Chapter 6
Industry 4.0 and Green Entrepreneurship for Environmental Sustainability: Exploring Barriers from an Indian SME Perspective

Himanshu Gupta, Sourav Mondal, Saumya Singh, and Manjeet Kharub

Abstract Industry 4.0 has been considered a significant conduit for sustainable goods and processes, and green entrepreneurship are being held up as a solution for many social and environmental challenges. However, green entrepreneurs face certain challenges and uncertainty in incorporating digitisation (such as Industry 4.0) in sustainability activities. This article discusses the role and barriers that industry 4.0 and green entrepreneurs confront for environmental sustainability in Small and Medium Enterprises (SMEs). Therefore, we begin with a study identifying barriers based on a case study of SMEs and outline recent contributions exploring this role. Theoretical supports (Resource-Based View (RBV), Natural Resource-Based View (NRBV), and Stakeholder Theory (ST)) are used to support this case study. With expert opinion, multi-criteria decision-making modelling (MCDM), such as the "Best-Worst Method" (BWM), is used to assess and rank the barriers. The findings show that among the main category of barriers are "technology-related barriers", whereas in the sub-category, "minimal technological resources and lack of technological infrastructure and facilities" are the top barriers to Industry 4.0 and green entrepreneurship on environmental sustainability. We then summarise the papers and conclude with suggestions for further research.

Keywords Industry 4.0 · Green entrepreneurship · Environmental sustainability · Barriers · Best-Worst methods

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Introduction

In recent years, the rapid industrialization of small and medium enterprises has played a noteworthy role in economic as well as financial development and negatively impacted the environment. Due to rising negative global environmental issues, many entrepreneurs and existing businesses have been forced to give priority to environmental protection over economic development [44]. In this regard, stakeholders such as the government, top management, and start-ups focus on and give importance to sustainable industrial development. The goal of sustainability has begun to alter the competitive environment, compelling organisations to embrace or employ digital technologies such as Industry 4.0 (I4.0) or the fourth industrial revolution, which play an important role in allowing industries to operate effectively and efficiently [45]. The growing body of research shows that I4.0 has become crucial for a company's performance, sustainable production and manufacturing development, and economic and competitive advantages at the national and global level. Further, this I4.0 helps advance the process, increases efficiency and profitability, and helps sustainability practises such as green practises. On the other side, Green Entrepreneurship (GE) involves creating new firms or modifying existing ones with an emphasis on environmental sustainability and social responsibility [21]. Green entrepreneurs strive to create and deploy innovative technology, goods, and services that have a positive environmental effect while making a profit. GE and I4.0 are closely related in that I4.0 technology may be utilised to assist GE and environmental sustainability [37]. For example, integrating IoT sensors and big data analytics may assist businesses in optimising energy and resource consumption, reducing waste, and lower greenhouse gas emissions. By boosting energy efficiency, lowering waste, and improving product quality, robotics, and automation may lessen the environmental impact of industrial operations. Moreover, I4.0 technology may foster GE by providing new possibilities for enterprises to produce and sell environmentally friendly goods and services and by helping in environmental sustainability. Companies, for example, may use sophisticated analytics and machine learning to create more sustainable goods across their entire life cycle, from manufacture to disposal.

Lots of research has been investigated in the areas of I4.0, GE, and sustainability. Leona Niemeyer et al. [32] and Yin et al. [61] studied I4.0 to improve and develop sustainable production and manufacturing in business. Schröder [51] shows the challenges of I4.0 for SMEs, whereas [34] studied and evaluated the barriers of I4.0 in supply chain sustainability contexts. Another study [22] shows the interrelationship between I4.0, digitalization, and opportunities with sustainability. In their study, [50] show the challenges and opportunities of I4.0. Polas et al. [43], in their study, show the relationship between blockchain technology and GE,here, they slightly discuss the importance of I4.0. Some studies [17] perform systematic literature reviews on I4.0 and environmental sustainability. This study tries to link I4.0 and sustainability. Castelo-Branco et al. [10] assess I4.0 from a developed country perspective in their study. Further, [37] studied barriers to GE and green initiatives from financial market perspectives.

Meanwhile, green entrepreneurs play a vital role in developing and incorporating I4.0 into manufacturing operations for environmental sustainability. Over the past several decades, the use of I4.0 has also aided sustainability in many ways. For example, this helps entrepreneurs develop smart manufacturing systems [61]. These further assist in monitoring and controlling energy consumption, water usage, and material waste, enabling businesses to improve resource efficiency and reduce carbon emissions. It also supports GEs transition to a "circular economy", "waste management," and maximum utilisation of waste. This enables businesses to develop and implement new sustainable products, services, and business models. Therefore, GE is critical to the growth of I4.0 and environmental sustainability. Several studies on GE, I4.0, and sustainability have been conducted (for example, [32, 61]). Nevertheless, most of the present research in this field is focused on establishing the role of I4.0 in sustainability, with no studies examining its relationships with GE in relation to environmental sustainability. Although green entrepreneurs try to develop I4.0 activities focused on sustainability, there are certain barriers faced by MSMEs. Some earlier research [34] examined the hurdle to I4.0. Therefore, there needs to be more research on the barriers to adopting I4.0 on green entrepreneurship and environmental sustainability in developed nations like Indian MSMEs. Experts have emphasised that studies in the area will help with I4.0, GE, and environmental sustainability. However, it is crucial to comprehend these barriers in depth before attempting to address them. Thus, the purpose of the study is to address the following research objectives (RO):

RO1 To study the relationship between I4.0 and GE in manufacturing SMEs.
RO2 To identify the barriers that may hinder I4.0 and GE on environmental sustainability.
RO3 To rank the identified I4.0 and GE on environmental sustainability.

The remainder of the research is structured as follows: The second portion contains a review of the literature, and the third section describes the research methods utilised in this research, the fourth section provides an analysis of the case study and results; the fifth section discusses the results, the sixth section presents conclusions, and the final section presents implications, limitations, and future research directions.

Literature Review

This section discusses I4.0, GE, and environmental sustainability. The first part of the literature review examines the theoretical views (RBV, NRBV, and ST) employed in this research, followed by literature on I4.0, GE, and environmental sustainability and their relationship. This study contextualises and operationalizes these theories by identifying influencing barriers (i.e., internal, external, and organisational barriers) that industry 4.0 and green entrepreneurs confront for environmental sustainability. These theories provide a new perspective and logical basis for identifying the relevant barriers from the literature that are potentially represented in the context.

Theoretical Framework

Resource-Based View (RBV)

Resource-Based View (RBV) is a theoretical framework used in strategic management to analyse a firm's internal resources and capabilities and how they can be leveraged to achieve a competitive advantage in the marketplace [6, 36]. The RBV suggests that a firm's unique resources and capabilities are the primary drivers of its competitive advantage, rather than the industry or market in which it operates. According to the RBV, capabilities refer to a firm's ability to use its resources to achieve its goals effectively, and this can be developed through internal processes, such as using I4.0 to develop effective and efficient production [6]. The RBV emphasises the importance of developing unique capabilities that are difficult for competitors to replicate. For example, firms that adopt I4.0 technologies to increase efficiency can reduce their carbon footprint and environmental impact. RBV can help firms identify and leverage their internal resources and capabilities to create sustainable competitive advantages. Moreover, GE can drive innovation and create new opportunities for sustainable growth [36]. By developing new products and services that prioritise environmental sustainability, green entrepreneurs can help address alarming environmental issues like climate change, resource depletion, and pollution. RBV, I4.0, and GE can be powerful tools for promoting environmental sustainability. Hence, this theory aids in identifying and categorising the technical, financial, strategic, and institutional-related resources required in SMEs and, without this, creates obstacles for them to encounter while attempting to embrace and develop I4.0 and GE practises for environmental sustainability.

Natural Resource-Based View (NRBV)

The Natural Resource-Based View (NRBV) is a strategic management theory that suggests that a firm's sustainable competitive advantage is derived from the unique resources and capabilities that are rooted in the natural environment [20]. This is because natural resources are typically characterised by high barriers to entry and are difficult to replicate or substitute. The NRBV highlights the importance of resource identification, assessment, and development in achieving competitive advantage [39]. It also emphasises the need for sustainable resource management practises that balance economic, social, and environmental objectives. Further, SMEs can use I4.0 technologies to improve resource efficiency and reduce environmental impact while identifying new sources of natural resources that can be used in manufacturing [36]. For example, some manufacturers are using renewable energy sources, such as solar and wind power, to power their factories and reduce their carbon footprint. Similarly, GE can also be viewed through the lens of the NRBV. Green entrepreneurs aim to create new products and services that are environmentally sustainable, such as eco-friendly packaging, energy-efficient lighting systems, and waste-reduction technologies. These entrepreneurs are innovatively leveraging natural resources to create value for their customers while promoting environmental sustainability [36]. In this case, NRBV provides a valuable framework for understanding and identifying the natural resource constraints and capabilities that manufacturing SMEs face while trying to adopt I4.0 and GE to achieve sustainable competitive advantage and promote environmental sustainability.

Stakeholder Theory (ST)

This stakeholder theory (ST) is a management and organisational theory that suggests that a company's success is not only determined by its financial performance but also by its ability to create value for a wide range of stakeholders, including employees, customers, suppliers, communities, and the environment [59]. According to this theory, a company should strive to create a balance between the interests of its various stakeholders rather than focusing solely on maximising profits for shareholders. By doing so, a company can build long-term, sustainable relationships with its stakeholders, enhance its reputation, and improve its financial performance [7]. Stakeholder theory suggests that companies have ethical and social responsibilities to their stakeholders beyond their legal obligations. This can be achieved through various mechanisms, such as stakeholder consultation, engagement, and collaboration. Further, with I4.0, stakeholders like employees, customers, suppliers, and the environment are impacted by the integration of advanced technologies. Further, GE also involves a wide range of stakeholders, such as investors, employees, customers, suppliers, and the environment [60]. Stakeholder theory suggests that companies should consider the interests of all these stakeholders when developing and implementing sustainable products and services [59]. This can include sourcing sustainable materials, reducing waste, and minimising environmental impact. In addition, stakeholder theory provides a valuable framework for understanding how companies can adopt I4.0 and GE to achieve environmental sustainability. By considering all stakeholders' interests, companies can create long-term sustainable value and build stronger relationships, leading to greater success in the long run. While developing I4.0 and GE initiatives for environmental sustainability, ST can assist in identifying the various barriers related to or affecting stakeholders and their divergent interests, concerns, and expectations of SMEs.

Industry 4.0 (I4.0) in SMEs

I4.0 can significantly impact SMEs in terms of opportunities and challenges. One of the key benefits of I4.0 for SMEs is the potential for increased productivity and efficiency [27]. By integrating advanced technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, SMEs can streamline their operations and improve their overall performance [25]. For example, businesses or start-ups can use IoT-enabled sensors to monitor their equipment and optimise their production processes or use AI algorithms to automate routine tasks and reduce errors. I4.0 can also provide SMEs with new opportunities for growth and innovation. By leveraging advanced technologies, SMEs can develop new products and services, enter new markets, and establish partnerships with other companies. For example, they can use digital platforms to reach new customers and markets or collaborate with other SMEs to develop innovative solutions. However, there are also several challenges that SMEs may face when adopting I4.0 [40]. One of the main challenges is the cost of implementing these advanced technologies, which can be prohibitively expensive for some SMEs. Additionally, challenges may be related to the skills and expertise needed to implement and manage these technologies. To address these challenges, SMEs can consider partnering with other companies or collaborating with research institutions to share the costs and expertise needed to adopt I4.0. Additionally, they can invest in training and development programmes to build the necessary skills and knowledge within their organisation. Overall, I4.0 presents both opportunities and challenges for SMEs. By adopting advanced technologies and leveraging new opportunities for growth and innovation, SMEs can achieve long-term success and remain competitive in the global market.

Green Entrepreneurship (GE) in SMEs

GE in SMEs refers to starting and running businesses that are environmentally sustainable, socially responsible, and economically viable [42]. Green MSMEs are those businesses that create products and services that help reduce environmental impact, conserve natural resources, and promote sustainable practises. In addition, GE in SMEs allows businesses to create value while promoting environmental sustainability and social responsibility [53]. It can also help businesses differentiate themselves in the marketplace and appeal to consumers who are increasingly concerned about sustainability. GE differentiates itself from other types of entrepreneurship because it focuses on creating businesses that generate profits and positively impact the environment and society. While traditional entrepreneurship is primarily concerned with maximising profits, GE seeks to balance economic, social, and environmental sustainability [56]. Green entrepreneurs are motivated by a desire to address environmental and social challenges such as climate change, resource depletion, and social inequality, and they see business as a means to create positive change. They are committed to sustainable practises, and their businesses often use eco-friendly technologies, reduce waste, and minimise their carbon footprint. Green practises in SMEs can face several challenges that can hinder their adoption and implementation [60]. Here are some of the common problems faced by SMEs when adopting green practises: a lack of resources, limited awareness and knowledge, resistance to change among the employees, a lack of supportive policies, and limited market demand, which can make it problematic for SMEs to justify the investment in green practises and products.

Relationship of I4.0 with GE

Industry 4.0 (I4.0), the Fourth Industrial Revolution, refers to integrating advanced technologies such as artificial intelligence, the Internet of Things (IoT), cloud computing, and robotics in manufacturing [49]. This new wave of technological transformation significantly impacts various aspects of business, including sustainability and environmental management. In contrast, GE refers to businesses that are designed to provide sustainable solutions to environmental problems [19]. The role of I4.0 in promoting GE and environmental sustainability and this technology can help businesses optimise resource use, reduce waste, and improve energy efficiency [49]. For example, IoT sensors can monitor energy consumption in real-time, allowing businesses to identify areas where energy can be saved. In addition, I4.0 technologies can enable businesses to adopt circular business models, which aim to reduce waste and promote resource reuse. Further, IoT-enabled tracking systems can help businesses track the lifecycle of products and materials, allowing them to identify opportunities for reuse and recycling [19]. Although I4.0 technologies can enable businesses to create more innovative and sustainable supply chains, for example, blockchain technology can be used to track the origin of raw materials and ensure that they are ethically and sustainably sourced. I4.0 technologies can facilitate the adoption of renewable energy sources, such as solar and wind power. IoT-enabled sensors can monitor energy production from renewable sources and help businesses optimise their use of these resources. In conclusion, I4.0 has the potential to play a significant role in promoting GE and environmental sustainability. By leveraging advanced technologies, businesses can optimise resource use, adopt circular business models, create smarter and more sustainable supply chains, and adopt renewable energy sources. It can lead to a more sustainable future where businesses can thrive while promoting environmental sustainability.

Research Gap and Existing Problems

Several studies on I4.0, GE, and environmental sustainability have been conducted separately. Although prior research has successfully shown the importance of I4.0 and GE in manufacturing SMEs, comparatively few studies have highlighted its importance for sustainable development. There are minimal studies on the impact of technologies on GE, and they are limited to specific areas. Balachandran and Sakthivelan [8] show the importance of technology on entrepreneurship, while [22] shows the importance of I4.0 on sustainability. Numerous businesses have integrated sustainability into their I4.0 to improve environmental sustainability. However, the literature lacks studies that examine the impact of technologies on the sustainability of manufacturing SMEs. Moreover, more research needs to be conducted on identifying challenges, barriers, fundamental difficulties, and problems adapting digital technologies (i.e., I4.0) in manufacturing SMEs. For instance, [34] provide a list of barriers to I4.0 in the other sector in a developed country [51], and Ghobakhloo et al. [23] present the barriers to technology applications; however, their suggestion that future studies are still pending. In addition, [43] also show the relationship between blockchain technology and GE. However, to the best of our knowledge, no prior study has shown the relationship between I4.0 with GE and environmental sustainability. Moreover, no study identified barriers or challenges impeding I4.0 and GE activity. None have explicitly integrated I4.0 and GE for environmental sustainability studies, as this study does. The details steps followed in this research have been provided in Fig. 6.1.

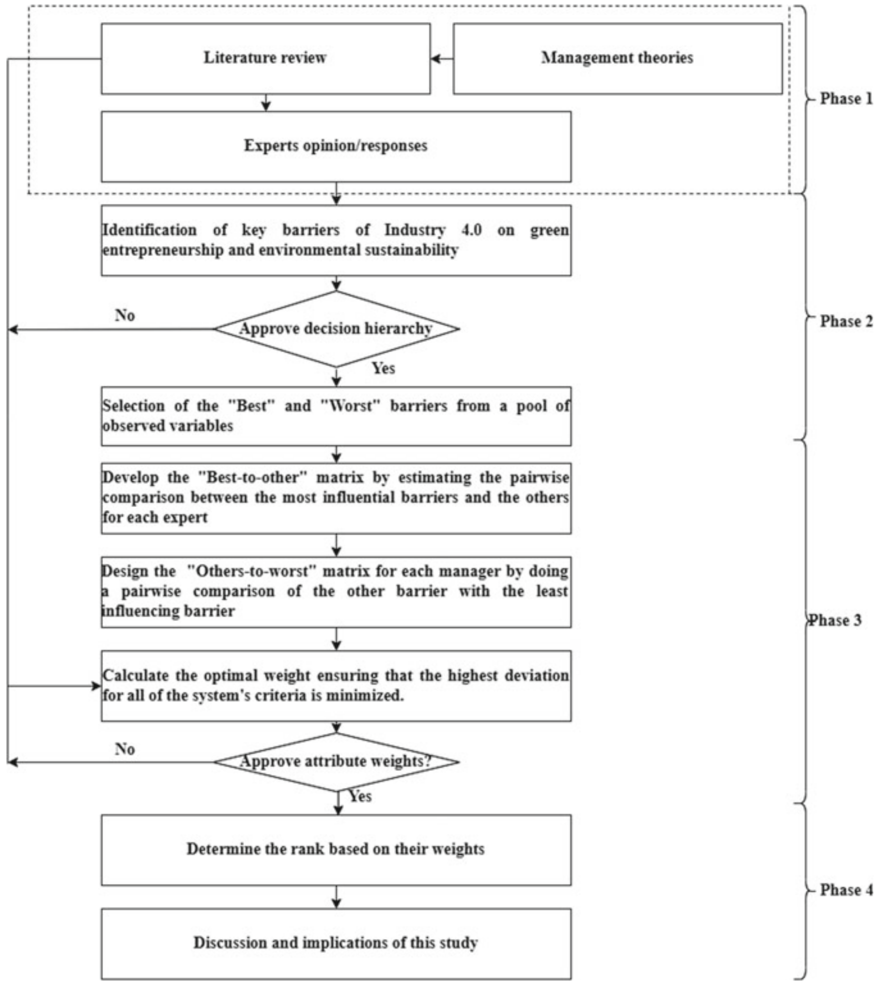

Fig. 6.1 Flow chart for carrying out research methodology

Methodology

This study applied a four-phase multi-case methodology (see Fig. 6.1) to analyse and rank the barriers. In the first phase of the research, barriers were identified; in the second phase, they were classified; in the third phase, expert responses were taken; and in the fourth phase, weight and rank were calculated. For weight and rank calculation [47] were used. The "Best-Worst Method" (BWM) is a "Multi-Criteria Decision-Making" (MCDM) technique used to evaluate items or alternatives based on their relative importance or value. BWM is preferred in comparison to other MCDM techniques because it requires fewer pairwise comparisons, improves consistency in the ranking, considers only integer values, reduces the computational burden, and can easily be combined with their methodologies'. In addition, this methodology is flexible, solves the inconsistency problems during pairwise comparison, is robust, provides an intuitive result, and produces valid and reliable results [47, 55]. Furthermore, consistency judgement is an important step in BWM to ensure the reliability of the results and should be performed before interpreting the rankings obtained from the participants. Consistency judgement involves checking whether the participants have responded consistently to the questions presented to them. Experts are asked to rank a set of items based on their relative importance. The ranking is done by choosing the best and worst items from a set of items. To ensure consistency, the same set of items is presented to the participants multiple times, and the rankings are compared across the different sets. In addition, consistency judgement in BWM involves calculating the consistency ratio (CR), which is a measure of how consistent the participants' rankings are across the different sets. The consistency ratio (CR) is used to evaluate the reliability and consistency of the obtained weights (a lower CR value indicates more consistency in ranking). The CR is calculated from the consistency index, and the value of CR varies between 0 and 1 (Table 6.7 in appendix shows the output of the CR). Here, a close value of 0 shows more consistency, whereas a close value of 1 shows less consistency [47]. Therefore, it has been used in different fields of research, for example, operations research, healthcare, tourism management, finance, energy management, marketing research fields, etc. Hence, in order to evaluate different barriers of I4.0 and GE in Indian MSMEs. The following are the detailed implementation and inference steps of BWM [47].

Step 1 Identify the set of relevant barriers (n) for the research and set of relevant barriers $\{c_1, c_2, \ldots, c_n\}$.

Step 2 Experts determine the Best (e.g., most desirable or most important) and Worst (e.g., least desirable or least important).

Step 3 The next step is to rank the best criterion above all other criteria. On a scale from 1 (equally significant) to 9 (extremely significant), an expert builds the best-to-others vector. This yields vector $A_{Bj} = (a_{B1}, a_{B2}, \ldots, a_{Bn})$ where a_{Bj} denotes the preference value of the "best criteria" B in relation to criterion j. It is clear that $a_{BB} = 1$.

Step 4 Similarly, experts use a 1–9 scale to generate the others-to-worst (OW) vector. 1 shows equally significant preference amongst the criteria, while 9 implies extremely significant preference. This will also produce the vector $A_{jW} = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$, where a_{jW} denotes the relevance value of criteria j over the "worst criterion" (W). It is clear that $a_{ww} = 1$.

Step 5 Then compute the optimised weights ($w_1^*, w_2^*, \ldots, w_n^*$) for each criterion.

In other words, we obtain the weights of criteria such that the highest absolute variations for every j can be minimised for $\left\{\left|w_B - a_{Bj}w_j\right|, \left|w_j - a_{jW}w_W\right|\right\}$. Therefore, the minimax model is constructed as follows:

$$\begin{aligned} &\min\max\left\{\left|w_B - a_{Bj}w_j\right|, \left|w_j - a_{jW}w_W\right|\right\} \\ &\text{s.t. } \Sigma_j w_j = 1 \\ &w_j \geq 0, \text{ for all j} \end{aligned} \tag{6.1}$$

While Model (6.1) is converted into a linear model, the results are improved, as shown in the model below.

$$\begin{aligned} &\min.\ \xi^L \\ &\text{s.t.} \\ &\left|w_B - a_{Bj}w_j\right| \leq \xi^L, \text{ for all j} \\ &\left|w_j - a_{jW}w_W\right| \leq \xi^L, \text{ for all j} \\ &\Sigma_j w_j = 1;\ \text{wj} \geq 0, \text{ for all j} \end{aligned} \tag{6.2}$$

Model (6.2) can be solved to get "optimal weights" ($w_1^*, w_2^*, \ldots, w_n^*$) and "optimal value" ξ^L. The consistency (ξ^L) of attribute comparisons near "0" is required.

Further, for the pairwise comparison of vector A_{BO}, and A_{OW} the "cardinal consistency" is considered [30]. Here the pairwise comparison is assumed cardinal-consistent if

$$a_{Bj} \times a_{jW} = a_{BW}, \text{ for all the value of j} \tag{6.3}$$

Here, a_{BW} is the "best criteria's" preference over the "worst criterion".

To assess the level of inconsistency in a pairwise comparison, a CR is necessary. The original BWM method uses an "output-based consistency measurement" that relies on the optimal objective value of the optimization model. However, an alternative approach is called "input-based consistency" measurement, which is easy to calculate and has a clear algebraic interpretation [30]. The "input-based consistency" can quickly determine the level of consistency in a decision maker by using the input the expert offers without the need for the entire optimization process; it is also called an "Input-Based Consistency Ratio" (CR^I) and is formulated as follows.

$$CR^I = \max_j CR_j^I \tag{6.4}$$

where,

$$CR_j^I = \begin{cases} \frac{|a_{Bj} \times a_{jW} - a_{BW}|}{a_{BW} \times a_{BW} - a_{BW}} & \mathrm{a_{BW}} > 1 \\ 0 & \mathrm{a_{BW}} = 1 \end{cases} \tag{6.5}$$

Here, CR_j^I is the local "input-based consistency ratio" for all criteria related with CR_j. Here "input-based consistency ratio" is used over the "output-based consistency ratio" because it may give immediate feedback, is simple to comprehend, is model-independent, and can provide decision-makers with a clear guideline for revising inconsistent judgment(s) [30]. In the Appendix, Table 6.6 provides the different threshold values and it is adopted from [30]. Further, Table 6.7 provides the obtained "input input-based consistency ratio" of different experts for different barriers.

Experts' Background and Case Analysis

Case Details and Experts' Background

In order to achieve the objectives, thirteen experts from ten different firms and academia were chosen. The experts are considered and chosen from diverse manufacturing SMEs with different work experiences (at least ten years), and they practise I4.0 and GE. For this study, participants were intentionally chosen from various functional areas in order to achieve more generalised outcomes. Experts with insufficient experience and no upper management roles were also disqualified. The further expert considered here is from the top management of that organisation, and having a specialised team, they have sufficient knowledge and experts. The details of the thirteen selected experts are presented in Table 6.1. Delphi techniques were used for data collection to identify the barriers. The Delphi technique is a structured communication method used to gather expert opinions from a group of individuals, typically to make informed decisions or predictions about a particular topic or issue [3]. The technique involves a series of questionnaires or surveys distributed to a panel of experts who anonymously provide their opinions and feedback. Experts from SMEs are selected here because they have a significant role in the Indian economy and are regarded as the country's backbone since they contribute considerably to job creation, GDP growth, and industrial output. In the Delphi method, instead of starting with an open question about what is most important to the subject under consideration, experts create individual models that are then combined, averaged, and analysed to draw a final conclusion, and it allows experts to work independently but on the same model until that model can be accepted without major additional modifications. Here, arithmetic mean aggregation and a threshold technique are employed to select the most important experts' responses. The Delphi method was then used in this research, which employs the same group of experts in each round to help define, analyse, and come up with useful evidence about the barriers. Furthermore, through the use of literature, expert feedback, and management theories, this method assists in obtaining a final list of obstacles, which are then classified into six main categories and twenty-eight sub-category impediments (as shown in Table 6.2). Then, using the BWM methodology, each of the experts (Table 6.1) was requested to individually identify the "best" as well as "worst" barriers among the "main category" as well as the "sub-category" barriers. The experts were then asked to rate the " Best-to-Others" (BO) and "Other-to-Worst" (OW) for all the main categories as well as the "sub-category" barriers, respectively, using a 1–9 scale. The pairwise comparison for main category barriers for all experts is presented in Table 6.3. Next, using Eq. (6.2) and the pairwise ratings obtained for all the "main category" barriers as well as the "sub-category" barriers, the weights of each of the main category and sub-category barriers are calculated. The detailed weights as well as the rankings for sub-category barriers, are presented in Table 6.4. Here Table 6.4 the obtained ranking using the arithmetic mean, whereas Table 6.5 in Appendix A shows the ranking calculation obtained from the geometric mean (for further analysis, we consider Table 6.4, which is obtained from the arithmetic mean). Table 6.3 provides a summary of the responses received from experts. Next, the weight of each "main-category" and "sub-category" barrier is calculated using Eq. (6.2), and "pairwise ratings" are obtained from all the barriers. After getting the "local weight" of each "sub-category" barrier, we calculate the global weight by multiplying each sub-category weight with its parent category weight (see the plot of Fig. 6.2). Based on the obtained weight, we provided the rank of each barrier. The detailed weights and rankings are presented in Table 6.4 as a plot of global weight (see Fig. 6.2).

Discussions

The research identified and finalised the barriers to I4.0 and GE on environmental sustainability using a mix of literature reviews, management theories, and many round discussions ("Delphi Techniques") with experts from Indian manufacturing SMEs. The identified barriers are then classified into six "main barriers" and twenty-eight "sub-barriers". According to the results, among the main categories of barriers, technology-related hurdles (TB) were identified as the most pressing challenges facing Indian SMEs in adopting and implementing I4.0 activities through green entrepreneurship to enhance environmental sustainability (see Table 6.4). One of the essential aspects of implementing I4.0 and GE in a manufacturing operation in an SME is technological support. This shows that the absence of technical know-how among manufacturing SMEs in developing countries like India causes impediments to the implementation, acceptance, and development of I4.0 and GE for sustainable development. In addition, these SMEs face severe challenges in acquiring and developing technologies, capabilities, knowledge, and infrastructure [29], for example,

Table 6.1 Information about experts involved in case analysis

Expert	Expertise	Experience	Experts academic background	Type of SMEs/ organisations
Expert-1	Head engineering	18	MBA	Textile Manufacturing
Expert-2	Senior operation manager	15	MTech	Steel manufacturing
Expert-3	Senior production manager	11	MTech	Electrical and electronics
Expert-4	Technical manager	15	MBA	Plastic manufacturing and processing
Expert-5	General manager	12	MBA	Automotive industry
Expert-6	Asst. Manager-Process Control	17	B.Tech	Agro based products
Expert-7	Manager-Operations	11	MBA	Metal and fabrication
Expert-8	Senior production manager	12	MTech	Automobile company
Expert-9	Senior operation manager	11	BE	Automotive industry
Expert-10	Senior Manager-Procurement	13	B.Tech	Automobile parts manufacturing company
Expert-11	Academician	12	PHD	Professor
Expert-12	Academician	10	PHD	Associate professor
Expert-13	Academician	15	PHD	Professor

implementing I4.0 on flexible production and manufacturing, monitoring and developing "waste management", recycling, regenerating, and reusing waste components. Lack of technical support creates enormous barriers to developing sustainability activities or achieving UNDP's sustainable development goals [38]. Certain technological factors, such as a lack of technological infrastructure in the I4.0 era, stifle the development of technological capabilities for green entrepreneurs and SMEs. The next pressing issue is the institutional or institutional-organisational barriers (IB) that create barriers to I4.0 and GE (see Table 6.4). These barriers, like technological barriers, are important impediments to I4.0 and GE. They include resistance to change, a lack of investment, a regulatory environment, a lack of skilled labour, and a lack of awareness and education. These barriers are also affected by the SMEs' external as well as internal factors [2]. To overcome these barriers, organisations may need to take proactive steps to educate stakeholders, invest in new technologies and

Table 6.2 Barriers to I4.0 and GE on environmental sustainability

Main barriers	Sub-barriers	Description	Code	References
Technology impediments (TB)	Minimal technological resources and lack of technological infrastructure and facility	Minimal technological resources and a lack of technological infrastructure and facilities can be significant barriers for green businesses adopting new technologies (such as I4.0) and digitising their operations	TB1	Fatimah et al. [18]
	Lack of technological collaboration between firm, industry and academia	Collaboration is essential for sharing knowledge, expertise, and resources to optimise technology use (i.e., I4.0) to increase efficiency, profit, competitive advantage and sustainability. The lack of these creates barriers to GEs developing environmental sustainability	TB2	Tseng et al. [58]
	Gap between I4.0 design and implementation	This creates barriers such as misalignment between GE and its strategic goals and the technology implementation strategy, cost overruns, reluctance to change, and opportunity limitations	TB3	Çınar et al. [12]
	Lack of focus on innovation and R&D capabilities	A lack of attention to innovation and R&D skills provides impediments to knowledge enhancement, process development, efficiency, and overall entrepreneur performance	TB4	Wu et al. (2020)

(continued)

Table 6.2 (continued)

Main barriers	Sub-barriers	Description	Code	References
Institutional and administrative barriers (IB)	Lack of commitment and communication from top management	Without top management commitment or engagement in I4.0 adoption, SMEs face challenges	IB1	de Sousa Jabbour [14]
	Lack of proper decision-making related to how to develop I4.0 activity for sustainability	The absence of adequate decision-making creates a barrier to sustainable activities, such as a clear understanding of the objectives, poor decision-making and planning, and added cost. This creates barriers GEs to developing and adopting I4.0 activities for long-term sustainability	IB2	Dwivedi et al. [16]
	Lack of use I4.0 for waste management and recycling facilities	The lack of use of I4.0 for waste management and recycling facilities can create several barriers, including inefficient waste management, lower recycling rates, as manual sorting and processing methods can be slow and inaccurate, increased negative environmental impacts, and barriers to sustainability and value creation	IB3	Chiarini [11]

(continued)

Table 6.2 (continued)

Main barriers	Sub-barriers	Description	Code	References
	Lack of understanding of customer requirements and market demand	These barriers created obstacles for GE to integrate I4.0 activities due to inefficient resource utilisation, wasted opportunities, low adoption rates, and a lack of meaningful value on return on investment	IB4	Lin et al. [33]
	Lack of government policies and regulations	The absence of government laws and regulations may provide a number of challenges for GEs seeking to develop and execute I4.0 operations. Inconsistent standards may cause interoperability challenges across various I4.0 systems and technologies, reducing their efficacy and acceptance	IB5	Kumar et al. [29]
Socio-cultural barriers (SCB)	Lack of social and stakeholder pressure	This reduces the transparency of stakeholders, trust between stakeholders and companies, innovation in I4.0 technologies and sustainability practices, and the company's reputation	SCB1	D'Souza et al. [13]
	Habit of use of traditional technologies	Habit of use of traditional technologies resists GEs from developing I4.0 activities and development practices that help in sustainable development	SCB2	Cai et al. [9]

(continued)

Table 6.2 (continued)

Main barriers	Sub-barriers	Description	Code	References
	Stereotyping and bias	Stereotyping and bias can lead to discrimination and prejudice, which can create a toxic work environment and hinder diversity and inclusion efforts	SCB3	Interview
	Lack of cultural awareness	Employees and leaders may lack awareness or understanding of other cultures, which can lead to cultural insensitivity and misunderstandings	SCB4	Tripathi and Gupta [57]
	Resistance to change	Cultural norms and values can sometimes resist change, making it difficult for organisations to implement new processes, and technologies, i.e., related to I4.0. Implementing new technologies can be disruptive and require changes to existing workflows and processes. Some employees may be resistant to change, which can slow down the adoption of I4.0 and other digital technologies	SCB5	Raj et al. [45]
Finance and economic barriers (FB)	High initial investment in developing I4.0 activities	Because of the substantial investment, this creates hurdles for GEs to develop I4.0 activities in their businesses, as well as impediments to developing environmental sustainability	FB1	Awan et al. [6]

(continued)

Table 6.2 (continued)

Main barriers	Sub-barriers	Description	Code	References
	Insufficient income and lack of clarity of financial benefit	The starting expenses of introducing new technologies (I4.0) or innovation may be substantial, and firms may be unwilling to invest unless they have a clear knowledge of the prospective financial rewards	FB2	Habib et al. [24]
	Lack of financial support by the government, banks and from investors	This creates barriers to GE to incorporating and practising I4.0 activities	FB3	He et al. [26]
	Lack of capital to carry out I4.0 activities	Adopting I4.0 technologies often requires considerable upfront expenditures in hardware, software, training, and maintenance, which may be prohibitively costly for many firms. A GE without adequate money causes challenges to the development of environmental sustainability	FB4	Shet and Pereira [52]
Knowledge and attitudinal barriers (KB)	Lack of proper technological know-how training of managers and businesses	Without adequate training, SME struggle to grasp the efficient use of I4.0 (i.e., automation, flexible production systems) or embrace new technology trends	KB1	Rizos et al. [48]

(continued)

Table 6.2 (continued)

Main barriers	Sub-barriers	Description	Code	References
	Lack of proper education level among employees	Employees at businesses and start-ups with insufficient education levels may lack the necessary skills and knowledge to fulfil their job functions successfully. This may lead to decreased productivity, worse work quality, and decreased job satisfaction and motivation	KB2	Struckell et al. [54]
	Lack of entrepreneurial skills and innovative thinking	This creates constraints for GEs associated with I4.0 activity, novel possibilities for expansion, efficiency difficulties, and overall sustainability-related activity	KB3	Moktadir et al. [41]
	Perceived lack of competency and fear of failure	This barrier has an impact on employee productivity, confidence, start-up success, and the integration of new technology, all of which hamper environmental sustainability	KB4	Kumar et al. [29]
	Entrepreneurial role and intentions	The negative attitude of green entrepreneurs creates barriers to incorporating I4.0 activity, which further helps in environmental sustainability	KB5	Abbasianchavari and Moritz [1]

(continued)

Table 6.2 (continued)

Main barriers	Sub-barriers	Description	Code	References
Strategic barriers (SB)	Lack of green manufacturing and operational capabilities development	This creates challenges and resistance for GE to expand I4.0 activities for increased production, effectiveness, and environmental sustainability	SB1	Karuppiah [28]
	Lack of standardisation	I4.0 technologies are still evolving, and there are currently no industry standards for many of these technologies. This can make it difficult for SMEs to choose the right technologies and ensure compatibility with existing systems	SB2	Tripathi and Gupta [57]
	Less intention towards the sustainability concepts	Medium and small manufacturing enterprises struggle to implement I4.0 activities for improved production and operational activity for sustainable development because of a lack of attention to sustainability on the part of the business, and they are more focused on profit	SB3	Lau and Hashini [31]
	Fierce competitive pressure	This barrier causes issues with thinking, investment in innovation, teamwork, and the general efficiency of a green entrepreneur in developing I4.0 practices for environmentally sustainable development	SB4	Alsaad et al. [5]

(continued)

Table 6.2 (continued)

Main barriers	Sub-barriers	Description	Code	References
	Unclear and complex organisational dynamic orientations	This barrier affects GE's use of I4.0 for environmental sustainability in ways such as a lack of clarity on aim and strategy, which causes problems in decision-making and reluctance to change in SMEs	SB5	Randhawa [46]

training, and work with policymakers to create a more supportive regulatory environment [35]. Third, another important barrier related to I4.0 and GE on environmental sustainability is financial and economic barriers (FB) (see Table 6.4). These hurdles include the cost of integrating new technologies and processes, investing in renewable energy sources, or upgrading to more energy-efficient equipment [15]. Moreover, SMEs may face severe competition from bigger firms with the means to engage in these practises, or they may struggle to find consumers willing to pay more for environmentally friendly goods and services. The following important barriers are related to strategic barriers (SB) and socio-cultural barriers (SCB), and the last and most important barriers are related to knowledge- and behaviour-based barriers (KB), which hinder the adoption and development of I4.0 and GE activities on environmental sustainability. Among the sub-category barriers, minimal technological resources and lack of technological infrastructure and facilities (TB1) are the most important issues related to I4.0 and GE, which hinder progress towards environmental sustainability (see Table 6.4). The absence of technical infrastructure creates impediments to the growth of I4.0, and activities connected to sustainability are a difficult challenge [45]. Manufacturing firms in India often lack critical technological infrastructure. These constraints are exacerbated by hurdles such as a lack of access to data and analytics,developing and deploying new technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and robots need significant investment in infrastructure and facilities [38]. Businesses that do not have access to this technology may struggle to keep up with rivals that do. This may limit their potential to enhance efficiency, eliminate waste, and boost output, which are critical for environmental sustainability. Moreover, they may be hampered in minimising their carbon footprint and environmental sustainability. The next sub-category barrier is the "gap between the design and implementation of I4.0" (TB3). This creates barriers without proper design and implementation, such as increased energy consumption, no control over waste, and increased cost and complexity for developing I4.0 activities, particularly in SMEs in developing countries [27]. The third most important sub-category barrier

Table 6.3 Identification of "Best" and "Worst" I4.0 barriers and sub-barriers

I4.0 category and sub-category barriers obtained from BWM	Identified as "Best" by experts	Identified as "Worst" by experts
Main-category barriers		
TB	2, 4, 7, 12	6
IB	1, 10, 13	12
SCB	11	5,7,9,13
FB	5, 8	3,10
KB	9	1,4,11
SB	3, 6	2,8
Sub-barriers of technology impediments		
TB1	3, 6, 9, 11	5,7
TB2	7, 8, 10	2,4,11,13
TB3	1, 5, 12, 13	3,8,10
TB4	2, 4	1,6,9,12
Sub-barriers of institutional and administrative barriers		
IB1	10	3,8,13
IB2	1, 3, 6, 12	7
IB3	2, 5, 8, 11	4,10
IB4	4	1,6,9,12
IB5	7, 9, 13	2,5,11
Sub-barriers of socio-cultural barriers		
SCB1	4, 9	3, 6, 10
SCB2	1, 3, 8, 12	7
SCB3	7	1, 2, 5, 9, 11
SCB4	2, 5, 6, 13	8, 12
SCB5	10, 11	4,13
Sub-barriers of finance and economic barriers		
FB1	7, 11	4, 6, 9, 12
FB2	2, 3, 5, 8	10, 11
FB3	1, 4, 9, 13	2, 5, 8
FB4	6, 10, 12	1, 3, 7, 13
Sub-barriers of knowledge and attitudinal barriers		
KB1	4, 8, 12	3, 11
KB2	11	1, 5, 8, 10, 13
KB3	3, 13	2, 6, 7
KB4	2, 5, 7, 10	9
KB5	1, 6, 9	4, 12

(continued)

Table 6.3 (continued)

I4.0 category and sub-category barriers obtained from BWM	Identified as "Best" by experts	Identified as "Worst" by experts
Sub-barriers of strategic barriers		
SB1	2, 5, 7, 9, 11	10
SB2	13	1, 4, 5, 8, 11
SB3	1, 6, 8, 12	3,7
SB4	4	6, 9, 13
SB5	3, 10	2, 12

Table 6.4 Ranking of barriers

Main barriers	Local weight	Sub barriers	Weight of sub-barriers	Global weight	Rank
TB	0.247	TB1	0.309	0.076	1
		TB2	0.230	0.057	4
		TB3	0.265	0.065	2
		TB4	0.195	0.048	7
IB	0.206	IB1	0.132	0.027	19
		IB2	0.291	0.060	3
		IB3	0.238	0.049	6
		IB4	0.140	0.029	17
		IB5	0.199	0.041	10
SCB	0.119	SCB1	0.173	0.021	22
		SCB2	0.279	0.033	12
		SCB3	0.119	0.014	27
		SCB4	0.262	0.031	15
		SCB5	0.168	0.020	24
FB	0.165	FB1	0.185	0.030	16
		FB2	0.342	0.056	5
		FB3	0.274	0.045	9
		FB4	0.199	0.033	13
KB	0.117	KB1	0.214	0.025	21
		KB2	0.108	0.013	28
		KB3	0.174	0.020	23
		KB4	0.274	0.032	14
		KB5	0.230	0.027	20
SB	0.146	SB1	0.324	0.047	8
		SB2	0.126	0.018	25
		SB3	0.234	0.034	11
		SB4	0.122	0.018	26
		SB5	0.194	0.028	18

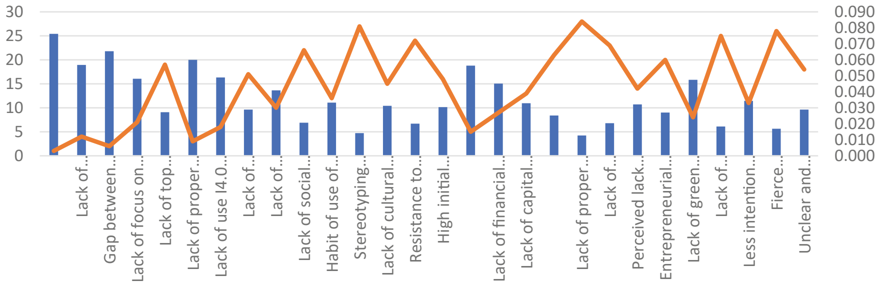

Fig. 6.2 Plot of global weight and global rank

is the "lack of proper decision-making related to developing I4.0 activity for sustainability" (IB2). These constraints impact I4.0, such as SMEs investing in I4.0 technology and processes that do not emphasise environmental sustainability. This might lead to needless expenditure, which can harm the SME's financial viability. It may also hinder SMEs' capacity to engage in GE methods, which may require substantial financial resources. Therefore, businesses may be unable to maximise their I4.0 investments to enhance environmental sustainability without thorough study and planning. This can reduce the environmental and financial sustainability advantages of I4.0 [4].

Conclusion

Sustainability is a worldwide critical issue, and India and other developing nations face several obstacles associated with political issues, finances, and technology, among other things. In addition, manufacturing SMEs are a sector that significantly contributes to the developing global economy but also faces several challenges. To cope with this challenging and rising global sustainability problem, industrial organisations and entrepreneurs must create a new innovative way that helps in coping with these challenges. There are several ways to solve this issue; however, the incorporation of digital technologies (such as I4.0) and GE plays a significant role. Further, to implement these, SMEs face several challenges, and it is necessary to identify the barriers. Therefore, this study identified a list of barriers that hampers the adoption, development and make the operation of I4.0 and GE on environmental sustainability in the manufacturing SMEs. This study further helps to rank these barriers based on obtained weight. This study identifies the technology barrier (in the sub-category "minimal technological resources and lack of technological infrastructure and facilities"), the institutional barrier (in the sub-category "lack of proper decision-making related to how to develop I4.0 activity for sustainability"), in financial, economic barrier (in the sub-category "insufficient income and lack of clarity of financial benefit”), in strategic barrier (among sub-category “lack of green manufacturing and operational capabilities development”), in socio-cultural barrier (among sub-category “habit of the use of traditional technologies”), and among attitudinal and knowledge-based barrier (among sub-category “perceived lack of competency and fear of failure”) are the most important I4.0 and GE barriers on environmental sustainability. As a result, this interdisciplinary research integrates three streams of literature, namely I4.0, GE, and sustainability. It builds on prior studies that either focused only on the application of I4.0 or GE on sustainability or addressed the hurdles in separate research.

Implications, Limitations and Future Recommendations

Implications

This research finding has significant implications for manufacturing SME managers, entrepreneurs, the government, policymakers, and academicians. This interdisciplinary study combined theoretical and empirical approaches to better understand the challenges that SMEs encounter during the development and implementation of Industry 4.0 and GE for sustainability. Because of their significant harmful impact (such as the creation of more pollution and waste generation) on the environment, the industrial sector is constantly in the news when policymakers and scholars examine environmental degradation. Manufacturing SMEs must accept and innovate long-term solutions to environmental problems caused by their operations. But given the size and complication of the procedures, the green entrepreneurs or green entrepreneurs of manufacturing SMEs face several challenges to implementing innovative solutions, such as the adoption, development, and implementation of Industry 4.0 activities. The present study provides a framework for manufacturing SMEs by identifying six “main-category” and twenty-eight “sub-category” barriers to Industry 4.0 and green entrepreneurship on environmental sustainability in the context of manufacturing SMEs. Overall, the “lack of proper decision-making” related to developing Industry 4.0 activities for sustainability can significantly affect the development or adoption of Industry 4.0 and green entrepreneurship on environmental sustainability in SMEs in India. To address these challenges, SMEs can focus on building awareness and understanding of the environmental benefits of I4.0 and work with experts to design and implement Industry 4.0 solutions that prioritise environmental sustainability. Governments can also support SMEs by providing funding and incentives to promote the adoption of Industry 4.0 solutions that prioritise environmental sustainability, as well as by promoting awareness of the environmental benefits of Industry 4.0. Policymakers and regulatory authorities in developing nations might also benefit from this study by testing the present framework in several other industries to better understand the underlying constraints. Policymakers should also concentrate on capacity development for the manufacturing sector by providing technology engagement assistance and skill improvement training to employers of manufacturing SMEs. Moreover, managers and business owners may design customised training seminars and programmes to improve their employees' technical abilities and competencies. Managers may use this study as motivation to invest more in research infrastructure for their businesses, empowering their teams to engage in Industry 4.0 and green practises. According to the findings of this study, managers and regulatory bodies need to take action on a macro level by formulating strategies, drafting policies, and allocating subsidies and funds to support activities that enhance research and technological capability in order to achieve sustainable development. Further, the results might be used by the government to implement reforms in areas like taxation, policymaking, workforce development, technical assistance, and incentive schemes.

Limitations and Future Recommendations

As every study has some limitations, this research also has some of them. This study, through literature and expert advice, identifies barriers to Industry 4.0 and green entrepreneurship for environmental sustainability. Future studies can focus on identifying a few more Industry 4.0 barriers, which can be explored more with a more comprehensive literature review. This study used MCDM techniques to evaluate the barriers. Future studies can use techniques such as structural equation modelling (SEM) to determine the relationship among barriers. Future studies can use larger data sets, as this study's techniques only used a few limited experts to conclude the results. Further future studies can use other Multi-Criteria Decision Making (MCDM) techniques such as the Bayesian or "Fuzzy Best-Worst Method" (BBWM or FBWM), which gives real-world situations by considering decision-makers' confusion. Further. This technique used thirteen experts, which can be increased with experts from more diverse fields. Undoubtedly, this preliminary study opens more opportunities for future work to be carried out.

Appendix

See Tables 6.5, 6.6 and 6.7.

Table 6.5 Ranking of barriers (when considering geometric mean)

Main barriers	Local weight		Sub barriers	Weight of sub-barriers		Global weight	Rank
	Geometric mean	Normalized weight		Geometric mean	Normalized weight	Normalized weight	
TB	0.202	0.254	TB1	0.239	0.335	0.085	1
			TB2	0.151	0.212	0.054	5
			TB3	0.185	0.260	0.066	3
			TB4	0.137	0.193	0.049	7
IB	0.173	0.218	IB1	0.105	0.138	0.030	14
			IB2	0.235	0.309	0.067	2
			IB3	0.178	0.234	0.051	6
			IB4	0.105	0.138	0.030	15
			IB5	0.137	0.181	0.039	10
SCB	0.089	0.112	SCB1	0.131	0.172	0.019	23
			SCB2	0.220	0.291	0.032	11
			SCB3	0.088	0.116	0.013	28
			SCB4	0.190	0.250	0.028	17
			SCB5	0.129	0.170	0.019	24
FB	0.125	0.158	FB1	0.127	0.176	0.028	18
			FB2	0.261	0.360	0.057	4
			FB3	0.202	0.280	0.044	9
			FB4	0.133	0.184	0.029	16
KB	0.091	0.115	KB1	0.160	0.212	0.024	21
			KB2	0.087	0.115	0.013	27
			KB3	0.127	0.169	0.019	22
			KB4	0.205	0.272	0.031	13
			KB5	0.174	0.232	0.027	20
SB	0.115	0.144	SB1	0.262	0.337	0.049	8
			SB2	0.096	0.123	0.018	26
			SB3	0.173	0.223	0.032	12
			SB4	0.099	0.128	0.018	25
			SB5	0.147	0.190	0.027	19

Table 6.6 Thresholds values for different combinations using "input-based consistency measurement"

Scales	3	4	5	6	7	8	9
3	0.167	0.167	0.167	0.167	0.167	0.167	0.167
4	0.112	0.153	0.190	0.221	0.253	0.258	0.268
5	0.135	0.199	0.231	0.255	0.272	0.284	0.296
6	0.133	0.199	0.264	0.304	0.314	0.322	0.326
7	0.129	0.246	0.282	0.303	0.314	0.325	0.340
8	0.131	0.252	0.296	0.315	0.341	0.362	0.366
9	0.136	0.268	0.306	0.334	0.352	0.362	0.366

* Adopted from [30]

Table 6.7 CR table of expert's response

Expert	Input-based consistency ratio						
	Main-category barriers	Sub-barriers					
		Technological	Institutional and administrative	Socio-cultural	Finance and economic	Knowledge and attitudinal	Strategic
Expert 1	0.125	0.153	0.097	0.153	0.153	0.153	0.153
Expert 2	0.083	0.214	0.153	0.214	0.153	0.153	0.083
Expert 3	0.153	0.083	0.153	0.153	0.125	0.153	0.153
Expert 4	0.153	0.125	0.214	0.153	0.153	0.153	0.153
Expert 5	0.153	0.125	0.083	0.125	0.083	0.153	0.125
Expert 6	0.083	0.153	0.153	0.153	0.153	0.153	0.153
Expert 7	0.097	0.179	0.153	0.153	0.125	0.214	0.179
Expert 8	0.153	0.125	0.153	0.153	0.153	0.153	0.153
Expert 9	0.153	0.153	0.153	0.125	0.069	0.153	0.153
Expert 10	0.153	0.153	0.153	0.179	0.153	0.153	0.153
Expert 11	0.153	0.097	0.083	0.153	0.179	0.153	0.153
Expert 12	0.153	0.125	0.083	0.153	0.125	0.153	0.097
Expert 13	0.153	0.083	0.153	0.153	0.153	0.153	0.125

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