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Developing A sustainability framework for Industry 4.0

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Abstract

With the development in industrialization, sustainability has emerged as a major issue in the global market. Ignorance of sustainability issues in any organization leads to huge financial losses and market reputation. With the development of new technologies developed economies have achieved sustainability in their industry sectors due to strong infrastructure. However, the adoption levels of sustainability practices in emerging economies are still limited. The current manufacturing trend in Industry 4.0 offers new key technologies e.g. cyber-physical systems, IoT (Internet of Things), additive manufacturing and big data analytics which are under the umbrella of Industry 4.0 known as key technologies for 4th industrial revolution. These new technologies are contributing to sustainability in a direct or indirect way. Identification of different enablers is necessary as it facilitates the adoption of sustainability practices in Industry 4.0. The present study aimed at the development of sustainability practices framework for Industry 4.0 for MSMEs (Micro Small Medium enterprises) sector. Initially, enablers to sustainability in Industry 4.0 were identified from the available literature on Sustainability and Industry 4.0. Further, a case study is done in one of MSMEs of India which is working on the adoption of Industry 4.0 practices. A hybrid MCDM (multi-criteria decision making) approach based on F-AHP (Fuzzy-Analytical hierarchy process) and DEMATEL (Decision making trial and evaluation laboratory) is utilized for the framework development. The results revealed that supply chain and environment related enablers are the main cause of barriers to sustainability in Industry 4.0. It is expected that the findings of this study will be beneficial for the researchers, policymakers and managers to improve the sustainability with the use of Industry 4.0 technologies within the emerging economies in MSMEs.

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Keywords: Sustainable manufacturing; sustainability; manufacturing; Industry 4.0; Fuzzy AHP; DEMATEL.

Introduction

The changing market needs, volatile customer demands, sustainability issues, and limited economic profits in various industry sectors have pushed many industries to revisit their existing organizational structure [1]. Due to the government policies and customer pressure it is necessary to consider the economic, environmental and social dimensions in manufacturing practices [2]. Industries are now looking for adoption of new technologies which can fulfil the sustainability requirements in which alternatives such as Big Data Analytics, Blockchain technology, Cyber-physical systems, cloud computing and Circular economy are popular [3]. These alternatives emerged as a support for sustainability in manufacturing and health care sectors. All these new technologies are known as key technologies for Industry 4.0 which is known as the 4th Industrial revolution [4]. The manufacturing sector plays a vital role in the development of economy in emerging economies but it is far away from achieving sustainability in manufacturing practices [5]. In the last few years many Multi-national companies having good brand image investing in emerging economies such as India, Brazil, China and Thailand due to less production costs as compared to developed economies [6]. To improve the sustainability and supply chain structure in the organization Industry 4.0 and its key technologies emerged as an effective solution in various industry sectors [7]. It is found that adoption of Industry 4.0 is successful only in large scale organizations only whereas the small and medium scale industries are still struggling in the adoption of Industry 4.0 practices [8]. Studies reported that various developed nations such as USA, UK and Germany have already implemented the new technologies and achieved sustainability in these technologies [9]. Availability of infrastructure is one of the key enablers in the adoption of new technologies in developed countries which is still a barrier in emerging economies [10]. Some studies have reported the generalized set of enablers but it is still questionable for the emerging economies [11]. With the limitation of these studies, there is a requirement of identification of key enablers for the MSMEs of emerging economies in all three sustainability dimensions i.e. social, economic and environmental. On the basis of the above issues and limitations in studies we have set up the following objectives:

1. Identification of key enablers of social, economic and environmental dimension for Industry 4.0 for MSMEs.
2. Development of a sustainability-based Industry 4.0 framework for MSMEs manufacturing sector in emerging economies.
3. Investigation and assessment of Industry 4.0 adoption level in MSMEs of emerging economies with hybrid MCDMs approaches.

To achieve the above-mentioned objectives initially enablers are identified from the research articles extracted from the Scopus and Web of Science database to explore the enablers and drivers for Industry 4.0. Further, a case study in the MSMEs which is adopting the Industry 4.0 technologies was selected for the case study. Expert opinions were taken to develop the hybrid approach based on F-AHP and DEMATEL. In the study, F-AHP is used to identify the influencing intensity of Industry 4.0 enablers and DEMATEL is used to find the inter-relationship among the Industry 4.0 enablers.

Data Collection and Methodology

Table 1 represents the list of 25 enablers identified from the teh extensive review of the literature related to topics like implementation case studies on Industry 4.0, Industry 4.0 initiatives, and sustainability in Industry 4.0 and finalized in different criteria after discussion with industry experts and academia working in the area of sustainable manufacturing and Industry 4.0.

In the present study, we have approached the researchers from the different countries working in the area of sustainable manufacturing and Industry 4.0 for the survey as the theories and perceptions related to sustainable manufacturing and Industry 4.0 are same in any region of the world. Hence, we have considered the electronics manufacturing industry located in Kala Amb industrial area from the northern part of India in Himachal Pradesh due to its geographic importance for the manufacturing of automobiles, electronics, and pharmaceutical goods. Also, the geographical region was located at approximately 500 Km from the author's base (MNIT Jaipur). As implementation of Industry 4.0 and sustainability practices vary with both political and economic factors so keeping in mind survey was contained to only one region. Kala Amb is known as the largest manufacturing hub for automobile components, pharmaceutical goods, and electronics components. In the Kala Amb lot of small-scale manufacturing industries are operating which are now focusing on the implementation of Industry 4.0 and sustainability practices and facing several issues. These industries provided valuable insights into the study.

A questionnaire was developed to collect responses from both industry professionals (From Kala Amb Industrial Area) and researchers. In the collection stage, all the respondents from industry were asked to rate the importance of enablers for our study according to their experience, expertise, and knowledge on the scale of 1 to 5.

Total participation time in the questionnaire responses ranged from 8-10 minutes. We have followed a pilot study before releasing the questionnaire to industry professionals and researchers. In the pilot study, the questionnaire was filled by 5 professors three from India and two from the United Kingdom with more than 15 years of teaching and research experience in Industrial engineering. The survey was sent to all the researchers through Email. All the responses were collected through the Google response sheet. Initially, we have searched the authors working in the area of Industry 4.0 and sustainability by using the keywords "Sustainability" OR "Sustainable manufacturing" and "Industry 4.0" on the Scopus and Web of Science database. The survey requests were sent to them at the mentioned email id by authors in their papers. These authors are also requested to provide the reference whom they can consider to provide better inputs in this study. The researchers from the United States, United Kingdom, Bangladesh, Germany, and Italy were approached through email. A total of 42 researchers were contacted for the response collection in which only 9 responses were collected and the response rate was 21.43%. All the responses were obtained from the researchers. The questionnaire survey was sent to a company (ABC) which manufactures electronic components and currently working on Industry 4.0 implementation and has already implemented sustainability practices. A total of 6 responses were collected from the ABC company. The total time duration for response collection was 2 months from June 2020 to August 2020.

In this study, we have used F-AHP for the pair-wise comparison of enablers of each enabler group. Enabler weight is computed through the pairwise comparison. The interrelationship between the enablers is found with the DEMATEL approach. Expert opinions were utilized for the pair-wise comparison and compute the enabler's weights with F-AHP. Further inter-relationship between enablers is identified with the DEMATEL approach.

Table 1: Enablers for sustainability in Industry 4.0

Enabler Name/Criteria	Description	Reference
Sustainable development policies (ECM1)	Government offers sustainable development policies for the manufacturing sector which will help to improve the sustainable environment of the organization	[3], [7], [12], [13], [17]
Smart factory components (ECM2)	Adoption of smart factory components (SFC) helps to improve sustainability in all three dimensions of sustainable manufacturing.	[3], [6], [9], [12], [14], [17]
Promoting IoT (ECM3)	Promotion of Internet of things helps the industries to compete with global industries and matching the international standards.	[7], [9], [15], [16], [17]
Smart Budget allocation (ECM4)	Adoption of smart budget allocation helps in the distribution of available	[3], [7], [9], [12], [16], [17]

	resources in an organization which can be used effectively in the industry.	
Management Support for sustainability adoption (ECM5)	Management support is necessary for the adoption of sustainability practices in the Industry 4.0 environment.	[3], [9], [11], [17]
Adoption of Sustainable energy resources (ENV1)	Adoption of renewable or sustainable energy sources helps to improve the performance and enhance sustainability in the industry.	[7], [9], [14], [12], [17]
Effective sustainable performance metrics (ENV2)	Adoption of proper performance metrics related to sustainability helps to track the manufacturing activities and adoption level of sustainability practices.	[8], [10], [14], [17]
Green designing and disposal processes (ENV3)	Adoption of green designing and disposal processes helps to enhance sustainability.	[2], [5], [9], [17]
Industrial ecology initiatives (ENV4)	Industrial ecology concepts in the industries promote the circular economy which also helps to tackle the environmental issues effectively.	[3], [5], [11], [15]
Educating society for sustainability (ENV5)	Society awareness regarding sustainability helps to improve the adoption rate of sustainability practices in Industry 4.0	[7], [8], [11], [13]
Adoption of additive manufacturing (IT1)	Adoption of additive manufacturing helps to reduce the waste and cost during production.	[12], [13], [17], [20]
Adoption of Cyber-physical systems (IT2)	This will help to achieve the sustainability and acceptance of advanced technology	[2], [5], [7], [11], [17], [18]
Adoption of machine learning systems (IT3)	It helps to improve precision and reduce human interaction.	[5], [6], [9], [17], [18]
Adoption of effective process optimization techniques and decentralized systems (IT4)	It helps to optimize the overall efficiency of the manufacturing system. The decentralized manufacturing system in the industry enables the tracking of departmental activities which needs to be optimized to improve the process focus.	[5], [9], [14], [18], [19]
Penetration of Flexible manufacturing system (IT5)	It helps to make quick changes in product medication and meets customer needs.	[7], [8], [11], [12], [15]
Adopting reverse logistics (SC1)	It helps in the execution of corrective actions as soon as possible in the process and product development.	[4], [8], [13], [15], [16]
Supplier commitment to sustainable procurement (SC2)	Supplier commitment is very important for sustainable procurement. It helps to provide a sustainable roadmap for sustainable development in the industry.	[9], [10], [11], [13], [16]
Digitalization of Supply chain (SC3)	Digitization of supply chain improve the sustainability in the supply chain and enhance the performance.	[6], [7], [10], [12], [15], [16]
Knowledge management promotion in Supply chain (SC4)	It helps to improve the supply chain practices which results in enhancement of logistic performance of the industry.	[4], [5], [9], [11], [15], [16]
Real-time tracking (SC5)	It helps to maintain the optimum stock level by tracking the inventory.	[2], [5], [9], [11], [12], [13], [14]
Effective life cycle analysis (OSC1)	Design, promotion and production of products should be based on the LCA (life cycle analysis) which helps to improve the sustainability.	[2], [5], [6], [9], [10], [17]
Improvement in man-machine interaction (OSC2)	The better interaction between man and machine helps to improve the sustainability of the final product.	[11], [12], [14], [15], [17],
Adoption of advanced health and safety modules (OSC3)	Adoption of advanced safety and health modules in the industry helps to develop a sustainable working culture in the industry.	[3], [5], [6], [11], [12], [17]
Data security and data handling (OSC4)	I4.0 technologies ensure the protection of data used for enhancing organizational performance.	[5], [6], [7], [10], [11], [17]
Understanding implications in sustainability (OSC5)	It is very necessary to understand the implications of sustainability at present and near future.	[5], [6], [8], [9], [14], [17]

ECM: Economical and Managerial; OSC: Organizational and Social; SC: Supply Chain; ENV: Environmental; IT: Information and Technology

In this study, we have adopted a Hybrid Fuzzy AHP-DEMATEL methodology. The procedure of methodology is discussed in the appendix. AHP approach was proposed by Thomas Saaty in 1981[21]. Fuzzy set theory can be integrated to improve the precision of the AHP approach [22]. DEMATEL approach is the most commonly used approach by authors for analysis of enablers [23-24].

Application of Fuzzy-AHP

To compute the weight of Industry 4.0 enablers fuzzy AHP approach is used. For the pair-wise comparison inputs taken from experts were utilized. Based on the feedback from experts and discussions, all the enablers were divided into five groups e.g. economic and managerial, environmental, organizational and social, information and technology and, supply chain. The detailed comparison made by experts from industries and academia is shown in Table 2.

Table 2: Pair-wise comparison matrix for enablers groups

Criteria	ECM	OSC	IT	SC	ENV	Weights
ECM	1	3	1	5	3	0.3488
OSC	1/3	1	1	5	3	0.2224
IT	1	1	1	5	3	0.2800
SC	1/5	1/5	1/5	1	1	0.0620
ENV	1/3	1/3	1/3	1	1	0.0842
Λ_{max}= 5.21502; CR= 0.09599						
ECM: Economical and Managerial; OSC: Organizational and Social; SC: Supply Chain; ENV: Environmental; IT: Information and Technology						

To check the consistency of inputs provided by experts consistency ratio (CR) is calculated and also the consistency index (CI) was checked. Matrices with the less than 0.1 consistency index were included for the further weight calculation. In case of inconsistency pair-wise comparisons were revised. Global weights of the enablers are calculated with their respective ranks which are shown in Table 3.

Table 3: Global weights for sustainability enablers in Industry 4.0

Main Enabler group	Main enabler group weight	Enabler	Consistency Ratio (CR)	Local Weights	Global weights	Rank
ECM	0.3488	ECM1	0.06808	0.0499	0.0175	23
		ECM2		0.0955	0.0351	20
		ECM3		0.0955	0.0335	21
		ECM4		0.3824	0.1345	16
		ECM5		0.3824	0.1324	17
OSC	0.2224	OSC1	0.077438	0.0469	0.0106	25
		OSC2		0.0548	0.0124	24
		OSC3		0.1391	0.0315	22
		OSC4		0.3277	0.0744	19
		OSC5		0.4363	0.0990	18
IT	0.2800	IT1	0.072625	0.0483	0.1716	15
		IT2		0.1141	0.4053	14
		IT3		0.1403	0.4984	13
		IT4		0.3353	1.1913	8
		IT5		0.3712	1.3191	7
SC	0.0620	SC1	0.69489	0.0431	0.6880	11
		SC2		0.0539	0.8608	9
		SC3		0.1369	2.1855	5
				0.3690	5.8889	3
		SC5		0.4016	6.4096	1
ENV	0.0842	ENV1	0.072854	0.0555	0.6473	12
		ENV2		0.0617	0.7189	10
		ENV3		0.1275	1.4862	6
		ENV4		0.2424	2.8254	4
		ENV5		0.5250	6.11837	2

Application of DEMATEL

Relationship between enablers and their cause and effect intensities were computed by DEMATEL approach. Experts opinions were again utilized to make the relationship comparison between the enablers group for Industry 4.0. The mean value of expert responses is utilized to make the direct relationship matrix which is shown in Table 4.

Table 4: Direct relationship matrix

Enabler Group	SC	ENV	IT	ECM	OSC
SC	0	2.4	3	2.4	2.2
ENV	1..4	0	2.6	3	2
IT	2.8	2.4	0	2	2.4
ECM	1.8	1.8	2.6	0	2
OSC	2.4	1.8	1.4	1.2	0

The normalized direct relation matrix is formed with the average direct relation matrix shown in Table 5:

Table 5: Normalized Direct relationship matrix

Enabler Group	SC	ENV	IT	ECM	OSC
SC	0	0.24	0.3	0.24	0.22
ENV	0.14	0	0.3	0.3	0.2
IT	0.28	0.24	0	0.2	0.24
ECM	0.18	0.18	0.2	0	0.2
OSC	0.18	0.18	0.12	0.12	0

The direct-indirect relationship and total relations between the enabler groups D and R for the comparisons were used and shown in Table 6:

Table 6: Direct-Indirect relationships and total relationship matrix

Enabler Group	SC	ENV	IT	ECM	OSC	R	D+R	D-R
SC	0	**1.53**	**1.72**	**1.55**	**1.55**	6.71	14.43	1.02
ENV	0	0	**1.56**	**1.47**	**1.41**	6.68	13.68	0.33
IT	**1.52**	**1.49**	**1.44**	**1.48**	**1.51**	7.42	14.88	0.046
ECM	0	0	**1.47**	0	0	6.77	13.31	-0.23
OSC	0	0	0	0	0	6.80	12.43	-1.17
Sum R	1.52	3.02	6.19	4.5	4.47	Threshold value=0.788		
The bold values show that relations are greater than the threshold value								

Research Findings

The results of the study reveal that supply chain, Environmental, Information and Technology are the main cause enablers whereas organizational & social and Economic are the effect enablers. The supply chain practices support the development of other enablers like Environmental enablers and Information & technology enablers. Also, the organizational & social enablers and economic enablers depend on the cause of enablers. This indicates that in the case organization economic and organizational and social enablers are struggling. Hence the management can conclude from Figure 1 that Supply chain and Environmental enablers have a strong influence on the adoption of sustainability practices in Industry 4.0. Figure 2 shows the casual relationship diagram for the main enablers criteria.

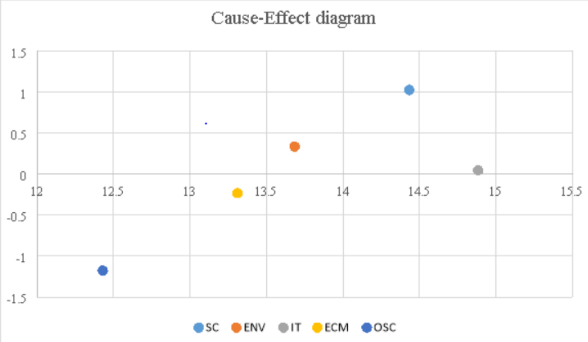

Figure 1: Cause and Effect diagram for main criteria enablers

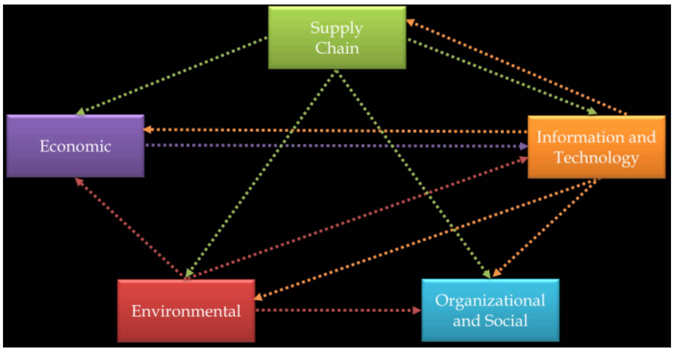

Figure 2: Casual relationship diagram for the main enablers criteria

Implications of the study

In the present study, we have utilized the hybrid approach based on F-AHP and DEMATEL for the sustainability framework in Industry 4.0 for emerging economies. In the past studies, it is found that many studies reported the computed Industry 4.0 enabler weights but the interrelationship between the enablers is not assessed. In this study, we have computed the enabler weights and assessed the effects of Industry 4.0 enablers upon the other enablers. This investigation can be helpful for the researchers for developing a framework for different industry sectors. The framework developed in the study will be helpful for the practitioners and policymakers from emerging economies to implementing sustainability practices in Industry 4.0. The sustainability Industry 4.0 framework proposed in this study is tested in the manufacturing organization of India. Further, the documented improvement due to this framework can be addressed in future studies by considering different performance metrics. The proposed framework is for MSMEs of emerging economies. However, the authors recommended that this framework can be utilized in the different sectors of MSMEs in emerging economies which needs some modifications in the initial inputs based on the industry sector. The authors have identified 25 enablers in five major dimensions i.e. economical and managerial, supply chain, information and technology, environmental, organizational and social based enablers which covers all the aspects of sustainability in the MSMEs of emerging economies. In the past studies few frameworks are proposed for Industry 4.0 with the sustainability consideration but those frameworks are more theoretical rather than the real-world documentation. In this study, we have designed framework MSMEs of the emerging economy by a hybrid approach based on F-AHP and DEMATEL approach which increases and strengthen the applicability of the proposed framework in emerging economies. It is expected that this research study will be helpful for the policymakers for developing the policies related to sustainability issues in Industry 4.0 in MSMEs. As MSMEs have a great contribution to the development of the economy in the emerging economies.

Conclusions

In line with the objectives of the study, authors have initially conducted an exhaustive literature review on papers extracted from WoS (Web of Science) and Scopus database on Industry 4.0 and sustainable manufacturing. The enablers for sustainability in Industry 4.0 were identified and further finalized with the expert discussion by keeping in mind the context for MSMEs of emerging economies. A manufacturing industry located in the Northern Indian region which has already implemented sustainability practices and implementing Industry 4.0 practices is considered for the case study. The expert panel from the industry and academia was formed for the expert inputs collections which were further analyzed with the F-AHP and DEMATEL approach. In this study, F-AHP helps to compute the enabler weights for sustainability in Industry 4.0 and the cause and effect of enabler groups were analyzed with the DEMATEL approach.
The results of this study reveal that supply chain, environmental and IT enablers are casual enablers while economic and social are effect enablers. The influence intensity of supply chain enablers is greater than the threshold value which shows that supply chain enablers to have a strong influence on other enablers.
The results in this study were built on the basis of inputs obtained from the expert panel within the case industry. However, for more robustness researchers can extend this study on a large scale survey in which more enablers for sustainability in Industry 4.0 can be considered. Also, this framework is tested and applicable for the MSMEs in a particular industry sector which can be further studied in other industry sectors i.e. healthcare sector. In this study, we have utilized a hybrid approach based on F-AHP-DEMATEL for the weight computation and inter-relationship between the enablers. In future studies, other hierarchical approaches can be utilized in the framework development. This study provides the threshold value of each enabler group which is an essential factor for the prediction of success of any newly developed framework. Also, this framework can be utilized in the developed nations but the researchers are recommended to consult the experts of the respective industry domain for inputs which need to be modified in the country and industry-specific study. Also, for the structural comparison researchers can further be addressed the Interpretive structural modelling technique and ANP (analytical network process) approach which will give the better visualization of the proposed

sustainability framework for Industry 4.0 which is developed in this study.

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