modernization is expected to influence social transformation dissemination, especially in developing countries (Luthra and Mangla, 2018). However, its implementation faces technological and social challenges (Fukuyama, 2018). Kamble et al. (2018) aimed to identify contemporary trends and future outlooks of the sustainable I4.0 framework and highlighted the need to study the effects of I4.0 on sustainable development more rigorously. Kiel et al. (2017) presented both the benefits and challenges of I4.0 in the context of sustainable value creation while highlighting the need for carrying out empirical research to understand the interplay between these concepts. De Sousa et al. (2018) identified few critical success factors for sustainability. These factors include leadership, commitment of top management, organizational change, learning and development, strategic alignment, empowerment, communication, project management, and culture. Despite covering so many success factors, the need for future research is also highlighted by De Sousa et al. (2018). Further, Müller et al. (2018) have identified prospects and challenges in the background of sustainability while equally stressing the need to carry out future research in integrating I4.0 with sustainability. As regards the environmental aspects, IIoT has explicitly contributed to the integration of ecological sustainability in the manufacturing sector (Sarkis and Zhu, 2018).

Müller and Voigt (2018) investigated the possible impact of I4.0 and Made in China policy on sustainable value creation in small and medium manufacturing organizations. The study of Müller and Voigt (2018) identified a research gap in establishing interdependencies amongst I4.0 and sustainability. Bag et al. (2018) presented a theoretical framework of I4.0 and sustainability that identifies the key enablers in driving supply chain sustainability. These include support of research institutes and universities; support of government; security of information technology and standards; law and employment policies; standardization of reference architecture; information transparency; commitment of management; human capital; change management, third-party audits; corporate governance; horizontal and vertical integration. Further, Bag et al. (2018) highlighted the need for empirical research on I4.0 and sustainability. Building upon the same, Birkel et al. (2019) offered a framework for risk assessment of I4.0 and sustainability and emphasized the need for an empirical investigation. The study of Luthra and Mangla (2018) examined the factors for the diffusion of I4.0 in supply chains and highlighted that management's supportive rules, collaboration, and transparency amongst supply chain members are the key factors. Fukuyama (2018) shared a model for integrating digital technologies with sustainable goals. However, rigor and empirical testing of the models are not evident.

2.4 Research gaps and context of the problem

The evolution of the organizations to adopt I4.0 has been complex and multifaceted because businesses struggle in adopting the evolving technologies while holding on to the 'sustainability aspect (Bag et al., 2018, Machado et al., 2020). I4.0 is at the heart of a digital renovation, and it is meticulously connected to the perceptions of embracing sustainability in the organizations (Birkel et al., 2019; Tiwari and Khan, 2020). This interrelation poses the question of how will I4.0 meet sustainability and carry a better future? Despite their importance in the contemporary period, there is a minimal empirical investigation about the linkage between the I4.0 and sustainability (Fukuyama, 2018; Birkel et al., 2019; Tiwari and Khan, 2020).

As discussed in section 2, where extant literature has been reviewed and critical research gaps have been identified, as presented below.

- The current research discussing the relation between digital technologies of I4.0 and sustainability is at the theoretic level and lacks rigor and comprehensiveness.
- The prior studies have not conceptualized the influence of I4.0 on GRI standards.
- Also, the prioritization of the significance of GRI standards in the context of I4.0 is not evaluated.
- Which technologies of I4.0 can enable the triple bottom line aspects of sustainability?
- The integration framework of I4.0 technologies with the GRI sustainability standards is not available.

To address the identified research gaps, a two-phase approach is proposed in this study. The proposed approach is a novel technique, and it is a fusion of descriptive statistics and multi-criterion technique.

3. Research methodology

This section offers an overview of the methodology for data collection, expert surveys, and data analysis. The sample for this study involved *n* =132 experts from *n*=36 industries that have implemented or are implementing the GRI framework with I4.0 technologies. They were carefully chosen from an e-mail distribution list comprising *n*=250 participants who attended a conference. The experts selected represent large organizations headquartered in India, Japan, China, Taiwan, Germany, the United States, and Italy. The response rate obtained was 52.8% (132/250) which is acceptable for the purpose herein.

An expert survey is used in this exploratory study considering the potential difficulties in measuring the influence of I4.0 on sustainability. This is important because very few organizations have implemented or are implementing the emerging concepts of I4.0 and sustainability. The survey involved two steps. The first step consisted of questions to capture the experts' perception about the influence of I4.0 technologies on accelerating GRI. The experts were asked to rate the influence of I4.0 technologies on GRI standards on a likert scale of 1 to 5, where 1 signifies that I4.0 technologies do not enable GRI standards and 5 meant that I4.0 highly enable GRI standards. An online survey was conducted for the collection of data. All questions were closed questions in terms of their nature. The average response time for completing the survey was approximately thirty minutes.

Basic descriptive statistics (mean score and standard deviation) were plotted for the GRI standards concerning I4.0 technologies. The internal consistency of the collected responses was checked using Cronbach's alpha. The relationship of the nine I4.0 technologies with multiple GRI standards was evaluated through analysis of variance (ANOVA) general linear model. During the investigation of the relationship between variables, researchers often use a t-test or ANOVA analysis to compare two groups (McGraw and Wong, 1996). The primary difference between t-test and ANOVA is that the t-test can only be utilized to compare two groups, whereas ANOVA can compare two or more groups. In line with the research of McGraw and Wong (1996), the study of Faulkenberry (2019) also emphasizes that ANOVA is a simple and robust methodology for evaluating the significance/impact of independent variables on the dependent variables, i.e., I4.0 technologies on GRI. The impact of the nine I4.0 technologies on GRI standards identified from extant literature has been studied through ANOVA general linear model. ANOVA makes a comparison of the effect of multiple factors on response. The overview of the research methodology is given in Figure 2. Prominent scholars have emphasized that ANOVA is a simple and robust tool for evaluating the impact of independent variables on the dependent variables (McGraw and Wong, 1996; Faulkenberry, 2019). Furthermore, the Fuzzy AHP technique is used to evaluate the significance of each of the GRI

Standards in the context of I4.0 implementation in manufacturing. Prominent scholars have identified the role of Fuzzy AHP in evaluating the performance in sustainability, manufacturing, technology management in I4.0 (Mangla et al., 2017).

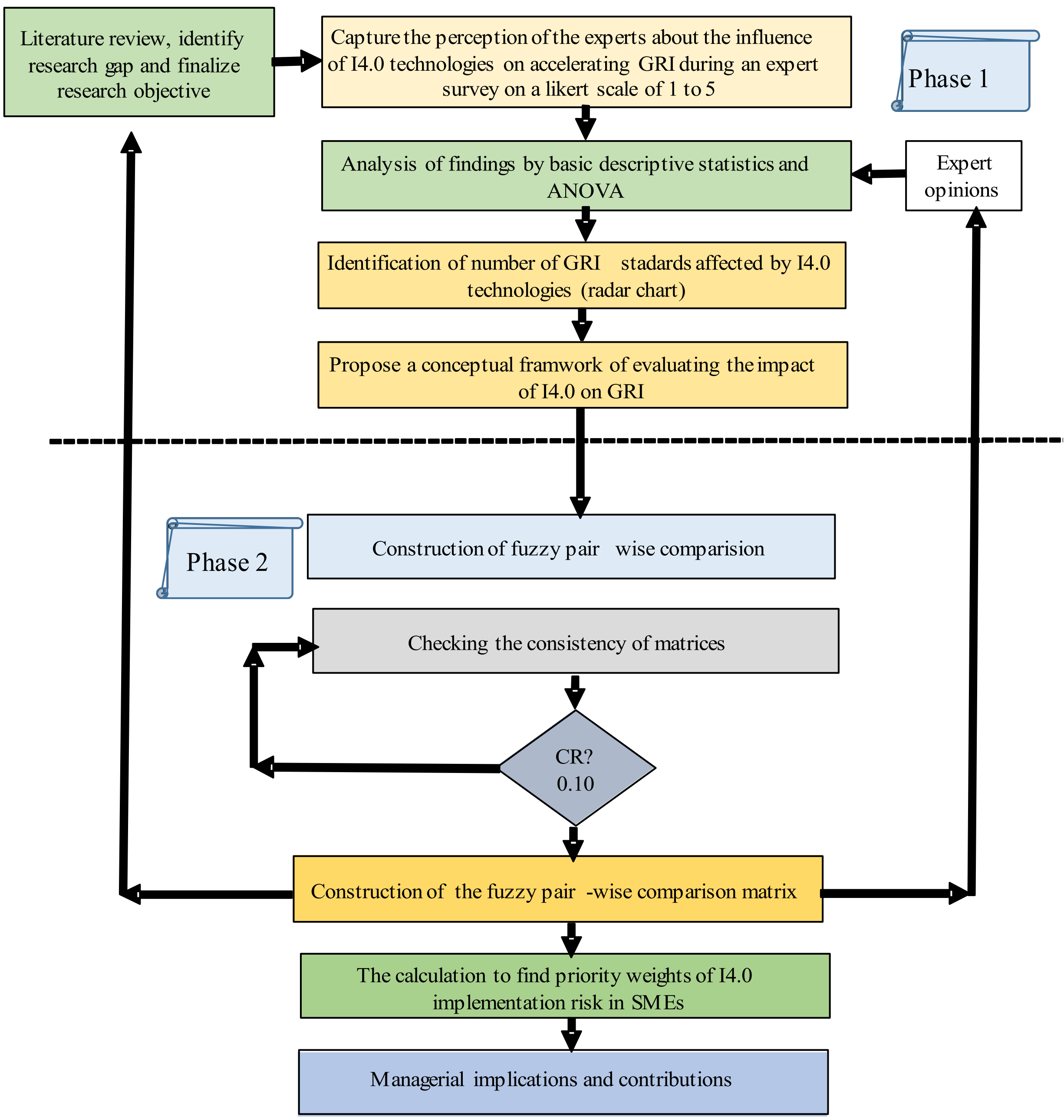

Figure 2: Methodology developed to evaluate the significance of each GRI standard

In the second phase of the work, the significance of each GRI standard is evaluated using the Fuzzy Analytical Hierarchy Process. The experts were asked to rate their perception on the significance of GRI standards using a Satty scale of 1 to 9. The GRI standards, which have received a rating >3 in the first phase of expert feedback, were used in Phase-2. The AHP is used by various researchers in the field of manufacturing, technology, innovation, strategy, business excellence, sustainability, sustainable production, and consumption supplier selection (Mangla et al., 2017). AHP technique is primarily used when team members are impeded by their diverse expertise and viewpoints (Zeshui, 2000). Additionally, since the experts are generally unable to explicit about their preferences due to the fuzzy nature of the decision process, this technique helps them providing an ability to impart interval judgments as a replacement for point judgments. Also, the study of Mangla et al. (2017) also emphasized that AHP offers superior results in contrast with the other knowledge-based decision-making techniques like ANP, TOPSIS, and ELECTRE.

4 Data analysis and results

This section offers the analysis of findings and proposes a conceptual framework for assessing the impact of I4.0 on GRI and discussion.

4.1 An empirical investigation

Figure 3 presents the basic descriptive statistics of expert's feedbacks on the influence of I4.0 on GRI. It illustrates high mean scores ranging from 3.12 to 4.40 in the n =19 standards, namely, energy, water, customer privacy, emissions, economic performance, supplier social assessment, supplier environmental assessment, environmental compliance, public policy, effluents and waste, training, and education, anti-corruption, market presence, customer health and safety, socio-economic compliance, indirect economic impacts, and employment. This implies that these GRI standards are highly enabled by I4.0 technologies. Further, Cronbach's alpha values are found to be 0.83 to 0.98, which validates the internal consistency of the data. The influence of individual I4.0 technologies on each of the 33 GRI standards is given in Figures 4 and Figure 5.

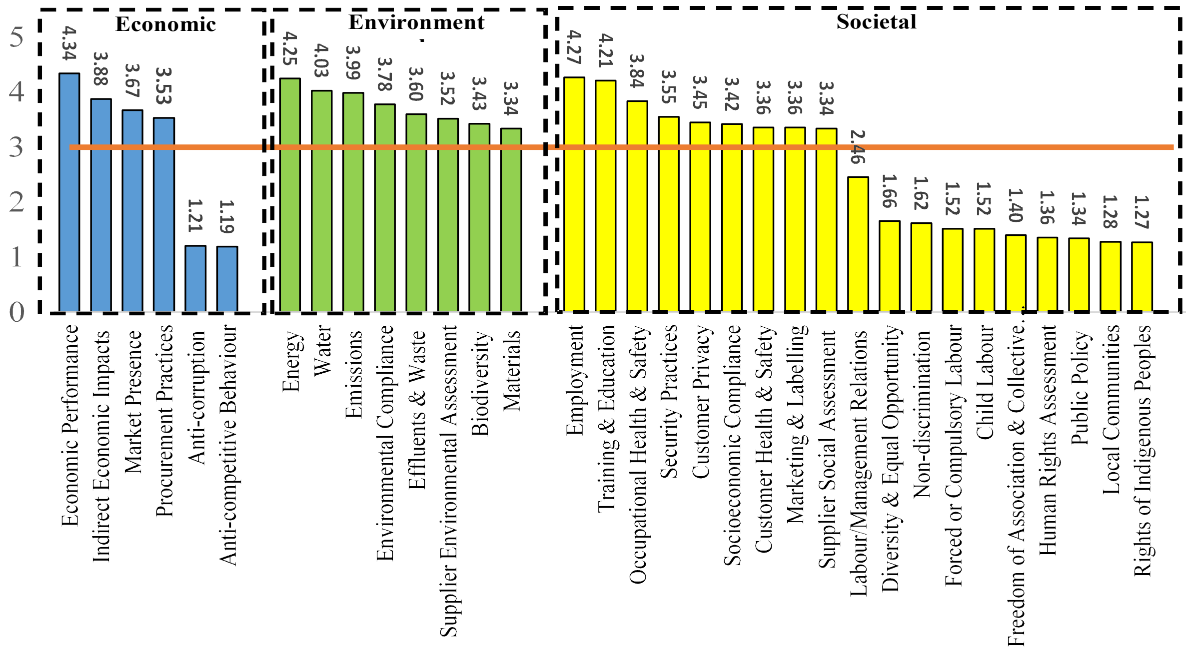

Figure.3. Basic descriptive statistics of expert's feedbacks on the influence of I4.0 on GRI

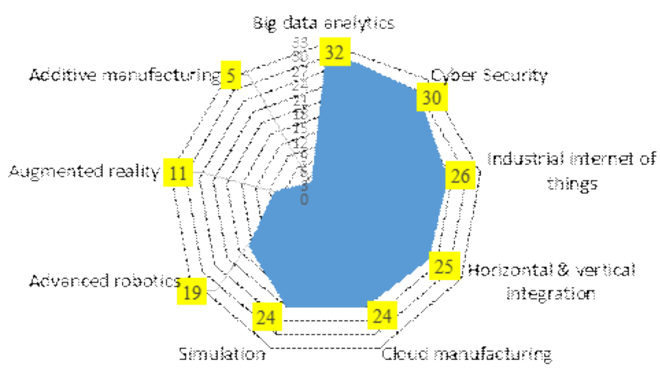

Figure.4. Radar chart of the number of GRI standards affected by I4.0 technologies

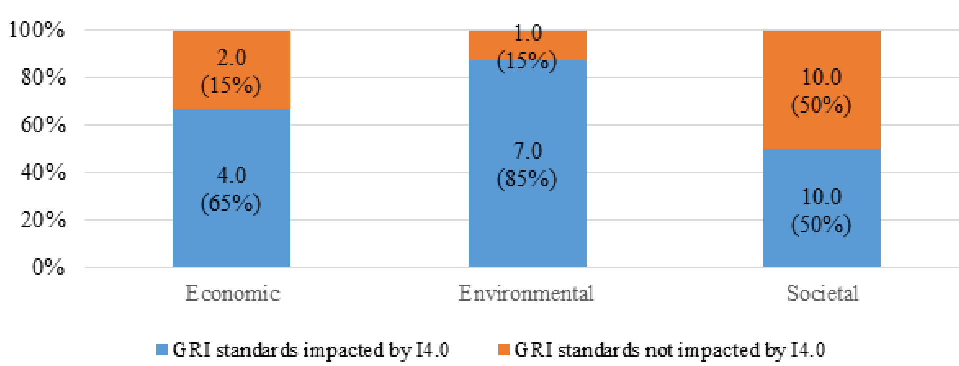

Figure. 5. Number of triple bottom line standards influenced by I4.0 technologies

The summary of basic descriptive statistics of expert feedback as shown in Figure. 5 indicate that I4.0 technologies influence 4/6 (65%), 7/8 (85%), and 10/10 (50%) of GRI standards in the manufacturing industries considering the mean score > 3 of experts' feedback. Among the economic indicators, "economic performance" seems to be highly enabled by I4.0 technologies considering a high score of 4.30 (Figure 3) followed by "indirect economic impact" (3.85), "market presence" (3.40), and "procurement practices" (3.25). "Anti-corruption" and "anti-competitive behavior" seem to be the lowest impacted by I4.0 technologies considering the low score (2.40) and 1.95, respectively, in Figure 3. In the environmental aspects of GRI, "energy", and "water" seem to be highly enabled by I4.0 technologies considering the high mean score of 4.40 and 4.05, respectively. This is followed by "emissions" with a mean score of (3.95), "environmental compliance" (3.65), "effluents and waste" (3.40), and "supplier environmental assessment" (3.35), respectively, as evident from Figure 3. The "biodiversity" seems to have the lowest impact, with a mean score of 1.80 (Figure 3). Among the societal aspects of GRI, the expert's feedback indicates a high rating for "employment", "training and education" seems to be highly enabled considering the high score of 3.90 (Figure 3). This is followed by the "customer privacy" (3.70), "customer health and safety" (3.65), "occupational health and safety" (3.54), "socio-economic compliance" (3.50), "marketing and labeling" (3.60), "security practices" (3.15). The balance of ten societal standards seems to have a low impact on I4.0 technologies considering the low score of 1.05 to 2.30 in Figure 3.

Furthermore, the radar chart of the number of GRI standards affected by I4.0 technologies (Figure 4) indicates that big data analytics impacts 96 % (32/33) of GRI standards considering the high mean score of > 3, and cybersecurity impacts 90 % (30/33), IIoT impacts 78 % (26/33), horizontal and vertical integration impacts 75 % (25/33), cloud manufacturing, simulation impacts 72% (24/33), and advanced robotics impacts 58 % (19/33) of the GRI Standards. Besides, augmented reality influences 33% (11/33), and additive manufacturing influences 15 % (5/33) of the GRI standard, as shown in Figure 5. The low rating of augmented reality and additive manufacturing can be attributed to their low level of application in the manufacturing, sales, and service functions as per expert's responses.

Further, the ANOVA in Table 1 shows the validity of the data. The augmented reality and additive manufacturing seem to have the least influence on procurement practices.

Table1: Summary of ANOVA for I4.0 technologies against GRI standards

		DF	Adj SS	Adj MS	F-Value	P-Value	S	R-sq	R-sq (adj)	R-sq (pred)
Autonomous Robotics versus GRI standards	GRI standards	32	2108.6	65.89	539.41	0.00	0.34	94.1%	94.23%	94.04%
	Error	1023	125	0.122	-	-				
	Total	1055	2233.6	-	-	-				
Additive Manufacturing vs GRI standards	GRI standards	32	2965.90	92.68	2185.96	0.00	0.205	98.56%	98.51%	98.46%
	Error	1023	43.37	0.0424	-	-				
	Total	1055	3009.27	-	-					
Cloud Manufacturing vs GRI standards	GRI standards	32	2268.03	70.87	843.71	0.00	0.289	96.35%	96.24%	96.11%
	Error	1023	85.94	0.084	-	-				
	Total	1055	2353.97	-	-	-				
Augmented reality versus GRI standards	GRI standards	32	2171.70	67.86	1824.01	0.00	0.192	98.28%	98.22%	98.16%
	Error	1023	38.06	0.037	-					
	Total	1055	2209.76	-	-	-				
Simulation versus Lean tools	GRI standards	32	2317.9	72.43	686.13	0.00	0.324	95.55%	95.41%	95.26%
	Error	1023	108	0.105	-	-				
	Total	1055	2425.9	-	-	-				
IIoT versus GRI standards	GRI standards	32	2390.6	74.70	574.09	0.00	0.360	94.73%	94.56%	94.38%
	Error	1023	133.1							
	Total	1055	2523.8							
Horizontal & vertical integration versus GRI standards	GRI standards	32	2397.30	74.91	1196.31	0.00	0.250	97.40%	97.32%	97.23%
	Error	1023	64.06	0.062	-	-				
	Total	1055	2461.36	-	-	-				
Big data analytics versus GRI standards	GRI standards	32	2205.7	68.92	476.34	0.00	0.380	93.71%	93.51%	93.30%
	Error	1023	148	0.144	-	-				
	Total	1055	2353.7	-	-	-				
Cybersecurity versus GRI standards	GRI standards	32	2443.67	76.364	2389.4	0.00	0.178	98.68%	98.64%	98.59%
	Error	1023	32.69	0.032						
	Total	1055	2476.36							

GRI standards		Advanced robotics	Additive manufacturing	Cloud manufacturing	Augmented reality	Simulation	Industrial internet of things	Horizontal & vertical integration	Big data analytics	Cyber Security
		Industry 4.0 Technologies								
Economic	Economic Performance	4.33	3.32	4.45	3.05	4.15	4.25	4.45	4.75	4.03
	Indirect Economic Impacts	3.35	2.35	4.03	2.75	4.03	4.03	4.03	4.65	4.03
	Market Presence	3.10	3.03	4.70	2.20	4.06	3.93	3.96	4.70	3.96
	Procurement Practices	3.05	3.07	4.35	1.03	3.80	3.05	4.06	4.55	4.05
	Anti-corruption	1.12	1.00	2.29	1.05	2.29	3.55	2.27	4.18	4.06
	Anti-competitive Behavior	2.15	1.32	2.29	1.06	1.06	1.06	1.09	3.23	3.50
Environmental	Energy	4.13	3.03	4.15	3.25	4.12	4.87	4.06	4.35	3.05
	Water	3.15	1.32	3.95	3.03	3.95	4.87	4.87	4.25	3.03
	Emissions	3.95	1.75	4.06	3.15	3.60	3.96	4.73	4.15	3.10
	Environmental Compliance	3.80	2.27	4.03	4.03	3.70	4.20	4.03	4.23	3.15
	Effluents and Waste	3.75	1.15	4.06	3.05	3.80	4.53	4.03	4.12	3.23
	Supplier Environmental Assessment	3.05	1.10	3.65	1.10	3.65	4.31	4.37	4.13	3.35
	Biodiversity	1.10	1.03	2.29	1.00	3.35	3.75	3.23	3.75	1.65
Societal	Employment	4.05	2.05	4.02	3.25	4.06	4.03	4.03	4.03	3.50
	Training and Education	3.12	1.65	4.75	3.00	4.32	4.35	4.00	3.93	4.15
	Customer Privacy	1.03	1.65	4.06	3.15	3.90	3.93	4.43	4.74	4.93
	Customer Health and Safety	4.02	2.05	3.65	2.03	3.96	3.93	3.15	3.96	3.12
	Occupational Health and Safety	4.12	2.05	3.34	3.02	3.92	4.12	4.18	4.15	2.29
	Socioeconomic Compliance	3.50	1.05	3.65	1.03	3.60	4.03	4.03	4.03	3.35
	Supplier Social Assessment	3.10	1.03	3.35	1.10	3.65	4.06	4.06	4.75	3.35
	Marketing and Labeling	3.12	1.03	4.03	1.03	4.12	4.20	4.12	4.75	4.21
	Security Practices	3.79	1.12	3.10	3.05	3.75	3.75	3.10	4.13	3.95
	Materials	1.13	4.23	3.12	1.00	3.67	3.12	2.67	3.55	3.50
	Public Policy	1.32	1.17	3.17	1.12	3.55	3.75	3.12	3.85	3.23
	Labor/Management Relations	3.12	1.03	3.12	1.06	3.12	2.75	2.67	3.15	3.03
	Human Rights Assessment	1.15	1.23	3.05	1.60	3.03	3.12	3.03	4.12	3.05
	Forced or Compulsory Labour	2.27	1.03	1.23	1.03	2.05	1.95	1.30	3.23	3.13
	Non-discrimination	1.10	1.12	1.67	1.17	2.23	2.15	1.03	3.03	3.02
	Child Labour	2.29	1.12	2.27	1.96	1.15	2.15	2.12	2.12	2.29
	Diversity & Equal Opportunity	2.29	1.00	3.03	1.03	1.03	3.12	3.32	3.05	3.03
	Local Communities	1.23	1.03	1.03	1.06	2.28	3.15	3.15	3.12	3.30
	Freedom of Association & Collective Bargaining	1.03	1.06	1.03	1.03	2.27	2.86	3.12	3.10	3.03
	Rights of Indigenous Peoples	1.15	1.03	2.29	1.03	2.10	2.45	2.95	3.30	3.02

Figure6. Conceptual framework indicating the impact of I4.0 technologies on GRI

As per the conducted survey, the rationale for a low rating to additive manufacturing could be because these technologies are mostly focused on the supply chain's manufacturing process, which does not influence procurement processes. Those two technologies are primarily focused on the manufacturing process of the supply chain. They do not directly influence the procurement processes. The associated P-value (Table 1) evaluated using ANOVA shows that I4.0 technologies do enable sustainability. Further, the P-value observed in all the cases where I4.0 technologies seemed to influence the respective GRI standard was 0.00. This signifies that the model used was valid. The mean scores of experts' feedback from a conceptual framework for assessing the impact of I4.0 technologies with GRI are shown in Figure 5.

The conceptual framework of the impact of I4.0 technologies on GRI, as shown in Figure. 6, depicts each GRI standard's significance. However, the relative dominance of each GRI standard remains unmapped. In this regard, the Fuzzy AHP (Avikal, 2014), a modified version of the analytical hierarchy process, is used in this study to compare one standard with the other and subsequently evaluate the cumulative dominance of each standard. The evaluated significance helps to determine the priority areas of GRI standards implementation of digital transformation. To better understand the methodological aspects, detailed insight into the steps involved in evaluating the cumulative score is presented below.

The steps involved in Fuzzy AHP are discussed below.

Step-1: Selection of the scale on which the responses are to be collected from the chosen decision-makers. Subsequently, the obtained responses are used to develop pairwise comparison matrices. In this study, the Saaty scale (Saaty, 2008), as shown in Table 2, is adopted to collect the developed questionnaire responses. The general representation of the criteria-criteria matrix is shown in Eq 1.

Table2: Judgement scale adopted to obtain the responses

'Saaty's crisp values (x)	Judgment definition	Fuzzified Saaty's value
1	Equal dominance	$(1, 1, 1 + \delta)$
3	Weak dominance	$(3 - \delta, 3, 3 + \delta)$
5	Strong dominance	$(5 - \delta, 5, 5 + \delta)$
7	Demonstrated dominance	$(7 - \delta, 7, 7 + \delta)$
9	Absolute dominance	$(9 - \delta, 9, 9)$
2, 4, 6, 8	Intermediate values	$(x - 1, x, x + 1)$, $x = 2, 4, 6, 8$

(1)

Where, $GRI_{ij} = 1$ for the diagonal members of the matrix, and $GRI_{ij} = 1/GRI_{ji}$. The rationale for this can be interpreted with the fact that the dominance of one risk over the other will be null. A sample decision matrix developed using the responses of Expert-1 is shown in Eq 2.

E^1 (2)

It has to be noted that a similar exercise is performed in the micro-level categorization of the GRI standard, i.e., economic standards, environmental standards, and societal standards. This results in a pairwise comparison matrix of GRI standards and the pairwise comparison matrices at the category level of each GRI standard. Similarly, the obtained pairwise matrices from Expert-1 for each category are shown in Eq 3-5.

$E^1=$ (3)

where, E1- Economic Performance; E2- Market Presence; E3- Indirect Economic Impacts; E4- Procurement Practices;

$E^1=$ (4)

Where, EN1-Energy; EN2-Emissions; EN3- Water; EN4- Effluents and Waste; EN5- Environmental Compliance; EN6- Materials; EN7- Supplier Environmental Assessment

$E^1=$ (5)

S1- Employment; S2- Occupational Health and Safety; S3- Training and Education; S4- Forced or Compulsory Labour; S5- Security Practices; S6- Supplier Social Assessment; S7- Customer Health and Safety; S8- Marketing and Labelling; S9- Customer Privacy; S10- Socio-economic Compliance

Step-2: Considering the crisp responses obtained in step-1, the fuzzy pairwise assessment matrix is developed using the fuzzified Saaty values shown in Table 2. Triangular membership functions are adopted in this study to fuzzy the crisp obtained crisp score. The general representation of the fuzzy weight can be shown as (a_1, b_1, c_1). The expression used for evaluating the range of ratings of experts is provided as Eq 6.

(6)

where i=1, 2, ……., n; j=1, 2, 3……..m; and k = 1,2,……..K number of experts

A sample fuzzified matrix developed by considering the responses of each decision-maker for the sub-criteria "economic GRI standards" is shown as Eq.7.

(7)

Step-3: The equivalent weight of each risk is assessed using a fuzzy synthetic method, which can be articulated as Eq 9. The evaluated cumulative weight of each risk is shown in Figure 3 (a) and 3(b)

Let X={A_1, A_2, ………A_n} be the set of alternatives and C={c_1, c_2, c_3…….c_m} are the set of criteria. Then as per the synthetic extent analysis m values for each alternative will be obtained and can generally be written as Eq.8.

, , ………… , i=1, 2, 3……..,n (8)

where, , , ………… is the extent analysis values of the i-th object for an m-th aim, the synthetic fuzzy value can be defined as Eq.9.

(9)

All w_i, i=1, M, are normalized fuzzy numbers with medium values equalling 1. denotes fuzzy multiplication operation. It may have to be noted that the fuzzy extent can also be defined as the result of fuzzy arithmetic or by using the extension principle.

Let us consider two fuzzy triangular numbers then, M_1= (x_1, y_1, z_1) and M_2= (x_2, y_2, z_2), then the operations are as follows

The local and global weights of GRI standards in the context of digital transformation are given in Figure 7.

Step 4: In this phase of analysis, the local and global hierarchy of each sub risk based on the cumulative score evaluated is obtained. This score further helps in the understanding interpretation of each identified risk.

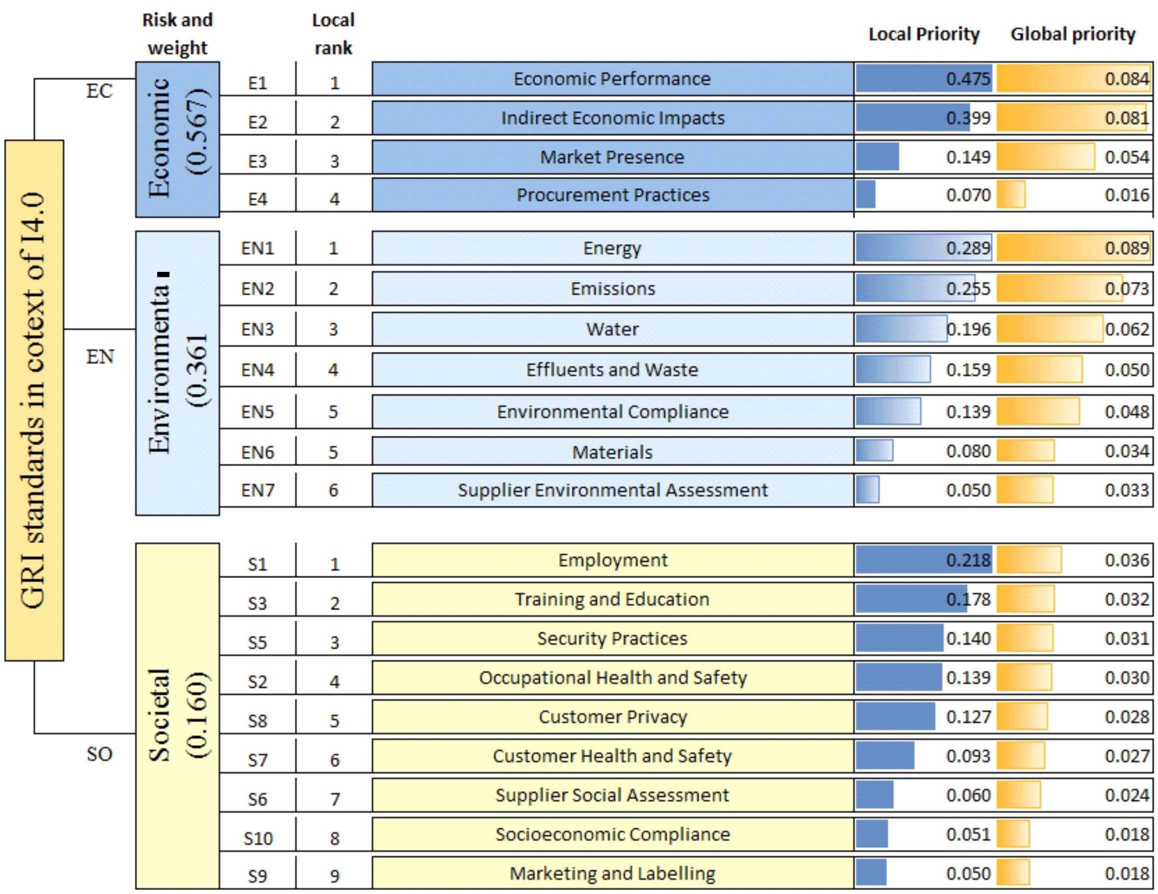

Figure 7. Local and global weights of GRI Standards

5. Discussion

The primary objective of this research was to examine the impact of I4.0 technologies on GRI triple-bottom-line standards. The GRI standard that is significantly influenced by all the I4.0 technologies is the "economic performance" and "indirect economic impacts" considering the high score of 0.47 and 0.39 among the evaluated economic standards (Figure 7). Furthermore, economic and environmental standards are validated by 65 % and 85 % of the technologies (Figure 5). Indirect economic impacts could be monetary or non-monetary. However, they are significant in terms of their impact on local communities and regional economies. Eight out of nine I4.0 technologies help to manage an organization's market presence considering the high mean score ranging from 3.03 to 4.70 (Figure 6). I4.0 is a paradigm shift from centralized to decentralized smart manufacturing, where the digital technologies of I4.0 help to reduce inventory, improve profitability, enhance transparency, and, most importantly, improve procurement practices and supply-chain efficiency (Machado et al., 2020; Dev et al., 2020) as righty indicated by the score of 0.149 in Figure 7. Furthermore, this fact is also reflected in the high mean score ranging from 3.03 to 4.55 in the impact of eight out of nine I4.0 technologies on procurement practices (Figure 6). There is little impact of I4.0 technologies observed in the anti-competitive behavior and anti-corruption parameters. Also, the application of I4.0 is limited to big data analytics and cybersecurity in anti-competitive activities such as bid-rigging, boycotts, price-fixing, dumping, and tying agreements, as indicated by its score of 3.23 to 4.18 in Figure 6.

In the environmental aspects, the GRI standard that is significantly influenced by all the I4.0 technologies is energy, considering the high score of 0.089 (Figure 7). Furthermore, "energy" is impacted by all the I4.0 technologies considering the high mean score ranging from 3.05 to 4.87 (Figure 6). An expert working in the energy sector noted that worldwide, energy management systems are integrated end-to-end, where the processes that make the value chain is analyzed and optimized in real-time, leading to a reduction of emission levels, and the same is validated by the high score of 0.073 in Figure 7. The deployment of digital technologies in smart grids aids in the optimization of conventional electric grids, resulting in less consumption of power and, consequently, lowering emission levels (Li and Zhou, 2011). Effluent and waste GRI standard is influenced by eight out of nine I4.0 technologies considering the high means score of 3.05 to 4.53 (Figure 6). An expert in waste management indicated that advancements in digital technologies and robotics help to sort and manage waste to improve recyclability.

Another expert working in the ministry of industrial promotion highlighted that collection of wastages by autonomous robotics, fully robotic recycling plants, landfill preparations, waste sorting, and hazardous waste treatment helps to manage effluent and waste. I4.0 technologies fashion new opportunities to prevent, decrease, and even abolish wastage, advance resource retrieval, realize higher standards of treatment and disposal, and to significantly reduce pollution. I4.0 technologies stimulate the transition to a circular economy through life-cycle analysis and cost; thereby enabling end-of-life products to be reclaimed, re-manufactured, recycled, and reused (Dev et al., 2020). The same is validated by the high score of 0.05 in the effluents and waste. The innovations of the I4.0 hold excellent prospects for improving environmental compliance and transforming the system essential to build cleaner, resource-secure, and inclusive economies, as indicated by the high mean score ranging from 3.15 to 4.33 in eight out of nine I4.0 technologies (Figure 6).

The GRI standard of supplier environment assessment is also impacted by seven out of nine I4.0 technologies (Figure 6), considering the high mean score ranging between 3.05 to 4.75. An organization is not only affected by its operations but also by its value chain involving suppliers. The multi-directional digital communication between system-wide networked machines, equipment, products, and customers helps in assessing and auditing suppliers (and their products and services) on the social criteria.

In the societal aspects, the GRI standard employment is influenced by eight out of nine I4.0 technologies, which are also reflected in the high mean score ranging from 3.25 to 4.06 (Figure 6).

Nevertheless, even in entirely mechanized areas, new-fangled occupations are being generated. Individuals are sought to oversee innovative technologies and fill the boundary between machinery and people. As per an expert, workforces with specialized knowledge continue to be valuable since they can support the optimization of procedures to use digital technologies of I4.0. The training and education sector is set for a significant and likely disruptive transformation by I4.0 technologies. The fact can be validated by its high score of 0.03 in Figure 7. Driven by the forces of globalization, progress in digital technologies, and increasing tech-savvy learners, learning is fast evolving in the direction of an open, available-at-all-times, and custom-made model, perchance breaking the stranglehold of traditional learning systems. This fact is also reflected in the high mean score ranging between 3.00 to 4.75 in the impact of eight out of nine I4.0 technologies in the training and education GRI standard (Figure 6).

Digital technologies of I4.0 have high potential in running the consumer health and safety industry sustainably, as indicated by the high impact of seven out of nine I4.0 technologies in consumer health and safety (Figure 6). Novel technologies can be deployed to fashion a safe environment by preventing humans from working in dangerous workplaces and activities. The innovations in IIoT help to improve health and safety data collection and prediction and prevention of risks and injuries. Environmental sensors proactively detect any possible menace to safety; a lot of potential hazards can be identified and handled on time by real-time monitoring, analytics by IoT, and cloud technologies. Customer privacy is the next GRI standard of societal aspects, being enabled by seven out of nine I4.0 technologies. The evolution of the internet into a medium of maintaining customer data has made consumer data privacy a primary concern. Customers fear that their behavior is being monitored without their consent. Cybersecurity has received a very high mean score of 4.93 concerning customer privacy (Figure 6).

Anchored in data science, I4.0 digital technologies can help to manage the transformation of civic projects and improve the health and safety of people. I4.0 is bringing digitization and connectivity to each facet of the business, including marketing. It is reflected in the high preference (seven out of nine technologies), as evident from Figure 6. This process results in strengthening their brand and customer relationships. The data in Figure 3 and Figure 5 reveals the low impact of I4.0 technologies in societal aspects like public policy, human rights assessment, forced or compulsory labor, labor-management relations, non-discrimination, child labor, diversity and equal opportunities, local communities, freedom of association and collective bargaining, and rights of religious people.

6. Implications

6.1 Theoretical implication

This research started with an objective to advances the theory on I4.0 and sustainability through an empirical investigation of the relationship between digital technologies of I4.0 and the GRI sustainability framework, including triple bottom line standards. This study is one of the pioneering works in the empirical investigation of the impact of I4.0 in accelerating the GRI implementation. This investigation adds to the theory of knowledge in a couple of ways: firstly, it offers an empirical examination of the impact of I4.0 technologies on GRI, and secondly, it offers a framework for the integration of I4.0 with GRI and the significance of GRI standards. The experts pointed out that while the focus of I4.0 is on automation and improvements in economic and environmental aspects, and little attention is paid to the societal aspects.

6.2Practicalimplication

On the practical side, this research helps to prioritize the I4.0 technologies for implementing GRI in manufacturing organizations. The priority thus drawn, benefit companies that are deploying

I4.0 strategies and companies that are seeking sustainable initiatives. Moreover, the findings of this study show an opportunity to create a fruitful alignment of I4.0 technologies to achieve sustainability effectively. I4.0 is anticipated to contribute to sustainability-associated matters under GRI 300 (environmental themes) and GRI 200 (economic themes). I4.0 technologies help organizations achieve business sustainability by creating various business models across the world. Also, the geographic restrictions amongst manufacturing locations end in the virtual sense because the IIoT setups of all industrial units connect in real-time via cloud computing. According to survey conducted, I4.0 technologies are mostly used to improve the productivity, quality, safety, emission levels, and delivery of highly customized products in the manufacturing industries. It is also noticed that adopting I4.0 technologies eventually leads to economic and environmental growth. The information collected and analyzed from real-time connected systems improves the consumer experience, cultivates novel direct selling and promotion strategies, and enables businesses to offer better post-sales support to consumers.

I4.0 technologies are an enabler for the smart grid, which can use renewable energy efficiently (Li and Zhou, 2011). Water is the most vital resource and is influenced by eight out of nine I4.0 technologies, with a high mean score ranging from 3.03 to 4.87 (Figure 6). New-fangled technologies have the perspective to provide momentous outcomes in the water conversation sector, validated by the high score of 0.062 in expert feedback, as shown in Figure 7. Likewise, emissions reduction is influenced by eight out of nine I4.0 technologies, which is indicated by the high mean score of 3.10 to 4.73 (Figure 6). Protagonists of I4.0 counter that the amalgamation of digital technologies with the machines allows for the extraordinary autonomy of high-tech machinery. However, some experts argue that I4.0, once entirely applied, could trigger mass layoffs and unemployment which can be validated by the high score of 0.03 of employment in Figure 7.

7. Conclusion and future research directions

This study mapped the perception of *n*=132 industry leaders and policymakers working towards the role of I4.0 technologies in accelerating the GRI implementation. At present, empirical investigation on the impact of I4.0 on GRI is still in the nascent stages. This investigation is viewed as one of the initial efforts in creating a new field of knowledge. The proposed conceptual framework indicating the impact of I4.0 technologies on GRI reveals a strong influence of I4.0 technologies on GRI standards. The existence of a relationship between the digital technologies of I4.0 and the triple bottom line standards of the GRI framework suggests that digitalization can act as a catalyst to improve sustainability factors and support the implementation of the GRI framework in organizations. Furthermore, the analysis indicates the high impact of big data analytics (96%), cyber-security (90%), IIoT (78%), horizontal and vertical integration (75%), cloud manufacturing (72%), simulation (72%), and advanced robotics 58 % on implementation of GRI standards in manufacturing industries in the context of digital transformation. On the other hand, augmented reality (33%) and additive manufacturing (15%) seems to have a low impact on GRI. These findings could serve as a base for manufacturing organizations to prioritize I4.0 technologies while drawing up the implementation plans of accelerating GRI adoption, focusing on the societal aspects that seem to have a low significance on industries during digital transformation.

The primary focus of this work was the investigation of I4.0 technologies with sustainability at a conceptual level. The authors have evaluated the impact of I4.0 technologies on the sustainability standards on the positive side, that is, how do technologies affect sustainability. Contrary to this, the risk posed by I4.0 technologies on the GRI standards has not been evaluated. Besides, the examination of interdependencies between I4.0 and GRI standards is another limitation of the work. However, the authors believe that this investigative study is in the right direction and may help in creating more structured models. Organizations that want to initiate Industry 5.0 may consider starting with a small-scale experiment within a controllable and affordable setting. Importantly, future studies may want to explore some of the critical challenges for integrating sustainability with I4.0 technologies. There is a need for practice-based, large-sample case studies that can identify and validate the factors that a business must contend with when integrating I4.0 with GRI. Future research can also may be carried to empirically establish the interdependencies between the I4.0 technologies and GRI standards in small and medium-scale organizations. Other relevant investigations could be around the comparison between developing and developed countries regarding the prioritization of I4.0 technologies to follow the GRI standards. For the supply chain aspect, further research is also required to better understand how to achieve alignment and consensus amongst the supply chain's members concerning I4.0 adoption to follow the GRI standards. Further studies may be required to assess the strategies embraced by various establishments in diverse settings for integrating I4.0 with GRI.

This research discloses that the impact of I4.0 technologies on societal aspects of GRI 400 across the organizations is minimal. This aspect needs to be studied in future research, especially in the context of Industry 5.0 (I5.0) and super society 5.0 policy formulated by Govt of Japan. I5.0 materializes when the digital components of technologies fully amalgamate with the physical domain in cooperation with human intelligence, which needs further investigations. The global labour market is progressively embracing new I4.0 technologies, which makes it easier for businesses to mechanize repetitive jobs. This development might disturb the balance between job responsibilities accomplished by individuals and those carried out by technologies and algorithms.

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