A Framework to Achieve Sustainability in Manufacturing Organisations of Developing Economies using Industry 4.0 Technologies' Enablers

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Abstract: Sustainability has emerged as one of the most important issues in the international market. Ignorance of sustainability aspects has led many manufacturing organisations to face huge financial losses. It has been observed that developed nations have successfully achieved sustainability in their manufacturing sectors. However, the rate of sustainability adoption in developing nations is significantly poorer. The current business trend offers new technologies such as the Internet of Things, Big data analytics, Blockchain, Machine learning, etc. These technologies can be termed under the Industry 4.0 paradigm when considered within a manufacturing context. It is significant to notice that such new technologies directly or indirectly contribute to sustainability. So, it is necessary to explore the enablers that facilitate sustainability adoption. This study aims to develop a framework to improve sustainability adoption across manufacturing organisations of developing nations using Industry 4.0 technologies. Initially, the enablers that strongly influence sustainability adoption are identified through a literature review. Further, a large scale survey is conducted to finalise the Industry 4.0 technologies' enablers to be included in the framework. Based on the empirical analysis, a framework is developed and tested across an Indian manufacturing case organisation. Finally, Robust Best Worst Method (RBWM) is utilised to identify the intensity of influence of each enabler included in the framework. The findings of the study reveal that managerial and economical, and environmental enablers possess a strong contribution toward sustainability adoption. The outcomes of the present study will be beneficial for researchers, practitioners, and policymakers.

Keywords: Sustainability; Manufacturing supply chain; Industry 4.0; Developing nations; New technologies, Empirical study, Robust Best Worst Method (RBWM).

1. Introduction

The constantly changing market needs and limited profit margins have push manufacturing organisations to revisit their existing process structures [1]. For this purpose, business managers constantly look to adopt new technologies for improving their entire supply chain and achieve sustainability [2]. Even to compete in the international market, it is essential to develop sustainable products. It has become mandatory to consider the environment and societal aspects of manufacturing along with the economic consideration [3]. Hence, organisations are in search of new technologies that could fulfil their sustainability requirements [4]. Several alternatives such as Circular Economy (CE), Internet of Things (IoT), Big Data Analytics (BDA), Cloud Computing (CC), and Blockchain (BC), etc. have turned up to support the manufacturing, service, and healthcare sectors [5].

These technologies are broadly considered under the umbrella of Industry 4.0, which is considered as the next generation of the industrial revolution [6]. Particularly in developing nations, the manufacturing sector plays a strong role in building the nation's economy [7]. Various Multi-National Companies (MNCs) have shown their interest to develop their manufacturing set up in developing nations such as China, India, Thailand, and Brazil due to low manufacturing costs and cheap labour [8]. However, to improve the supply chain structure and achieve sustainability, Industry 4.0 has emerged as the most prominent solution in the present manufacturing scenario [9]. Nevertheless, Industry 4.0 adoption appears to be successful only in large scale organisations [10], whereas SMEs, especially in developing nations, struggle to achieve sustainability effectively [11].

The emerging economies of the world have succeeded in generating financial gains through their manufacturing sector; but, it is important to notice that these nations have been far away from achieving sustainability within their system [12]. Table 1 represents the status of emerging economies in achieving sustainability.

Table 1. Status of emerging economies in achieving sustainability [6][13][14]

S. No.	**Country**	**GDP (Billion US $)**	**EPI Score (Global rank)**	**Renewable energy usage**	**GHGE (Global %)**	**MCG (%)**	**HDI (Global rank)**	**Type of economy**
1	United States	20,494	71.19 (27)	14.7%	14.75%	18.9%	0.924 (13)	Developed
2	China	13,407	50.74 (120)	24.5%	27.50%	39.5%	0.752 (86)	Developing
3	Japan	4,971	74.69 (20)	15.0%	2.99%	29.7%	0.909 (19)	Developed
4	Germany	4,000	78.37 (13)	29.0%	1.98%	30.1%	0.936 (5)	Developed

5	United Kingdom	2,828	79.89 (6)	27.9%	1.20%	19.4%	0.922 (14)	Developed
6	France	2,775	83.95 (2)	17.5%	0.97%	28.9%	0.901 (24)	Developed
7	India	2,716	30.57 (177)	16.98%	6.43%	19.0%	0.64 (130)	Developing
8	Italy	2,072	76.96 (16)	37.3%	0.93%	24.0%	0.880 (28)	Developed
9	Brazil	1,868	60.70 (69)	80.4%	2.25%	21.0%	0.759 (79)	Developing
10	Canada	1,711	72.18 (25)	65.0%	1.63%	28.1%	0.926 (12)	Developed

Note: EPI- Environmental Performance Index, GHGE- Green House Gas Emission, MCG- Manufacturing Contribution to GDP, HDI- Human Development Index

Among the top ten emerging economies based on GDP, there are only three developing nations, namely; China, India, and Brazil. Similarly, the United States holds the highest GDP in the world, but its environmental performance index ranks 27th globally and uses only 14.7% of renewable energy resources for consumption. However, the case of developing nations is even worse. China ranks 120th, India 177th, and Brazil- 69th for EPI. The same is the case for the human development index, where these countries rank 86th, 130th, and 79th respectively. It is painful to know that 35% of global greenhouse emissions are generated by these 3 developing countries collectively. Among these nations, the contribution of the manufacturing sector towards GDP is significant. Hence, it is strongly needed to achieve sustainability among developing nations through the manufacturing sector [15].

It is noticed in various studies that some organisations in developed nations such as Germany, the United States of America, the United Kingdom, etc. have already succeeded in achieving sustainability by adopting new technologies, especially Industry 4.0 [16]. Availability of infrastructure and advanced technological setups act as foundations for these nations, whereas these same factors also act as missing elements for developing nations [17]. Several authors [18–20] have reported a generalised set of Industry 4.0 technologies' enablers that smoothens the pathway to sustainability, but the applicability of these enablers is questionable in developing nations. Accordingly, there is an immediate requirement to identify the key Industry 4.0 technologies' enablers leading to sustainability in the context of SMEs of developing nations by considering economic, environmental and societal aspects [21]. The present study attempts to explore the key Industry 4.0 technologies' enablers that directly influence sustainability in manufacturing organisations of developing economies and determine their intensity of influence for achieving sustainability. Hence, a hybrid empirical-decision making approach is adopted in this study.

Based on the above-discussed issues the following objectives have been defined for the present study:

- To identify an exhaustive set of Industry 4.0 technologies' enablers to achieve sustainability as reported by researchers in the academic literature;
- To develop an Industry 4.0 technologies' enablers based framework within the context of manufacturing organisations from developing nations for achieving sustainability;
- To determine the intensity of Industry 4.0 technologies' enablers and assess their adoption influence by employing a decision-making approach.

To achieve the above-defined objectives the following process has been followed. Initially, an exhaustive literature review is carried out to explore the key Industry 4.0 technologies' enablers to achieve sustainability in manufacturing organisations of developing nations. Further, a large scale survey-based empirical analysis by considering the manufacturing industry of India is carried out to validate and confirm the list of enablers included in the study. India is a developing country and one of the fastest growing economies. Finally, Robust Best Worst Method (RBWM) is used to compute the weights of each shortlisted enabler to assess their intensity in achieving sustainability. The findings of the present study are equally beneficial for researchers as well as practitioners. This is a unique study that reports 29 key Industry 4.0 technologies' enablers to achieve sustainability and portray the directions for improving the status of sustainability in manufacturing organisations in developing nations. Policymakers can retrieve essential inputs to improve the policies for manufacturing organisations of developing nations.

2. Literature Review

It is important to explore the existing work before initiating any research [22]. Hence, a systematic literature review was conducted in order to ensure that the data to be reviewed was as relevant as possible. The literature review is presented in the following three sub-sections that include: article selection, industry 4.0 technologies' enablers, and literature gaps.

2.1 Article Selection

It is essential to consider the most relevant articles before conducting a literature review. Similarly, it is important to ensure the comprehensiveness and quality of the collected articles. Thus, the present study utilised a systematic literature review approach as suggested by [23], [24], and [25]. An initial search of articles was conducted on Scopus, Web of

Science and Google Scholar databases. The following keywords were used for searching relevant articles, "new technologies and sustainability for industry 4.0" OR "enablers for sustainability" AND "Industry 4.0 technologies' enablers and sustainability". This initial search provided 988 articles. Later on; various other filters were used, e.g. (a) inclusion of only journal articles (393 articles), (b) inclusion of only English language articles (347 articles), (c) removal of duplicate articles across search databases (112 articles), (d) forward snowball and backward snowball technique (64 articles). The forward and backward snowball technique helped in ensuring that the articles that were shortlisted were strictly co-related with the area of research and served its purpose. Furthermore, the final shortlisted articles were studied individually to determine their relevance for the present research. The industry 4.0 enablers addressed in these studies were initially mapped in an excel sheet and later the repeating enablers were eliminated to ensure that the final list only contained unique enablers. The time horizon taken for the study was 2011- October 2019. The authors included research articles from the engineering, mathematics, computer science, decision science, management and accounting fields. Similarly, only journal articles were chosen for the study while all other types of articles that included book chapters, editorial notes, conference articles, short reviews, erratum, etc. were excluded during the article selection process. Articles 'in press' and 'under review' were considered during the initial screening process. The purpose of focusing on journal articles was to ensure the quality of data required for the present research.

2.2 Industry 4.0 Technologies' Enablers to achieve Sustainability

Manufacturing organisations play a vital role in building a nation's economy. Hence, it is essential to explore the critical enablers that lead to manufacturing sustainability. Liu et al. [26] insisted on the adoption of green design and disposal systems that strongly contribute to sustainability. Manufacturing organisations can proof their future not just by meeting the financial targets [27] but also by merging the environment and societal aspects with it [28]. Liu [29] also pointed out "adoption of sustainable energy resource system", "effective sustainability performance metrics", "adoption of industrial ecology initiatives", and "customer awareness for sustainability" as some crucial enablers leading to sustainability in manufacturing organisations. Similarly, it has been observed that manufacturing companies are one of the primary sources for generating pollution through harmful gas emissions [30]. Hence, companies must focus on preventive measures for reducing the emission leading to the pollution of the environment [8].

The role of stakeholders is extremely important in achieving organisational sustainability [5]. It is required for the management to have a strong involvement and commitment towards the adoption of sustainability [31]. However, Moktadir et al. [32] stated that it is necessary to understand the key benefits and long term implications of sustainability to meet organisational goals. Managers must be aware of sustainability supportive policies [33]. Koplin et al. [31] highlighted the role of management towards sustainability adoption and listed out some critical enablers namely; “Policies of rewards and incentives for sustainability adoption”, “smart budget allocation”, “management engagement for sustainability adoption”. Management holds a strong command over the financial decisions to be made in alignment with organisational goals [34]. Hence, it becomes critical to allocate the budget smartly over different sections of the organisation. Promotion of industry IoT assists organisations to keep track of global advancement and helps in achieving sustainability throughout their process structure [35].

On the other hand, supply chain and logistics have a strong impact on operational and financial performance [36]. Hence, to withstand global competition, it is essential to digitise supply chain activities, which will help in real-time tracking of suppliers. Xu et al. [37] mentioned that it is extremely important to receive sustainable raw materials from a supplier if it is desired to manufacture a sustainable product. Adopting reverse logistics facilitates the reduction of product development costs and improve organisational profit margins [38]. It is desired to promote the adoption of knowledge management in the supply chain to make it more effective and competent to exert strong pressures of meeting sustainability requirements [29]. Some frameworks [39–41] proposed by researchers to achieve sustainability have focussed on the economic and environmental aspects of the organisations; but, have failed to capture the role of supply chain and logistics in achieving overall sustainability. It is necessary to understand that achieving organisational sustainability is not possible without greening the existing supply chain [42].

According to Beekaroo et al. [43], “many organisations struggle to achieve sustainability due to ignorance of the societal aspects”. Adoption of sustainable human resource management and practising health and safety modules within organisation leads to the roadmap towards sustainability. Moktadir et al. [32] portrayed various enablers such as “enhancement of man-machine-material interaction”, “understanding the implications of sustainability”, and “effective product life cycle analysis” for achieving sustainability in manufacturing organisations. Garbie [44] pointed out in their study that organisations should carefully track various stages of the product based on the life cycle analysis to fulfil the desired quality and after-sales service. Furthermore, the adoption of a decentralised system and constant tracking of stock and in-process inventory helps in the smooth running of the entire production system [45]. Managing data security and privacy strengthens sustainability in many aspects [46].

Apart from the organisational prospects, the information and technology showcase a significant contribution in achieving sustainability [14]. Based on the new technology and industrial revolution, the adoption of cyber-physical system has emerged as an important aspect. Similarly, "adoption of machine learning system", "effective execution of process optimisation techniques", "practising advance quality improvement techniques" are some of the critical enablers that smoothen the pathway to sustainability [47]. Lu [48] insisted on the adoption of an advanced information sharing system, which ultimately helps in analysing the existing process data more effectively. "Adoption of additive manufacturing system" and "penetration of flexible manufacturing system" are extremely important to compete with global competitors [44]. It is desired that the manufacturing system should be flexible enough to adapt to the continuous changes desired by customers to sustain their product globally [49]. A detailed list of Industry 4.0 technologies' enablers influencing sustainability adoption are portrayed in Table 2.

Table 2. Industry 4.0 technologies' enablers reported by existing literature to achieve sustainability

S. No.	**Industry 4.0 technologies' enablers**	**Description**	**Literature support**
1	Green design and disposal system	Adoption of environmentally friendly design and disposal system supports sustainability	[32]
2	Adoption of sustainable energy resources system	Enhancing the usage of sustainable and renewable energy resources will ensure improved performance	[28,29]
3	Educating customers for sustainability	Awareness of sustainability concepts among the customers will enhance its adoption rate	[5,32]
4	Adoption of industrial ecology initiatives	Industrial ecology initiatives promote CE and tackle environmental concerns effectively	[26, 37, 40]
5	Adoption of cyber-physical system	Adopting a cyber-physical system will lead to a sustainable future and facilitate advance technology acceptance	[29,41,48]
6	Adoption of a machine learning system	Machine learning system will reduce human interaction and improve precision in the manufacturing organisation	[38,49,50]
7	Adoption of an additive manufacturing system	Additive manufacturing system reduces manufacturing costs and helps in developing sustainable products	[1,51,52]

8	Penetration of the flexible manufacturing system	Flexible manufacturing system assists in quick product modification to meet sustainability and customer requirements	[37,38]
9	Effective sustainability performance metrics	Adoption of sustainability performance metrics ensures tracking of manufacturing activities and aligning sustainability	[48,53]
10	Continuous monitoring of reduction emission	Reduction in emission is an important aspect to protect the environment pollution	[54,55]
11	Adoption of effective process optimisation techniques	Optimisation techniques help in standardising the manufacturing process and design-related activities	[56,57]
12	Adoption of advanced quality improvement techniques	Adopting quality improvement techniques helps in improving the organisational performance	[58]
13	Advanced information sharing systems	Smooth and effective information sharing system helps in building collaboration among the system aligned activities	[1,5]
14	Sustainable human resource management	Sustainable human resource management is an essential aspect to roadmap sustainability by considering human relations and related activities	[51,52]
15	Adoption of health and safety modules	Health and safety measures adopted within the organisation provides stability to employees and develops a sustainable working culture	[29,43]
16	Constant tracking of stock and in-process inventory	Effective monitoring of existing stocks and in-process inventory will ensure uninterrupted functioning of the manufacturing process	[1,5]
17	Adoption of the decentralised system	Adoption of the decentralised system facilitates the tracking of departmental activities and enhance process focus	[28,29]
18	Enhancement of man-machine-material interaction	Improving the man-machine-material interaction will strengthen the sustainability of the final product	[48,53]
19	Adopting reverse logistics	Reverse logistics ensures the execution of corrective actions on product and process development	[37,38]
20	Adoption of sustainability supportive policies	Government offers various sustainability supportive policies for the manufacturing organisations to develop an overall sustainable environment	[1,50]
21	Promoting Industry internet of things	Promotion of industry IoT helps the organisations to compete at the global level and achieve international standards	[32,50]
22	Smart budget allocation	Smart budget allocation helps in distributing the available financial resources effectively among the entire organisational structure	[51,52]
23	Adoption of smart factory components	Adopting smart factory components ensures overall sustainability including economic, environmental and societal concerns	[29,43]
24	Management engagement towards sustainability adoption	It is necessary to have strong involvement of management and positive perception towards sustainability adoption	[1,5]

25	Policies of rewards and incentives for sustainability adoption	Policies of rewards and incentives for sustainability adoption will enhance the employee involvement towards sustainability	[28,29]
26	Managing data security and handling	Industry 4.0 ensures securing the organisational data and using it for improving the operational performance	[37,38]
27	Understanding the implications of sustainability	It is important to understand the exact implications of sustainability and its impact on the near future	[29,43]
28	Effective product life cycle analysis	Design, analysis, production, promotion, and abortion of product should be analysed based on product life cycle analysis	[1,50]
29	Digitisation of supply chain activities	Digitising the supply chain activities improve supply chain performance and boosts sustainability	[48,53]
30	Real-time tracking of suppliers	Real-time tracking of suppliers assists in keeping the inventory stocks at optimum levels	[32]
31	Promoting knowledge management in supply chain	Practising knowledge management in the supply chain improves supply chain sustainability and logistics performance	[51,52]
32	Supplier commitment for sustainable procurement	It is required to have a strong commitment of suppliers to execute sustainable procurement practices to roadmap sustainable product development	[1,5]

2.3 Literature Gaps

Based on the literature reviewed on Industry 4.0 technologies' enablers for sustainability, the following knowledge gaps in the academic literature were identified.

- The existing literature has highlighted several studies [8,34,51] that helped in showcasing the enablers that assist in achieving sustainability across manufacturing organisations. However, very few studies have pointed out the enablers relating to new technologies.
- Researchers [3,37] in the existing literature portrayed a list of enablers influencing sustainability. Nevertheless, these studies have failed to establish a linkage on how these enablers impact the adoption of sustainability.
- Several studies [38,59] based on the enablers for sustainability adoption in manufacturing organisations have only used empirical analysis as a tool for framework validation. Although, it is essential to employ any decision-making approach.
- The mere identification of enablers supporting sustainability in manufacturing organisations is not sufficient [60]. Hence, it is essential to identify the intensity of influence of each enabler on sustainability adoption through multi-criteria decision-making approaches.

- Various studies [31,43] have shared success stories of new technology adoption across developed nations. However, very few studies were able to succeed in achieving sustainability among manufacturing organisations in developing economies.
- Few studies [61-63] have developed an enabler specific framework and considered only Technology, Organisation and Environment (TOE) to enhance sustainability adoption. But, these frameworks have not been verified and hence, their applicability is questionable.

The above-mentioned gaps suggest the need for research work that highlights the enablers supporting sustainability adoption across manufacturing organisations in developing nations. Furthermore, it is required to determine the intensity of the influence of these enablers in sustainability adoption. These gaps support objectives defined at the beginning of this study.

3. Research Methodology

This study initially conducted a systematic literature review to explore the key enablers based on Industry 4.0 technologies, which supports sustainability adoption. The identified enablers were further tested through a large scale survey to ensure that the selected set of enablers possessed a strong influence on sustainability adoption across manufacturing organisations of developing economies. An empirical analysis was then carried out to group the selected enablers and finalise them. Later, a manufacturing case organisation was selected to conduct a case analysis. An expert panel was formed by including the members of the case organisation. This panel was utilised to categorise the selected enablers. Then, an enabler based framework to enhance sustainability adoption was developed and supplied to the case organisation. The inputs for the RBWM approach were also obtained through the expert panel. The results of the RBWM approach helped in identifying the intensity of each enabler on sustainability adoption.

3.1 Research Methods Adopted for the Study

The present research was underpinned by a mixed method research approach. The methodological flow of the research is illustrated in Figure 1.

Figure 1. Overall flow of the research methodology that underpinned the present study

3.1.1 *Empirical analysis*

To provide a strong theoretical foundation for this research work, an empirical analysis which consisted of the combination of both qualitative and quantitative approaches was followed. The main objective of the study was to develop a framework to enhance sustainability adoption across manufacturing organisations of developing nations using Industry 4.0 technologies' enablers. In order to have a better understanding of the enablers, it was essential to perform an empirical analysis. The Statistical Package for the Social Sciences (SPSS) is a software for editing and analysing data collected from a questionnaire-based survey [64]. Therefore, an investigation through an empirical study was carried out by using SPSS 21.0 to finalise the enablers. Cronbach alpha was used to check the reliability and validity of the collected data [65,66]. Exploratory factor analysis was used to develop a factors structure of the drivers.

3.1.2 *Robust-BWM approach*

The MCDM literature offers a huge variety of approaches for solving complex decision-making problems [51]. However, the applicability of these approaches depends strictly upon the nature of the problem [29]. In the present situation, it was desired to calculate the weights of enablers influencing sustainability adoption. For this purpose, AHP, SWARA, MOORA and other approaches are available. Nevertheless, Best Worst Method (BWM) offers a better option over these approaches as it uses less paired comparisons and overcomes certain drawbacks of AHP [67]. Furthermore, different variants of BWM are proposed in the existing literature. Among these variants, RBWM is considered to be the most stable as it effectively handles vagueness and uncertainty [68]. It also considers a range of comparisons among two enablers instead of allotting a specific number. This uniqueness of operation enriches the applicability of RBWM for the present case.

4. A Real-World Case Application

This section describes a real-world case application. The details are provided in following subsections.

4.1 Problem Definition and Organisation Description

According to the objectives defined for this study, an automotive manufacturing company was selected as a case organisation. The ABC organisation was established in 1976 and is situated in the central region of India. It holds around 850 employees working in three shifts with an annual turnover of $ 190 million. The organisation has a wide range of clients throughout the country, but they have failed to earn themselves as a brand on the international platform. For this reason, management is constantly working to meet international product standards and achieve sustainability. After a discussion with top management, they agreed to help the authors in developing and testing the framework to achieve sustainability using Industry 4.0 technologies' enablers within their firm.

Initially, an expert panel which consisted of a total of 6 experts was established. This included one top management executive, two project managers, one supply chain and operations head, one R&D head and one warehouse and packaging supervisor. All team members of the expert panel individually held more than 15 years of experience; the two project managers and supply chain head possessed a strong exposure to handling international business while the experts from the warehouse and R&D had handled green and sustainability initiatives in the past. Their expert opinion was sought to develop the questionnaire instrument and perform its content validity. Secondly, inputs for RBWM were also obtained to identify the intensity of the influence of enablers on sustainability adoption.

4.2 Survey Analysis

4.2.1 *Questionnaire development and data collection*

An empirical study was conducted to check the statistical establishment of all identified Industry 4.0 technologies' enablers to achieve sustainability. A questionnaire was prepared based on a 1-5 scale (i.e. 1 - strongly disagree and 5- strongly agree). The pre-testing of the questionnaire was done with the help of area experts and academics who held large experience in this area. Based on their inputs, the language of some questions was amended and made simpler to understand. After the modification, a final questionnaire was prepared and a small sample was used for pilot testing. The research team initially used a convenience sampling method for data collection but after meeting some respondents, they referred us to the company's staff who were working in the same area. After following this process, the research team was able to collect 247 respondents. However, after the screening process, a total of 230 responses were used to conduct the empirical analysis, which is quite acceptable. The details of the participants' profiles are presented in Table 3.

Table 3. Participants' profiles

Characteristics		**Total**	**Percentage (%)**
Gender	Male	167	72.61
	Female	63	27.39
Education	Undergraduate	50	21.74
	Graduate	74	32.17
	Postgraduate	81	35.22
	Others	25	10.87
Work experience (in years)	0-5	29	12.61

	6-10	48	20.87
	11-15	62	26.96
	16-20	42	18.26
	Above 20	49	21.30
Position	Senior Level Manager	34	14.78
	Medium Level Manager	68	29.57
	Manager	76	33.04
	Others (employee in sourcing, logistics, production, operation, and other services, etc.)	52	22.61
Department	R & D	25	10.87
	Shop Floor	74	32.17
	Warehouse and Logistics	28	12.17
	HR	21	09.13
	Supply Chain	37	16.09
	Others (Marketing, Finance, and other services, etc.)	45	19.57
Type of Manufacturing	Automobile and Automotive Component Manufacturing	79	34.35
	Electronics and Electrical Manufacturing	39	16.96
	Textile and Apparel Manufacturing	26	11.30
	Machine Tools Equipment and Engineering Manufacturing	29	12.61
	Chemical and Pharmaceuticals Manufacturing	27	11.74
	Others (FMCG and Food Manufacturing, etc.)	30	13.04

4.2.2 *Measurement of biasness*

When primary data is collected, it can be affected by biased views of respondents. To minimise this, the authors kept all the responses opinions anonymous [69]. To make the study objectives more understandable, these were sent to the respondents, alongside a brief description of the study so that they could dedicate more time to filling the questionnaire and provide bias-free responses.

4.2.3 *Reliability and validity checks*

With the help of reliability and validity tests by using SPSS 21.0, the authors did not only check the accuracy of the collected data but also assessed the ‘goodness of a measure’. For measuring reliability, we used Cronbach’s alpha (α) and its recommended values [70]. Field [64] indicates that if the factor loading of each variable is greater than 0.5, there is convergent validity for the data. In this work, the overall Cronbach’s alpha (α) value was 0.830, so as per previous literature the data was considered acceptable. Field [64] further reported that if the factor loading of each item is greater than 0.5, it shows both the internal consistency and convergent validity of the instrument. After establishing the factor structure of enablers to achieve sustainability using EFA, the convergent validity of the instrument was measured by calculating the Cronbach alpha value, where the range was between 0.838 and 0.933.

4.2.4 Exploratory Factor Analysis (EFA)

EFA is a multivariate technique that is widely employed to determine the factors structure. With the minimum loss of information, EFA has the ability to reduce the number of variables into a set of structures. In this study, EFA was used to define the factor structure of the identified Industry 4.0 technologies' enablers to achieve sustainability. Before using EFA, the data should be suitable for such purpose. For this, Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity were conducted. Eisinga et al. [65] suggest that the KMO value should be greater than the minimum recommended value (0.60) and that the Bartlett's Test of Sphericity to be significant at $p < 0.01$. In this case, the sampling adequacy value for each enabler was above the acceptable value of 0.50. Thus, the analysis showed that the collected data fulfilled the recommended criteria and suitability to apply EFA. Field [64] suggested that with varimax factor rotation, EFA was carried out to determine the factor structure for enablers; an Eigenvalue (>1) was used to obtain the final factor structure. As shown in Table 4, all drivers were structured into five main drivers with a total variance of 71.27%. The factor loading of each main driver under its respective sub-capabilities was in the range of 0.635 - 0.911, above the acceptable level of 0.60. The commonalities range was 0.463 - 0.853, also above the acceptable limit of 0.40. Three enablers, i.e. 'Adoption of an additive manufacturing system', 'Adoption of advanced quality improvement techniques' and 'Constant tracking of in-process and stock inventory' were dropped from further analysis due to low loading as per the acceptable level 0.60 [71].

Table 4. EFA analysis results

Group	Indicator	Loading	Commonalities	Cronbach (α)
Group 1	Adoption of machine learning system	0.911	0.836	0.926
	Adoption of cyber-physical system	0.897	0.815	
	Adoption of effective process optimisation techniques	0.881	0.802	
	Penetration of the flexible manufacturing system	0.872	0.789	
	Adoption advanced quality improvement techniques	0.832	0.714	
	Advanced information sharing systems	0.751	0.598	
	Adoption of additive manufacturing system	0.635	0.472	
Group 2	Continuous monitoring of reduction emission	0.908	0.875	0.933
	Adoption of sustainable energy resources system	0.862	0.778	
	Effective sustainability performance metrics	0.844	0.755	
	Educating customers for sustainability	0.843	0.794	

	Green design and disposal system	0.828	0.710	
	Adoption industrial ecology initiatives	0.751	0.672	
Group 3	Management engagement towards sustainability adoption	0.903	0.843	0.887
	Adoption sustainability supportive policies	0.899	0.844	
	Adoption of smart factory components	0.787	0.658	
	Smart budget allocation	0.762	0.596	
	Promoting Industry internet of things	0.716	0.566	
Group 4	Digitisation of supply chain activities	0.866	0.763	0.838
	Real-time tracking of suppliers	0.864	0.758	
	Adopting reverse logistics	0.744	0.662	
	Supplier commitment for sustainable procurement	0.678	0.509	
	Promoting knowledge management in the supply chain	0.650	0.492	
Group 5	Adoption of health and safety modules	0.904	0.853	0.918
	Sustainable human resource management	0.895	0.828	
	Effective product life cycle analysis	0.868	0.787	
	Enhancement of man-machine-material interaction	0.826	0.779	
	Managing data security and handling	0.781	0.657	
	Understanding the implications of sustainability	0.623	0.463	

4.3 Framework Development

The exploratory factor analysis indicated that out of 32 shortlisted enablers, 29 were found to be suitable for the present problem. These enablers were spread over 5 groups. Thus, the results were further shared with the expert panel to categorise the enablers and develop the framework. Based on the experts' feedback and similarity of the enablers, these groups were named as informational and technological, which contained informational and technological enablers. All environment enablers were in the environmental group. The third group contained all the enablers related to managerial and economical aspects, the supply chain management group contained all the enablers related to supply chain management while the last group contained all enablers related to organisational and social factors. Accordingly, a framework was developed to enhance sustainability in manufacturing organisations. Figure 2 indicates the details of the developed framework. The framework was tested in the case organisation to identify the intensity of influence of the selected enablers in sustainability adoption.

4.4 Multi-Criteria Decision Making Analysis

The framework developed in the previous section was then tested through the RBWM approach. In the RBWM approach, the experts were asked to make the pairwise comparisons major group and subgroup enablers separately [72]. During the process of paired comparison, it was possible for the experts not to be able to overcome the vagueness and fail to handle uncertainty.

Figure 2. Framework to enhance sustainability adoption

Hence, instead of allotting a crisp value for a comparison of two enablers, a defined range was given. The procedure followed to execute the RBWM is presented below.

Step 1: Finalising the criteria - This step included the finalisation of the criteria that needed to be included for problem-solving. Here, a set of criteria (C_1, C_2, C_3…. C_n) was used to decide between alternatives.

Step 2: Allotment of best and worst criteria - This step included allotting the best and worst criteria across the major group and all the corresponding sub-groups.

$A_B = (a_{b1}, a_{b2}, a_{b3},\ldots a_{bn})$

$A_W = (a_{w1}, a_{w2}, a_{w3},\ldots A_{wn})$

Step 3: Determining the paired comparisons - Instead of providing a finite value, a range was provided. For example, the relation between enabler A and enabler B was given in the range of 2.5 and 3.5. Hence, an optimum value within this range was tested rather than allotting a finite value 3.

Step 4: Determining the best solution - To obtain the best solution, the Soyester method was utilised for the present problem. According to the Soyester method, the present problem can be formulated based on the following model.

Min ξ^R

Subject to $W_B - A_{Bj} W_j + A_{Bj} Y_B - \xi^R \leq 0, \ \forall j, B$

$A_{Bj} W_j - W_B + A_{Bj} Y_{B'} - \xi^R \leq 0, \ \forall j, B'$

$$W_j - A_{jw} W_w + A_{jw} Y_w - \xi^R \leq 0, \quad \forall j, w$$

$$A_{jw} W_w - W_j + A_{jw} Y_{w'} - \xi^R \leq 0, \quad \forall j, w'$$

$$- Y_B \leq W_j \leq Y_B, \qquad \forall B, j$$

$$- Y_{B'} \leq W_j \leq Y_{B'}, \qquad \forall B', j$$

$$- Y_w \leq W_w \leq Y_w, \qquad \forall w, j$$

$$- Y_{w'} \leq W_w \leq Y_{w'}, \qquad \forall w', j$$

$$= 1$$

$$W, Y \geq 0,$$

This approach ensured the protection of uncertainty and helped decision-makers and practitioners predict the best possible influence values of enablers over the sustainability adoption. The comparison ranges, best and worst enablers for the major group provided by the expert panel are shown in Table 5.

Table 5. Best and worst comparisons of major group enablers

Main group enabler	Range	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Average Weight
Informational and Technological (IT)	B_{max}	2.25	1	7.5	6.5	2.5	3.5	0.191
	B_{min}	1.75	1	6.5	5.5	1.5	2.5	
	W_{max}	4.25	6.5	1	1	5.5	4.5	
	W_{min}	3.75	5.5	1	1	4.5	3.5	
Environmental (EM)	B_{max}	1	2.5	5.5	5.5	1	6.5	0.234
	B_{min}	1	3.5	4.5	4.5	1	5.5	
	W_{max}	8.45	3.5	2.5	2.5	6.5	1	
	W_{min}	7.55	2.5	1.5	1.5	5.5	1	
Managerial and Economical (ME)	B_{max}	4.5	6.5	1	1	6.5	1	0.263
	B_{min}	3.5	5.5	1	1	5.5	1	
	W_{max}	2.15	1	7.5	6.5	1	6.5	
	W_{min}	1.85	1	6.5	5.5	1	5.5	
Supply chain management (SC)	B_{max}	3.5	2.5	3.5	2.5	5.5	5.5	0.152
	B_{min}	2.5	1.5	2.5	1.5	4.5	4.5	
	W_{max}	3.65	4.5	4.5	5.5	2.5	2.5	
	W_{min}	2.35	3.5	3.5	4.5	1.5	1.5	
Organisational and Social (OS)	B_{max}	8.45	4.5	2.5	2.5	4.5	2.5	0.161
	B_{min}	7.55	3.5	1.5	1.5	3.5	1.5	
	W_{max}	1	2.5	5.5	5.5	3.5	5.5	
	W_{min}	1	1.5	4.5	4.5	2.5	4.5	

Similarly, comparisons were made for each subgroup. The final weights of each subgroup enablers are presented in Table 6.

Table 6. Final weights of enablers influencing sustainability adoption

Main Group	Group Weight	Sub-Factor	Local Weight	Global Weight	Global Rank
Informational and Technological (IT)	0.191	IT1	0.083	0.016	26
		IT2	0.321	0.061	4
		IT3	0.213	0.041	10
		IT4	0.203	0.039	11
		IT5	0.045	0.009	28
		IT6	0.091	0.017	25
		IT7	0.042	0.008	29
Environmental (EM)	0.234	EM1	0.086	0.020	22

		EM2	0.318	0.074	1
		EM3	0.256	0.060	5
		EM4	0.045	0.011	27
		EM5	0.185	0.043	8
		EM6	0.110	0.026	19
Managerial and economical (ME)	0.263	ME1	0.239	0.063	3
		ME2	0.258	0.068	2
		ME3	0.144	0.038	12
		ME4	0.188	0.049	6
		ME5	0.170	0.045	7
Supply chain management (SC)	0.152	SC1	0.270	0.041	9
		SC2	0.207	0.032	15
		SC3	0.180	0.027	18
		SC4	0.227	0.035	14
		SC5	0.116	0.018	24
Organisational and social (OS)	0.161	OS1	0.185	0.030	16
		OS2	0.222	0.036	13
		OS3	0.179	0.029	17
		OS4	0.117	0.019	23
		OS5	0.159	0.025	20
		OS6	0.140	0.022	21

5. Study Findings and Discussions

In line with the research objectives of the present study, an exhaustive literature review was conducted to explore the Industry 4.0 technologies' enablers that strongly influence sustainability adoption across manufacturing organisations in developing economies. Later, a manufacturing case organisation was selected to develop and test the framework to enhance the sustainability adoption rate. An expert panel formed within the case organisation was utilised to test the content validity of the questionnaire instrument developed to conduct a large scale survey. The responses obtained through the survey were tested and an exploratory factor analysis was conducted to group similar factors. After conducting the empirical analysis, the findings were utilised to develop an enabler based framework to enhance sustainability adoption.

Further, the RBWM approach was applied to identify the intensity of the influence of enablers on sustainability adoption. The results revealed that among the major group enablers were Managerial and Economical enablers (ME), which obtained the highest weight (0.263), followed by Environmental enablers (EM- 0.234), Informational and Technological enablers (IT- 0.191), Organisational and Social enablers (OS- 0.161), and Supply Chain Management enablers (SC- 0.152). Khurana et al.'s [73] study support the above results by indicating in their study that managerial and environmental enablers strongly affect sustainability adoption. Among the subgroup of enablers, the adoption of a sustainable energy resource system (EM2- 0.074) held the highest intensity of influence on sustainability adoption, followed by the adoption of sustainability supportive policies (ME2- 0.068), management engagement towards sustainability adoption (ME1- 0.063), adoption of cyber-physical system (IT2- 0.061), and effective sustainability performance metrics (EM3- 0.060). Shankar et al. [2] and Liu et al. [29] also indicated that the adoption of sustainable energy resource systems and consideration of sustainability supportive policies are necessary prerequisites for sustainability adoption.

Among the informational and technological enablers, adoption of cyber-physical system (IT2), adoption of effective process optimisation techniques (IT3- 0.041), and penetration of flexible manufacturing system (IT4- 0.039) emerged as the most prominent enablers that support sustainability. Cai et al. [30] highlighted that if a manufacturing system is rigid, it becomes really difficult for the practitioners to incorporate the changes based on reverse feedback. Similarly, a cyber-physical system transits a manufacturing system towards the next generation and eliminates the chances of errors in the production system. Among the environmental enablers (EM), adoption of sustainable energy resource system (EM2), effective sustainable performance metrics (EM3), and green design and disposal system (EM5- 0.043) were the most critical enablers. The study conducted by Piyathanavong et al. [34] also pointed out that the greening of activities throughout the organisation is essential if the organisation wants to achieve sustainability. They argued that despite adopting greener activities, it is mandatory to have sustainable performance metrics that could monitor and track the activities over sustainability.

Among the managerial and economic enablers, adoption of sustainability supportive policies (ME2), management engagement towards sustainability adoption (ME1), smart budget allocation (ME4- 0.049), and promoting industry internet of things (ME5- 0.045) resulted as the most significant enablers that correlate to sustainability. Niaki et al. [74] insisted on management involvement towards sustainability adoption and stakeholders' participation as an essential component to withstand the business on a global platform. Decisions related to policies, strategies, and finance stands with the management and hence, to penetrate sustainability effectively their involvement is essential. Among the supply chain management enablers, digitisation of supply chain activities (SC1- 0.041), supplier commitment for sustainable procurement (SC4- 0.035), and real-time tracking of suppliers (SC2- 0.032) turned up as sustainability favouring enablers. Seuring et al. [5] reported that sustainability is extremely difficult to achieve without greening the entire supply chain and logistics. It includes from the idea generation stage and up to after-sales service. Digitisation of supply chain activities helps industrialists in keeping a constant track over the production process and controlling the occurrence of errors with an immediate effect.

Among the organisational and social enablers, sustainable human resource management (OS2- 0.036), adoption of health and safety modules (OS1- 0.030), effective product life cycle analysis (OS3- 0.029), and managing data security and handling (OS5- 0.025) resulted as the most critical enablers that need to be practised by organisations. Xu et al. [37] argued that achieving sustainability in its correct form has always been a debatable topic. Many researchers have discussed the inclusion of economic and environmental aspects to achieve sustainability; but, many of them have missed to capture the social aspect. The contribution of manufacturing organisations towards the handling of social aspects is as important as their contribution to nations' GDPs. Similarly, effective product life cycle analysis helps industrialists to adopt decisions on promotions, modifications, and disposal accurately.

5.1 Study Implications

The present study makes significant contributions to researchers and practitioners working in the sustainability domain. The implications of this study are as follows.

- The literature on sustainability offers a large number of frameworks [16,75] that support sustainability adoption, but the majority of them are generalised. However, the present study develops a framework for sustainability adoption across manufacturing organisations of developing nations using Industry 4.0 technologies' enablers.
- This study identifies a unique set of 29 enablers, based on Industry 4.0 technologies, which contribute to the achievement of sustainability. The identified enablers were verified through experts' opinions. The study can thus be beneficial for industrialists involved in the sustainability adoption process. The exhaustive set of enablers can be utilised by researchers to conduct allied studies in the sustainability domain.

- The majority of sustainability-oriented frameworks [35,76] reported in the literature have not been verified. However, the framework developed in this study was verified empirically and through a multi-criteria decision-making method.
- Researchers in the literature [3,51] have identified the enablers that support sustainability adoption. However, only a few of them have highlighted the intensity of their influence in the adoption process. This study employed the RBWM approach to determine the intensity of each enabler included in the framework.
- The simultaneous adoption of all the enablers is extremely difficult [77]. However, the weights of enablers determined in this study will assist companies involved in sustainability adoption to focus on high-intensity enablers on priority.
- The framework developed in this study was tested in an Indian context. Other developing economies can utilise the present framework by making modifications to it in consultation with the domain experts of that country.

6. Conclusions

This study develops a framework for manufacturing organisations to enhance sustainability adoption. It determines a unique set of 29 Industry 4.0 technologies' enablers that strongly influence sustainability adoption. The study employs a unique combination of empirical and multi-criteria decision-making approaches to solve the present problem. Initially, the study conducts an empirical analysis to finalise the enablers influencing sustainability adoption. Later, a framework was developed and tested in a manufacturing organisation to improve sustainability and compete at an international level. Further, the RBWM approach was utilised to determine the weights of enablers included within the framework. The results reveal that managerial and economical enablers were found to be the most critical for sustainability adoption; while, environmental enablers also possessed a strong influence in achieving overall sustainability. It is important to notice that the adoption of sustainable energy resources systems, adoption sustainability supportive policies and effective sustainability performance metrics were among the top influencing enablers that support sustainability adoption. Accordingly, it is suggested that government policies favouring sustainability adoption through the execution of new technologies will have a positive impact on strengthening nations' economy. Similarly, the promotion of a sustainable energy resource system will create awareness among manufacturing organisations and help them improve their sustainable performance.

6.1 Limitations and Future Research Directions

The present study explored Scopus, Web of Science and Google Scholar to identify the articles and list the key Industry 4.0 technologies' enablers influencing sustainability adoption. Researchers may further increase the number of databases for the literature search in order to identify more articles to support the study as it is possible that some studies that influence sustainability might not have been identified and considered. In this work, an empirical study has been conducted in a single India manufacturing company. Thus, future research can be conducted by considering multiple manufacturing companies and organisations in other industrial sectors and countries. This will increase the reliability and validity of the results obtained from the present study. Similarly, this study highlights the intensity of the influence of enablers towards sustainability adoption. Nevertheless, it does not shed light on the structural relationship among these enablers. Researchers may extend the present study findings by applying various structural techniques such as interpretive structural modelling, decision-making trial and evaluation laboratory, fuzzy cognition maps, analytical network process, etc. to establish the inter-relationships among the enablers included in the developed framework. Finally, the present research is equally beneficial for researchers, practitioners and policymakers. The developed hierarchical framework may be applicable to various Indian manufacturing organisations and other developing countries' manufacturing organisations with marginal or no modifications. The study will, therefore, assist developing nations in achieving sustainability across their manufacturing sector.

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