Evaluating Strategies for Environmental Sustainability in a Supply Chain of an Emerging Economy

ABSTRACT

Due to an increased pressure to be environmentally sustainable, many manufacturing organizations, especially from developing countries like Bangladesh, are attempting to make necessary changes in practices and supply chains. However, those attempts need to be applied strategically with the objective to be both environmentally sustainable and economically viable. This paper offers a decision-making methodology by integrating a fuzzy cognitive map (FCM) and data envelopment analysis (DEA) for evaluating strategies for environmental sustainability based on their impact on the overall supply chain network of an organization. This paper first identifies 18 generic strategies for environmental sustainability and three supply chain performance measurement (PM) factors. Afterwards, the cause-effect relationships among these strategies and PM factors are utilized to capture the complicated relationships by FCM. The extended delta rule (EDR) learning algorithm was used in association with FCM to quantify the impact of those strategies on supply chain PM factors. Finally, DEA is used to prioritize strategies using these impact values. A real-life case using a fast-moving consumer goods (FMCG) manufacturer from Bangladesh is presented to justify the applicability of the proposed methodology. The results reflect the usefulness of this methodology for evaluating strategies for environmental sustainability in a supply chain (SC), specifically in the FMCG sector of an emerging economy. Thus, other manufacturing organizations from any industry can use this methodology to evaluate strategies for environmental sustainability.

Keywords: Environmental Sustainability; Fuzzy Cognitive Map; Extended Delta Rule; Learning Algorithm; Data Envelopment Analysis; Bangladesh Fast-Moving Consumer Good (FMCG) Chain.

1 INTRODUCTION

Managing environmental sustainability is crucial for manufacturing organizations because uncontrolled manufacturing and product disposal have become major problems associated with environmental degradation (Alam et al., 2016; Calabrese et al., 2018). Recent amendments on legal frameworks about environmental conservation often regulate international trades and can claim penalties for violating regulations (Fullerton & Muehlegger, 2019). As a consequence, manufacturing companies of diverse industries have begun implementing practices and strategies to become more environmentally sustainable (Piyathanavong et al., 2019). The number of such companies is increasing because many realize that sustainability practices render production effective and efficient, as well as to avoid paying penalties for violation of regulations (Baker et al., 2019; Sarkis & Zhu, 2018; Keeso, 2014, p. 6).

Sustainability is defined as meeting all present needs while ensuring the ability of future generations to meet theirs (WCED, 1987). Reviewing the 500 most cited research papers on sustainability, it was found that sustainable practices—whether in supply chain (SC) management or any other business activity—are a function of two linked principles: (1) they must enhance ecological health, follow ethical standards to further social justice, and improve economic vitality, and (2) they must be prioritized whereby the environment comes first, society second, and economics third (Markman & Krause, 2016). Sustainability has 3 dimensions: economic, environmental, and social (Henriques & Richardson, 2013). As one significant dimension, environmental sustainability involves managing limited resources of the biophysical world by reducing and managing the use of resources in processing, as well as assuring that generated waste from those processes does not surpass limits which could create harm to the natural environment or mankind (Goodland, 1995).

Due to increased demand and globalization, organizations from different industries are exposed to a competitive SC environment where suppliers, mediators, and stakeholders can deploy certain procedures harnessing a better profit margin yet losing focus on environmental and social performance (Hsu et al., 2016; Awan et al., 2018b). Present customers, with increased knowledge regarding sustainability, believe that standards are needed for the organization delivering the end product and also for corresponding SC members (Awan et al., 2017; Seuring et al., 2008). Thus, managing sustainability in the SC is of great importance. Sustainability in the SC is indicated by SC activities—especially minimizing harmful impacts on the environment (Markman & Krause, 2016).

Environmental sustainability practices are increasingly acknowledged as critical among the overall dimensions of sustainability (Nallusamy et al., 2016). Manufacturing companies around the world have attempted to meet ongoing environmental challenges by applying various environmentally sustainable (ES) operational practices e.g., green supply chains (GSCs), greener and cleaner production, ‘lean & green’ systems, life cycle assessment (LCA), and reverse logistics (RL) (Piyathanavong et al., 2019). Moreover, the release of ISO 14001:2015 (a worldwide recognized certification for Environmental Management Systems) has created a more flexible, context-specific, and effective way for attaining environmental sustainability (Fonseca, 2015; Fonseca & Domingues, 2018; Mazzi et al., 2016; Murmura et al., 2018). Also, since the development of the theoretical backbone of circular economies (CE) concept by Pearce & Turner (1990), extensive research (Reichel et al., 2016; Masi et al., 2017; Fonseca et al., 2018; MacArthur, 2013; Lieder & Rashid, 2016) has focused on reinforcing environmental sustainability in manufacturing organizations while maintaining economic growth.

Barriers (Shahbazi et al., 2016), necessary components (Dangelico & Pontrandolfo, 2015), drivers (Naidoo & Gasparatos, 2018; Malesios et al., 2019), and indicators (Angelakoglou & Gaidajis, 2015) of environmental sustainability have been discussed in the context of Swedish automotive industry, Italian companies, small and medium enterprises (SME), for example. Additionally, theoretical methodologies to create ES approaches (Mårtensson & Westerberg, 2016; Leigh & Li, 2015; Røyne et al., 2015), and to evaluate environmental sustainability of an organization (Huda, & Mahmud, 2018; Angelakoglou & Gaidajis, 2015), have examined for the modern corporate world, U.K. leading timber distributors, Sweden chemistry industry, European non-ferro mining industry, and other studies. Several studies (Mariadoss et al., 2011; Costantini et al., 2017; Chege & Wang, 2019; Sueyoshi & Goto, 2018; Radu et al., 2020; Basu et al., 2018) have analyzed effectiveness of different ES strategies with respect to perspectives including overall innovation, eco-innovation, technology innovation, resource utilization, carbon emission reduction, and pollution prevention.

ES Strategies or practices should be prioritized, considering the limitations of resources and scope in emerging economies. After identifying such strategies or practices, different studies have prioritized them, for example, for a Taiwanese electronic company, the Chinese shale gas industry, Chinese hydrogen economy, and an Indian poly-plastic manufacturing company, specifically based on effective direction of business functions, stakeholder and administrator viewpoints, strengths, weaknesses, opportunities, and threats (SWOT) analysis, and associated risks in ‘fuzzy’ environments (Chen et al., 2012; Ren, Tan, et al., 2015; Ren, Gao, et al., 2015; Mangla et al., 2015).

Researchers have dealt with various issues regarding environmental sustainability in emerging economies, including for India, Malaysia, Thailand, and Serbia (Basu et al., 2018; Hsu et al., 2016; Piyathanavong et al., 2019; Arsić et al., 2017). In Bangladesh, higher exports of ready-made garments (RMG), as well as expansions in pharmaceuticals, steel, shipbuilding, and shipbreaking industries, support greater economic growth (Tumpa et al., 2019). Studies have discussed barriers and assessment methodologies for environmental sustainability in the context of Bangladeshi RMG, textile, and leather industries (Hossain & Roy, 2016; Islam et al., 2018; Moktadir et al., 2018; Suhi et al., 2019; Tumpa et al., 2019).

When identifying ES strategies and prioritizing them, studies have lacked some critical aspects: some have used non-intelligent methodologies (Basu et al., 2018; Whitehead, 2017; Mangla et al., 2015; Ren, Gao, et al., 2015; Luthra et al., 2013), some did not provide specific case study examples (Lee & Kwon, 2019; Hsu et al., 2016; Ahmed et al., 2016; Montabon et al., 2016), and almost of all performed decision-making based on criteria other than overall SC performance. Few studies [USA and Sweden (Morel & Kwakye, 2012); Sri Lanka (Wanninayake & Randiwela, 2018), India (Nagaraju & Thejaswini, 2014), Pakistan (Abbasi & Hassan, 2013)] on emerging economies focus little on environmental sustainability in the FMCG supply chains. This study tries to answer the following research questions (RQ):

RQ 1*:* What are generalized ES strategies applicable to most manufacturing organizations?

RQ 2*:* What are the most important ES strategies for SC, especially in the FMCG sector of emerging economies?

By answering these questions, this study aims to extract strategies for environmental sustainability through analysis of the literature and to prioritize them using fuzzy cognitive maps (FCM), the extended delta rule (EDR), and data envelopment analysis (DEA). This is based on strategies' assumed performance on overall SC (in other words, based on the impact they produce on the overall Supply Chain PM factors). This prioritization problem can be solved using multiple-criteria decision-making (MCDM) techniques (Chowdhury and Paul 2020). With MCDM techniques, one can select among alternatives based on specific criteria (Nallusamy et al., 2016).

The growing popularity of decision-making approaches has paved the way for different methods of MCDM, e.g., the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), analytical network process (ANP), analytical hierarchy process (AHP), VIKOR, best worst method (BWM), and ELECTRE (Serrai et al., 2017). These algorithms employ expert opinion, but fail to capture interdependencies [except ANP which involves hierarchical considerations, but involves non-intelligence and complexity in modeling as suggested by Kiszová & Mazurek, (2012)] among the decision elements, ultimately resulting in low accuracy in the final result (Annema et al., 2015). In this study, FCM with EDR is used because of the combined advantage of using expert opinion, integrating intelligence, and considering possible interdependencies (cause-effect relationships) each strategy has with other strategies and overall Supply Chain PM factors (Rezaee & Yousefi, 2018). DEA is incorporated in this decision-making process because of its efficacy in dealing with multiple decision options to achieve an objective (Rezaee & Yousefi, 2018).

This paper is structured as follows. Section 2 briefly discusses related studies on environmental sustainability from the perspective of different industries. It addresses existing research gaps and also the contributions of this study in overcoming those gaps. Finally, it recommends some ES strategies and SC performance measurement (PM) factors. Section 3 explains the theoretical background of this research, followed by Section 4 which elaborately discusses a proposed methodology. In Section 5, the application of the proposed methodology is demonstrated with a case study focused on a fast-moving consumer goods (FMCG) company. Discussion of the results of this study is discussed in the next section. Finally, the conclusions containing implications of this research, the limitations of this study, and the future scope for further studies in this field are discussed in Section 7.

2 Literature Review

This section summarizes the previous researches on environmental sustainability, and their contributions, methodology, context of those studies and main limitations and finally proposes some ES strategies which will be prioritized using the methodology proposed in this study.

2.1 Previous Studies

Much research on environmental sustainability in SC management has been carried out in developed countries (Piyathanavong et al., 2019; Awan et al., 2017; Hsu et al., 2016; Blome et al., 2014; Walker et al., 2014; Pasha et al., 2012). Mariadoss et al. (2011) identified 14 distinct innovation-based sustainability strategies in 19 different cases from 47 business to business companies (companies that are involved in intercompany transactions while sourcing or supplying product or services). Chen et al. (2012), using ANP, identified and prioritized Green Supply Chain (GSC) Management strategies to effectively direct business functions and activities in the Taiwanese electronics industry. Mittal and Sangwan (2014) specified and prioritized factors restricting green management. They used a Fuzzy TOPSIS methodology and indicated which sectors required more focus. Goyal et al. (2015) identified 12 sustainability practices in a literature review and from experts' judgments, and then prioritized them using AHP to improve corporate sustainability performance in the manufacturing sector. These practices were prioritized to identify essential practices to ensure logical allocation of limited resources.

Pigosso and McAloone (2016) worked with 30 best approaches and prioritized them on the basis of different stages of products' life cycles through content analysis. Naidoo and Gasparatos (2018) examined the key drivers for the adoption of corporate environmental sustainability in the retail sector. The study determined 3 major strategies and 11 sub-strategies. Environmental greening efforts are prioritized based on effects on creating marketing value using the Back Propagation Neural Network model (Lee & Kwon, 2019). Radu et al. (2020) identified corporate environmental and carbon strategies within 137 Canadian corporate sustainability reports, and further explored the alignment between carbon and environmental sustainability (and their integration) through qualitative content analysis and a cluster analysis technique.

Industries of emerging countries have recently expressed an interest in attaining SC sustainability despite the unclear financial benefits (Esfahbodi et al., 2016). Luthra et al. (2013) evaluated strategies for implementing GSCM in manufacturing industries of India. This study, through experts' opinion and a literature review, identified 30 strategies categorized into four dimensions: non-members of SC, downward stream SC members, organizational perspective, and upward stream SC members. Somsuk (2014) and Somsuk and Laosirihongthong (2017) ranked the drivers in the way of executing GSCM in Thailand's electronic industry using Fuzzy AHP (FAHP) and Fuzzy Delphi-FAHP methodologies. Mangla et al. (2015) prioritized responses in GSC to manage risks of an Indian plastic manufacturing company using FAHP. Solutions to overcome hindrances to sustainability in China's shale gas industry have been ranked based on stakeholders' perspectives using Fuzzy ANP and Interpretive Structural Modeling (ISM) (Ren, Tan, et al. 2015).

Hsu et al. (2016) developed a theoretical model to determine influences of sustainable SC initiatives on RL outcomes, as well as the impact of eco-reputation and eco-innovation orientation strategies on the deployment of sustainable SC initiatives. Data were collected from an emerging economy, Malaysia. Some researches have tried to prioritize environmental practices in different industries of Brazil. Their primary focus was on GSCM, and they used AHP methodologies to compile a preference list [Sellitto & Hermann 2016 (Peach industry); Sellitto 2018 (footwear and metal-mechanics industries)]. Basu et al. (2018) determined pollution prevention initiatives and their implementation across five polluting industries (iron and steel, cement, pulp and paper, leather, pharmaceutical) in India. Dhull and Narwal (2018) and Mathiyazhagan et al. (2018) attempted to rank drivers related to GSCM of India's manufacturing and construction industries using MCDM frameworks (Fuzzy TOPSIS and AHP). Solutions to overcome restrictions in implementing eco-design practices in piston and ring fabricating companies of India were prioritized using FAHP and Fuzzy TOPSIS (Singh & Sarkar, 2019). Piyathanavong et al. (2019) discussed fundamental issues for implementation of environmental sustainability approaches in manufacturing industries of Thailand.

Industries in Bangladesh also have been trying to adopt sustainable SC practices (Tumpa et al., 2019). Chowdhury (2012) claimed that the amount of research on the sustainability of SC is not satisfactory at this point in time. Chowdhury and Quaddus (2015) identified top vulnerabilities of the RMG sector in Bangladesh, and identified resilient strategies to mitigate them. The study developed an optimization model using Quality Function Deployment (QFD). Moktadir et al. (2018) evaluated drivers and sub-drivers for attaining a sustainable manufacturing process and CE in leather industries of Bangladesh. They classified drivers into four types and prioritized them using graph theory and a matrix approach. Islam et al. (2018) used Fuzzy importance and a performance analysis hybrid method for assessment of GSC practices (GSCP) and identification of the most critical GSCP based on four viewpoints, including suppliers, manufacturers, customers, and logistic service providers in the context of the leather industry of Bangladesh. Tumpa et al. (2019) determined 15 barriers based on opinions of 30 Bangladeshi textile practitioners and others from SC management divisions. Then a hierarchical cluster analysis technique was used to identify the most critical hurdles. Suhi et al. (2019) presented a framework for identification of environmental sustainability indicators and their evaluation based on their weight by BWM for Bangladeshi industries.

MCDM techniques are often applied for decision-making problems involving multiple conflicting objectives (Kabir et al., 2014). Decision makers are now following MCDM methods to find the optimal solution where there are several criteria to consider. Some of the applications of MCDM techniques are outlined in Table 1.

Table 1: Applications of multi-criteria decision-making (MCDM) techniques.

Authors	Contribution	Methodology	Case Country
Chen et al. (2012)	Identified and prioritized GSC Management strategies to effectively direct business functions and activities	ANP	Taiwan (Electronic Industry)
Mittal and Sangwan (2014)	Specified and prioritized factors restricting green management	Fuzzy TOPSIS	Not Specified (Emerging Countries)
Mangla et al. (2014)	Evaluated several factors responsible for performance of GSC	Decision making trial and evaluation laboratory (DEMATEL)	India (A plastic manufacturing company in the North)
Goyal et al. (2015)	Prioritized practices for the manufacturing sector to excel in corporate sustainability performance	AHP	Generalized Discussion (Manufacturing organization)
Ren, Tan, et al. (2015)	Presented the ranking of hurdles to attain a sustainable shale gas industry and viable measures to overcome those hindrances	Fuzzy ANP and ISM	China (Shale gas industry)
Mangla et al. (2015)	Ranked the responses to managing risks in a GSC of an Indian poly-plastic manufacturer	FAHP and TOPSIS	India (A plastic manufacturing company)
Comaniţă et al. (2015)	Assessed optimal alternatives of bioplastics for use in packaging, considering the impact of different criteria	ELECTRE	For EU legislation (Packaging production industry)
Ahmed et al. (2016)	Developed a framework for deciding on end-of-life vehicle management alternatives based on sustainable criteria	DEMATEL and FEAHP	Malaysia (Automobile industry)
Somsuk and Laosirihongthong (2017)	Ranked the drivers in the way of executing GSCM	Fuzzy Delphi-FAHP	Thailand (Electronic Industry)
Ahmad et al. (2017)	Analyzed and ranked effects of various external forces on the sustainability of oil and gas SC	BWM	Not specified (Oil and gas industry—survey done with USA, the Netherlands, U.K., and

			other European countries' experts)
Arsić et al. (2017)	Prioritized strategies for improvement of ecotourism in a national park of Serbia	Multi criteria ANP and fuzzy ANP	Serbia (National Part Djerdap)
Rostamzadeh et al. (2018)	Proposed a framework to evaluate the criteria based on sustainable SC risk management	Fuzzy TOPSIS-CRITIC	Iran (Oil Industry)
Awasthi et al. (2018)	Constructed a framework for selecting global suppliers considering risks related to sustainability from sub-suppliers	FAHP-VIKOR	Not specified (Electronic goods manufacturing company)
Sellitto (2018)	Prioritized environmental practices having a focus on GSCM.	AHP	Brazil (Footwear and metal-mechanics industries)
Dhull and Narwal (2018)	Ranked drivers related to GSCM	Fuzzy TOPSIS	India (Manufacturing Industries)
Chou et al. (2019)	Provided policy makers and practitioners with a fuzzy perspective on national HRST competitiveness evaluation, and attempted to improve accuracy and reconstruct the priority of each measurement dimension in HRST competitiveness	FAHP-Fuzzy TOPSIS	Nine Southeast Asian countries, namely, Singapore, South Korea, Taiwan, Hong Kong, Malaysia, China, Thailand, the Philippines, and India (Science and Technology)
Singh & Sarkar, (2019)	Prioritized solutions to overcome restrictions in implementing eco-design practices	FAHP and Fuzzy TOPSIS	India (Piston and ring manufacturing company)
Suhi et al. (2019)	Identified and assessed environmental sustainability indicators.	BWM	Bangladesh (Different Manufacturing Industries e.g., garments, leather)

In the context of environmental sustainability, we addressed four pertinent literature gaps. First, limited research has been done in the environmental sustainability of FMCG focusing on the overall SC and there are few papers on Bangladeshi FMCG. Second, most research from both developed and developing countries do not provide specific case studies (e.g., Mittal & Sangwan, 2014; Somsuk, 2014; Pigosso & McAloone, 2016; Dhull & Narwal, 2018), relying instead on generalized results. Third, most do not consider cause-effect relationships among GSCP or strategies when prioritizing them [only Ren, Tan, et al. (2015), Chen et al. (2012), and Ngan et al. (2019) considered causal relationships]. Fourth, most studies did not use an intelligent decision-making approach. This study aimed to overcome such limitations. A great amount of literature was reviewed to assemble a potentially ideal set of ES strategies for different enterprises. Two things were required for selecting the best possible strategies: quantitative measures of the cause-effect relationships between every possible pair of strategies and SC performance factor relevant to the particular industry of the study; and quantitative measures of current scenarios within the company in relation to the extent of application of those strategies. The first input was used to determine an FCM and both measures were input into the EDR learning algorithm. The outputs from EDR were further used as inputs to DEA and by comparing the outputs, we could determine which strategies would be more beneficial for a particular company.

Thus, the main contributions of this study are summarized as follows:

- Development of a methodology for assessing strategies for environmental sustainability in supply chains.
- Development of an intelligent system which can provide suggestions to aid selection of important strategies to implement sustainability in different SC scenarios.

2.2 Environmentally Sustainable (ES) Strategies and Supply Chain Performance Measurement (PM) Factors

This section presents strategies for environmental sustainability in supply chains which were devised from reviewing the literature and conducting brainstorming sessions. Supply chain PM factors are also outlined in Table 2.

Table 2: List of ES strategies and PM factors

Strategies and PM Factors		Symbol	Description	Reference	Objective of the Paper
Environmentally Sustainable (ES) Strategies	Pollution prevention through recycling & reuse	S1	Recycling and reusing materials used in production not only reduces costs of new materials but also plays a vital role in pollution prevention.	Hoque & Clarke, (2013) [1] Govindan et al., (2014) [2]	To provide information on current usage of pollution prevention activities.[1] To evaluate effects of lean, resilient, and GSCM approaches on sustainability of SC.[2]
	Usage of eco-efficient materials	S2	Eco-efficient materials are well known for their minimum impact on the environment and their recyclable properties.	Shahbazi et al., (2016)	To investigate strategies to support material efficiency improvement and barriers of achieving it.
	Usage of materials recycled from disposed components in the production process	S3	Use of recycled materials in production lowers manufacturing costs, lessens the impact on the surrounding environment and reduces dependency on suppliers.	Diabat & Govindan, (2011) [1] Thurner & Roud, (2016) [2]	To construct a framework of factors impacting the deployment of GSCM.[1] To provide deeper understanding of strategic alternatives of firms based on green management.[2]
	Usage of non-pollutant gas as a source of energy	S4	Non-polluting gases do not emit primary and secondary pollutants, and thus air pollution and ozone depletion are alleviated.	Chiou et al., (2011)[1] Røyne et. al., (2015) [2]	To explain the relationship among GSC, green innovation, environment, and core competency.[1] To demonstrate the significance of developing environmental strategies using the LCA method.[2]
	Collaboration with R&D department for eco-innovation	S5	Design and production teams can combine efforts to develop eco-friendly products or processes which require less resources, consume minimum energy, and have no negative effects on the environment.	Singh & Sarkar, (2019)	To extract and rank the enablers to eradicate hindrances for deploying eco-design practices.
	Selecting suppliers committed to adopt and certify ISO 14001:2015	S6	Organizations should be involved in green purchasing and should always prefer and encourage suppliers who deliver such materials.	Somsuk, (2014) [1]; Sidhu & Arora, (2020) [2] Awan et al., (2018a)[3]	To rank sustainability core competency drivers in GSCM.[1] To set standard on suppliers' execution of sustainability when applying ISO 14001.[2] To verify the impact of agreement governance on cooperation.[3]
	Proper disposal of components	S7	Non-usable and discarded materials should be disposed of appropriately depending on their properties and harmful effects.	Hsu et al., (2008) [1] Ji et al., (2014) [2]	To explore effects of sustainable SC initiatives on RL, competitive advantage of RL, and drivers of GSC initiatives.[1]

					To explain the bottom line of the environment based on ecological influence and carbon footprint.[2]
	Source-based emission reduction	S8	Materials known to emit pollutants or harmful gases in later stages of production should be avoided in the first place.	Dangelico & Pontrandolfo, (2015)[1] Govindan et al., (2014) [2]	To investigate capabilities for a firm to acquire best performance through product- and process-related environmental activities.[1] Investigate hindrances, while applying a GSCM, based on material acquisition efficacy.[2]
	Mileage reduction for freight transport	S9	Well thought out facility location and routing plans can reduce vehicle travelling distances, greatly decreasing emissions of pollutants such as carbon-dioxide and monoxide.	Caritte et al., (2015)	To provide adequate knowledge about decarbonization and environmental performance.
	Reduction in relative energy consumption from benchmarks	S10	Benchmarking helps companies compare their energy consumption with others which in turn can reduce costs.	Sorrell, (2015)	To provide a general review on issues and challenges of energy demand reduction.
	Material savings and better utilization of by-products	S11	Greater savings on materials means lower emissions of harmful substances, reduced impacts on the environment and better economic efficiency.	Dangelico & Pontrandolfo, (2015)	Similar to S8.
	Renewable energy technologies (ventilation and energy use in buildings)	S12	Sustainable energy sources and technologies are preferred since they have negligible effects on the environment.	Kolokotroni et al., (2015)	The advantages of ventilation strategies on lowering energy usage.
	Recovery and utilization of residual energy and heat	S13	Initiatives to utilize heat energy and other residual energies improves efficiency and lowers the consumption of fossil fuels.	Chen et al., (2015)	To demonstrate the importance of recovery and utilization of residual heat and energy.
Environmentally Sustainable (ES)	Usage of eco-friendly production technology and equipment	S14	Adoption of production technology and equipment not only reduces emitting pollutants into the environment but therefore can also provide a safer working environment for employees.	Mårtensson & Westerberg, (2016)[1] Sellitto, M. A., & Hermann, (2016) [2]	To suggest a theoretical approach to providing ways to select effective environmental strategies.[1] To prioritize green practices based on GSCM.[2]
	Elimination of hazardous waste at source level	S15	Hazardous wastes should be eliminated immediately following proper waste management techniques.	Basu et. al., (2018)	To investigate pollution prevention strategies and their implementation.

	Better utilization of process-generated scrapped items	S16	There should be scope to utilize scrapped items as much as possible instead of entirely discarding them.	Proposed in this article	-
	Introduce application of big data	S17	Big data is an enormous collection of structured and unstructured datasets that can extract information about previous events and evaluate current situations or states of a company.	Proposed in this article	-
	Continuous monitoring of data related to plant emissions to control hazardous situations before occurring	S18	Monitoring the data continuously allows the company to detect any anomalous data and proactively and prudently deal with a situation.	Proposed in this article	-
Supply Chain PM Factors	Cost	P1	The total cost of the supply chain is comprised of actual cost (costs directly involved in production and other indirect costs) and opportunity cost (costs given up while selecting a different alternative) which should be kept as low as possible.	Beamon, (1999)[1]; Maestrini et al., (2017) [2]	To provide a framework for selection and evaluation of performance measures.[1] To perform a structured assessment of SC performance measurement.[2]
	Flexibility	P2	The capability of a company to adapt to uncertainties and frequent shifts in demands in the market is a crucial factor in retaining the market share.	Beamon, (1999); Maestrini et al., (2017)	Similar to P1.
	Customer responsiveness	P3	Being aware of demands and changes in customers' needs and reacting quickly indicates a high level of customer responsiveness and is one of the most significant factors in evaluating SC performance.	Beamon, (1999); Maestrini et al., (2017)	Similar to P1.

3 THEORETICAL BACKGROUND

3.1 Fuzzy Cognitive Map (FCM)

A Fuzzy Cognitive Map (FCM) is essentially a directed graph. It is a method that explains how a system works by creating a model which is quantitative in nature. It can represent a complex system. In the complex system, different elements have causal relationship among them and these relationships can be shown through FCM. Two things constitute a cognitive map: variables or concepts which need to be defined; and the cause-effect relationships between each possible pair of these concepts (Özesmi & Özesmi, 2004), indicating the impact of a concept (if it remains active) on other concepts. The concepts related to the system under study are represented as nodes. These nodes are connected by lines with arrowheads, each arrowhead expressing the causal relationship between the pairs of concepts connected via each line (Papageorgiou et al., 2006). FCM uses fuzzy concepts to quantify the different causal relationships among the concepts. This approach in a cognitive map seeks to quantify the strength of relationships by allocating numbers from -1 to 1 or from 0 to 1 (Kosko, 1986). FCM offers flexibility in system modelling with numerous concepts without too much complexity (Papageorgiou et al., 2004).

Practical fields are undergoing rapidly changing trends. As discussed earlier, the strategies to achieve environmental sustainability are not independent of one another but correlated. So, the strategies possess causal-effect relationships between one another as well as have relationships with PM factors. As a method of representing and analyzing these complex relationships when making decisions about which strategies to implement, FCM is one of the best possible intelligent tools discovered to date.

To understand the insights of FCM, Figure 1 illustrates four concepts and their interrelationships expressed by weights.

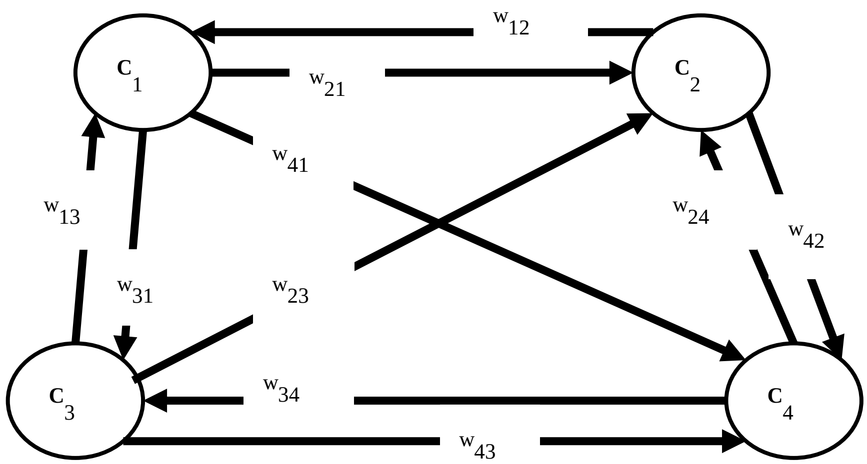

Figure 1: A simple example of a cognitive map

In Figure 1, the four concepts are shown as C_1 to C_4. The arrowheads indicate the causal relationships between the connected concepts. W_{ij} indicates the weight or extent of influence C_i (post-synaptic node) will carry if C_j (pre-synaptic node) is active. W_{ij}can carry one of three types of values within the -1 to 1 range. W_{ij} equals zero and represents no impact existing on C_i if C_j remains active. A W_{ij} greater than zero indicates a positive impact and when less than zero, represents a negative impact.

To analyze FCM, the model needs to be expressed mathematically. The equations for FCM (extended form and matrix form) are given below:

$$A_i^{(k+1)} = f(A_i^{(k+1)} + \sum_{\substack{j=1 \\ j \neq i}}^{n} W_{ij}^{(k)} A_i^{(k)} \quad \text{(1)}$$

$$A_{new} = f(A_{old} + \sum W \times A_{old}) \quad \text{(2)}$$

where,

$A_i^{(k+1)}$ indicates C_i concept's value at $(k+1)^{th}$ iteration.

f indicates the squashing function i.e. hyperbolic tangent $[\tanh(\lambda x)]$, sigmoid $[\frac{1}{1+\exp(-x)}]$, and general exponential functions $[\frac{1}{1+\exp(-\lambda x)}]$.

A indicates the matrix of values of concepts of order $N \times 1$.

W indicates the weight or adjacency matrix of order $N \times N$.

Repeating the calculations of FCM equations continues until either the concept values simultaneously achieve a stable state or reach a state of entropy (diverging) or satisfying the predetermined number of iterations (Papageorgiou et al., 2006).

To generate an FCM for any complex system, the inputs can be historical data and expert judgements. When both inputs are used, the approach can be defined as semiautomatic (Rezaee & Yousefi, 2018). The main challenge in semi-automatic FCM is the precise estimation of weights (W_{ij}) based on experts' opinions using a learning algorithm. Learning algorithms determine a close to accurate weight estimation, reduce the chance of concept values being divergent, and give the feel of an intelligent system.

After aggregating all the studies related to FCM with learning algorithms, researchers found three major types of algorithms used in FCM: Hebbian-based, population-based, and hybrid algorithms (Papageorgiou et al., 2012). These three types of algorithms are related to the field of neural networking. The Hebbian algorithm is well suited for identifying the weights from historical data. But in the cases of using expert opinions as input, the Hebbian algorithm could produce divergence when the concepts are correlated. As ES strategies (used as concepts to figure out FCM) are not orthogonal with each other, approaches other than Hebbian should be used to avoid non-convergence. Studies found that the limitations of these approaches can be overcome using the EDR learning algorithm(Rezaee & Yousefi, 2018). The EDR learning algorithm is described here, step by step.

- Input the existing concept state matrix A^0 and the initial weight matrix W^0.
- Calculate the total error $E = \sum_{j=1}^{m}(t_j - A_j^k)^2$.
- Update the concept matrix values:

$$A_i^{(k+1)} = f(A_i^{(k+1)} + \sum_{\substack{j=1 \\ j\neq i}}^{n} W_{ij}^{(k)} A_i^{(k)})$$

- Update the weight matrix:

$$W_{ij}^{(k+1)} = \gamma W_{ij}^{(k+1)} + \alpha(t_i - A_i^k) A_j^{(k)} f'(A_i^{(k)})$$

- Evaluate whether to terminate by checking the following condition:

$$\frac{\partial E}{\partial w_{ij}} = \frac{\partial}{\partial w_{ij}} \sum_{j=1}^{m} (t_j - A_j^k)^2 < \varepsilon$$

Here, t_j is the target value for the j^{th} element (j^{th} concept) of the A matrix. The main objective of using this learning technique is to manipulate the weights in such a way that the difference between the t_j and A_j is minimized.

3.2 Data Envelopment Analysis

Data envelopment analysis (DEA) is a non-parametric method used for determining the performance efficiency of decision-making units (DMUs) (Dotoli et al., 2015). The DEA model was developed by Charnes et al. (1978). An earlier DEA model was known as the CCR model and is also known as the frontier estimation method which analyzes multiple inputs and outputs. Ranking the factors becomes complicated when cause-effect relationships exist among them. In this case, DEA acts as an effective tool for ranking the decisions based on their efficiency scores (Charnes et al., 1978).

In the DEA model, n decision making units are assumed where each DMU_j produces m number of inputs and s number of outputs. The criteria required to be decreased is considered the input where the output is always desired to be increased for improving efficiency (Rezaee & Yousefi, 2018). The DEA-CCR model has two categories–input-oriented and output-oriented. In the input-oriented DEA-CCR model, the inputs are minimized without any change in outputs. Alternatively, the output-oriented DEA-CCR model aims to maximize outputs with fixed inputs. However, both models yield the same result. In this study, the output-oriented DEA-CCR model has been used.

$$g_k = min \left(\sum_{i=1}^{m} v_i x_{ik}\right) \quad \ldots\ldots(3)$$

Subject to

$$-\sum_{r=1}^{s} u_r y_{rk} + \sum_{i=1}^{m} v_i x_{ik} \geq 0 \; for \; j = 1, \ldots\ldots, n$$

$$\sum_{r=1}^{s} u_r y_{rk} = 1$$

$$u_r \geq 0, r = 1, \ldots\ldots, s$$

$$v_i \geq 0, i = 1, \dots \dots, m$$

Where

n: number of alternatives/DMU

m: number of input criteria

s: number of output criteria

x_{ik}: value of ith input criterion for kth alternative

v_{rk}: value of rth output criterion for kth alternative

u_r and v_i: non-negative variable weight to be determined by the solution of the minimization problem

g_k: efficiency

4 PROPOSED METHODOLOGY

This study aims to propose a methodology for evaluating ES strategies for manufacturing organization supply chains. Strategies are compared by focusing on the effectiveness of making the whole SC network efficient, flexible, and responsive. The illustrative description of the proposed methodology for prioritizing these strategies is given in Figure 2.

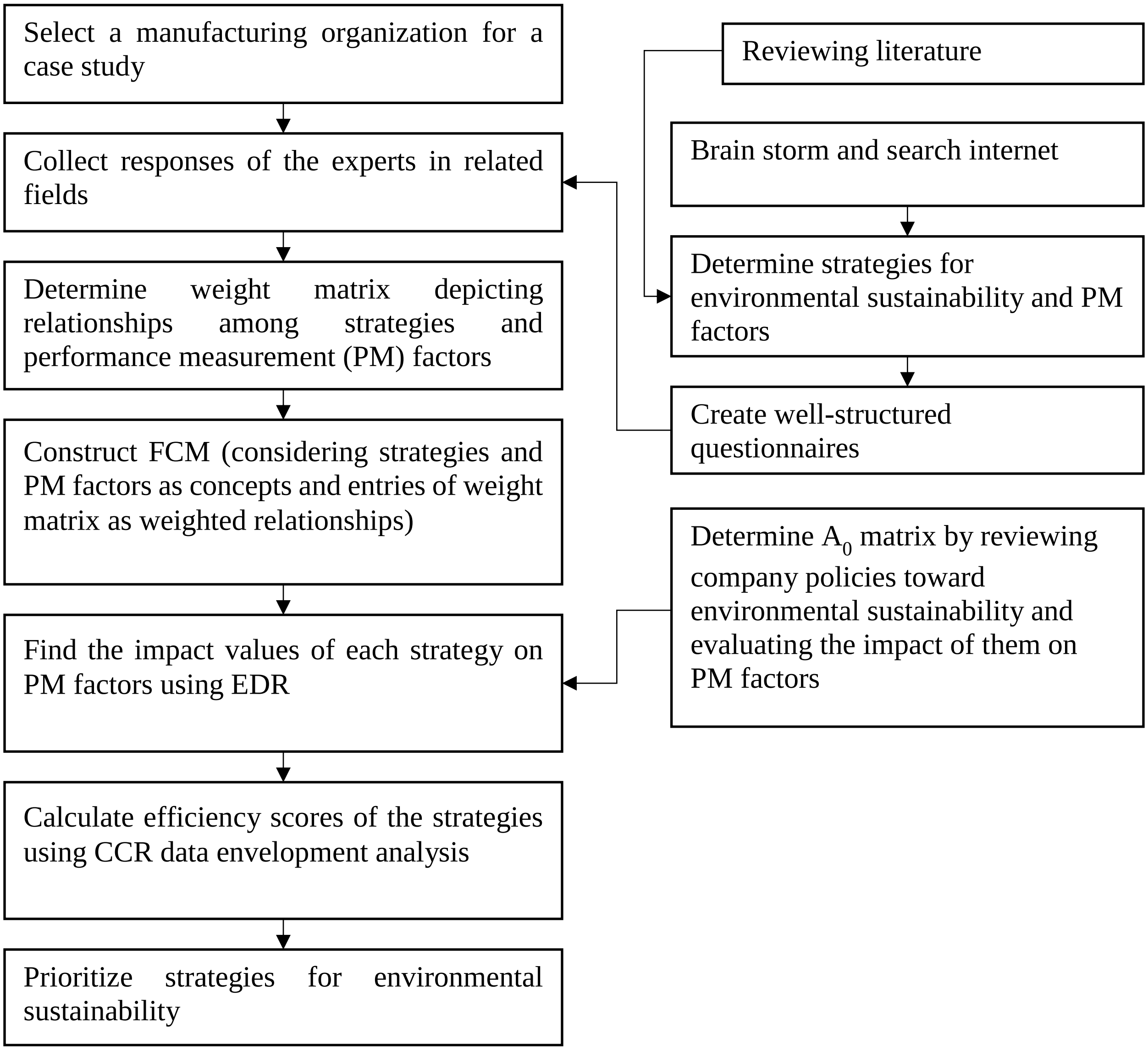

Figure 2: Methodology flow chart for prioritizing ES strategies

The proposed methodology contains four major phases:

a) Review the literature and undergo brainstorming sessions for compiling possible ES strategies and SC network PM factors to use as metrics for comparing strategies.

b) Form FCM based on these strategies and PM factors.

c) Using the EDR, evaluate the impact of each strategy on the PM factors.

d) Prioritize the strategies using CCR DEA.

The details of these four phases can be covered by following 10 steps as given below.

Step 1: Select a company to propose suitable ES strategies.

Step 2: From several articles published in journals found in databases e.g., Scopus and ScienceDirect, particularly noting recently emphasized practices for achieving environmental sustainability.

Step 3: Brainstorm and carefully search into the internet to formulate some new approaches to achieve environmental sustainability. (The approaches gathered throughout steps 2 and 3 will possibly be the desired strategies for environmental sustainability.)

Step 4: Identify the most convenient and effective PM factors of the overall SC network of any manufacturing organization through reviewing literatures the same way mentioned in step 2.

The above 4 steps constitute phase (a).

Step 5: Create structured questionnaires to ascertain the opinions of experienced personnel in fields related to the industry to which the company belongs.

Step 6: Collect responses from the questionnaires and convert them into numerical values in the [-1, 1] range. (After completing step 6, the adjacency or weight matrix ($[W_{ij}]$) corresponding to the FCM will be achieved.)

Step 7: Construct an FCM with the strategies, PM factors, and weight matrix.

Steps 5-7 constitute phase (b).

Step 8: Gather qualitative information about the company's current efforts toward implementing those strategies and how they contribute to these PM factors. Transform them into quantitative information and thus form the A^0 matrix.

Step 9: Find the quantitative values of the impact of the strategies on these PM factors using EDR.

Steps 8 and 9 constitute phase (c).

Step 10: Prioritize strategies by analyzing the quantitative values of impacts through CCR DEA.

Step 10 completes task of phase (d).

5 Application of Proposed methodology

As fast-moving consumer goods (FMCGs) are sold in large quantities, the summation of the small profit margin on each product results in large amounts for companies in emerging economies like Bangladesh (Nagaraju & Thejaswini, 2014). However, due to high volume sales and the discarding nature of FMCGs, the disposed components (by both consumer and SC members) has become alarming (Padmanabhan, 2016). FMCG enterprises both in developed and emerging economies are attempting to reduce associated environmental impacts (Morel & Kwakye, 2012; Wanninayake & Randiwela, 2018). Despite attempts to highlight environmental sustainability in FMCG sectors [USA and Sweden (Morel & Kwakye, 2012); Sri Lanka (Wanninayake & Randiwela, 2018), India (Nagaraju & Thejaswini, 2014), Pakistan (Abbasi & Hassan, 2013)], the scale of their applicability can be questioned because of a focus only on consumer perception and/or organizational performance instead of the overall SC. This study focused on a FMCG company to provide strategic guidelines on environmental sustainability in the overall SC.

The proposed model mentioned in Section 4 is used to prioritize the ES strategies for a FMCG manufacturing company in Bangladesh. The case company, here code named 'XYZ' for the sake of confidentiality, formed in 1999 and is a leader in producing fast FMCG and is placed within the top most FMCG companies in Bangladesh. This company is one of the market leaders in producing hair nourishment, skin care, male grooming, edible oils, and foods. This company has generated a market in Asia and Africa by strengthening its brand portfolio. The company started its journey in Bangladesh through packaging operation of hair oil. Later it stretched it business with producing hair oil.

The case company's motto is to ensure a safe, organized, convivial, empowering, and nondiscriminatory workplace and has attempted to establish sustainability in a way that links environmental performance and economic growth. Recently, the company faced some problems adopting strategies for achieving environmental sustainability and wanted some better strategies with better environmental outcomes. The proposed methodology was implemented to determine the most beneficial strategies for the company to implement.

5.1 Prioritization of Environmentally Sustainable (ES) Strategies

In this part of study, prioritization of ES strategies of the case company will be demonstrated in a detailed manner following the four phases and ten steps outlined earlier.

Phase (a): To find ES strategies and PM factors

Step 1: A FMCG company 'XYZ' had been picked up to propose ES strategies. Reasons for selecting this specific sector and description of the company has been given in the opening paragraphs of this section.

Step 2: Articles were selected with search engines (e.g., Google Scholar) and databases (ScienceDirect and Scopus), with keywords 'strategies for sustainable supply chain', 'environmentally sustainable strategies', 'approaches for sustainable supply chain', 'green supply chain practices', and 'green approach to avoid pollution'. The time preference during the search was initially set 'since 2016' and was then pushed earlier. Finally, selection of ES strategies and PM factors was done based on (i) relevance to the theme of this study, (ii) assumed impact toward achieving environmental sustainability, and (iii) quality of publishers (Elsevier, Emerald, John Wiley & Sons, Taylor and Francis, and Springer were preferred). The 15 most important strategies are mentioned, described, and given symbols (S1 to S15) in Table 2.

Step 3: Through procedural brainstorming, 3 more ES strategies were found which were solely proposed by this study and given in Table 2 with descriptions having symbols S16, S17, S18.

Step 4: The PM factors were extracted from the literature using the same approach mentioned in Step 2. The found 3 PM factors are given in Table 2 with descriptions having symbols P1, P2, P3.

Phase (b): To construct an FCM

Step 5: Creating Questionnaires:

After creating a list of ES strategies and generalized PM factors, some questionnaires were prepared to make it easier for the experts in the related industry (FMCG industry) to evaluate the causal relationships among the strategies and PM factors. The whole questionnaire contained 36 (multiple choice grid type questions for the ease of respondents) questions in total to determine the weight matrix. Among them, 18 questions (Category 1 questionnaire) were designed to understand strategy-strategy relationships and another 18 (Category 2 questionnaire) were prepared to capture strategy-performance factor relationships. Multiple choice grid-type questions is an approach to present multiple questions within one interrogative sentence. Both categories of questionnaire are used to extract the weight. Complete questionnaires for both categories are given in Appendix A.

Step 6: Collecting responses and converting them into numerical values:

The responses were collected from faculties of renowned universities and professionals in different companies having experience working in the environment, health, and safety (EHS) sector (Respondents' profiles are given in Table B1 of Appendix B). Certain measures were taken to reduce response biases while collecting responses (e.g., organizing one to one interview to reduce decision bias, randomizing questions and answer options, making questions easily understandable and using interval scale questions to reduce respondents' difficulty to answer). The internal consistency of the responses was evaluated using SPSS software. The Cronbach's alpha was found to be 0.929, which is enough to validate responses (Butts & Michels, 2006; Olatunji et al., 2017). All responses were converted into specific weights by the weighted average method. The scale used for strategy-strategy relationships was {0.2, 0.4, 0.6, 0.8, 1.0}, representing {negligible, low, moderate, high, very high} relationships, respectively, and the scale used for strategy-PM factors was {-1.0, -0.5, 0, 0.5, 1.0}, in the categories {strongly negative, slightly negative, no impact, slightly positive, strongly positive} relationships. The calculated weight matrix is given in Table 3. In Appendix C, the weight matrix is shown in Table C1 with short descriptions of strategies and factors.

Step 7: Constructing an FCM:

All the strategies and PM factors found in earlier steps were considered as nodes of the FCM. The weight matrix calculated in step 6 represented all the quantities related to the cause-effect relationships of the strategy-strategy and strategy-PM factor pairs. The corresponding FCM is given in Figure 3.

Table 3: Weight matrix representing cause-effect relationships among ES strategies and SC performance measurement factors

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	P1	P2	P3
S1	0	0	0	0	0.75	0.46	0.71	0	0	0	0.75	0	0	0	0.54	0	0	0	0	0	0
S2	0	0	0	0	0.79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S3	0.75	0.54	0	0	0.63	0	0	0	0	0	0.75	0	0	0	0	0.79	0	0	0	0	0
S4	0	0	0	0	0.75	0	0	0.71	0.58	0.71	0	0	0	0.58	0	0	0	0.71	0	0	0
S5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.83	0	0	0	0
S6	0.67	0.58	0.63	0.50	0.63	0	0.63	0.71	0.46	0.58	0.58	0	0	0.63	0.58	0	0.71	0.71	0	0	0
S7	0	0	0	0	0	0	0	0	0	0	0.63	0	0	0.67	0.63	0.83	0.42	0.67	0	0	0
S8	0	0	0	0.79	0.58	0.46	0.46	0	0	0	0	0.67	0.58	0.50	0	0	0.75	0.58	0	0	0
S9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S10	0.46	0.63	0.50	0.54	0.58	0.54	0.50	0.50	0.46	0	0.63	0	0	0.58	0	0	0.75	0	0	0	0
S11	0.79	0.50	0.83	0	0.63	0	0	0	0	0	0	0	0	0.63	0	0	0.83	0	0	0	0
S12	0	0	0	0	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S13	0	0	0	0.71	0.54	0	0	0	0	0	0	0.79	0	0.71	0	0	0.75	0	0	0	0
S14	0	0.71	0	0	0.75	0	0	0	0	0	0	0	0	0	0	0	0.42	0	0	0	0
S15	0	0.58	0	0	0.58	0.42	0.50	0.75	0.29	0.54	0	0	0.46	0.50	0	0	0.75	0.50	0	0	0
S16	0.79	0	0.71	0	0.58	0	0	0	0	0.71	0	0	0	0	0	0	0.50	0	0	0	0
S17	0	0	0	0	0	0	0	0	0	0	0	0	0	0.67	0	0	0	0	0	0	0
S18	0	0	0	0	0.58	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0
P1	0.4	-0.2	0.6	-0.6	-0.1	-0.1	0	0.1	0.5	0.3	0.8	0.6	0.6	-0.4	0	0.9	0.50	0	0	0	0
P2	0.5	0	0.2	-0.2	0.6	-0.1	0.1	0.3	0.3	0.3	0.7	0.5	0.5	0.2	0.4	-0.3	0.60	0.1	0	0	0
P3	0.4	0.3	0.4	0.1	0.6	0.3	0.4	0.5	0.1	0.1	0.7	0.8	0.5	0.6	0.7	0.5	0.85	0.5	0	0	0

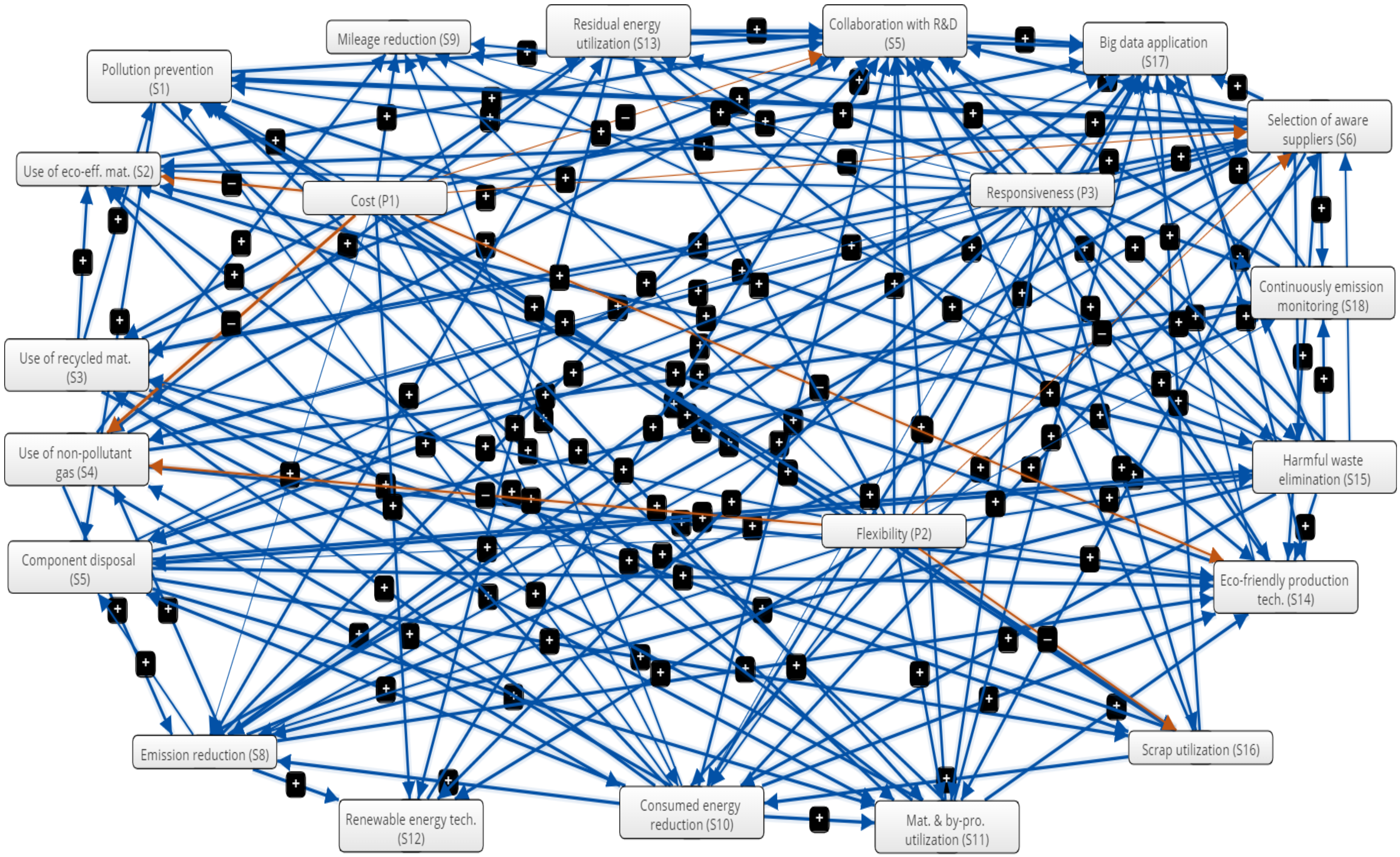

Figure 3: FCM of ES strategies and PM factors

Phase (c): To evaluate impact values

Step 8: Determining the A_0 matrix:

For finding the value of impact of each strategy on the PM factors, two inputs were needed (discussed in 3.1): the weight matrix and the initial concept state matrix (A^0) matrix. Enough information was collected through observing the company plants physically, interviewing the responsible officers, and reviewing internet information about the practices' portfolio to evaluate the A_0 matrix. The A_0 matrix for the company under study is given below:

$$A^0 = [.7 \quad .2 \quad .45 \quad 0 \quad .4 \quad 0 \quad .85 \quad 0 \quad .15 \quad 0 \quad .4 \quad 0 \quad .55 \quad .25 \quad 0 \quad .1 \quad 0 \quad 0 \quad .4 \quad .2 \quad .35]'$$

Step 9: Finding impact values of each of the strategies on PM factors:

Impact values of every ES strategy on PM factors were found using the EDR learning algorithm and was implemented with the help of MATLAB. Additional information added to the algorithm is given in Table 4.

Table 4: Description, value or expression of symbols used in EDR

Symbol	Description	Values or Expression
f	Normalization or squashing function	$\frac{1}{1+\exp(-x)}$
$f'(x)$	Derivative of 'f' function	$x(1-x)$
A	Learning rate	0.3
ɣ	Adjusting factor	1
$\frac{\partial E}{\partial w_{ij}}$	Partial derivative of error	$\lvert -2 \times (t_i - A_i) \times A_j \times A_i \times (1-A_i) \rvert$
ε	Termination value	0.00055
n	Number of nodes in FCM	21
m	Number of strategies in FCM	18

Using the above information in the algorithm, the weight matrix ($[w_{ij}]$) and initial concept state matrix A^0 were fed into the code of the EDR.

Some guidelines followed in this code are:

- All entries of initial derivative matrix would be 1.

- The target matrix $[t_j]$ considered each strategy separately to evaluate their impact on PM factors. As we had to find separate impact values of 18 strategies on 3 PM factors, the EDR code was run 18 times, each time with a different $[t_j]$ matrix. For example: to find the 1st strategy's impact value, the target matrix would be as follows:

$$t = [1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]'$$

  And the 2nd strategy would be:

$$t = [0 \quad 1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]'$$

- When the termination condition was reached, the value of the last three rows (19th, 20th, 21st rows) of the latest A matrix (concept state matrix) were the impact values of that strategy on the three PM factors (cost, flexibility, and responsiveness, respectively).

Following the above-mentioned instructions, the impact values were found and these values are provided in Table 5.

Table 5: Impact values of ES strategies found by EDR

Strategies	PM Factors		
	Cost	Flexibility	Responsiveness
S1	0.7704	0.7924	0.7825
S2	0.6157	0.6762	0.7611
S3	0.8088	0.7277	0.7823
S4	0.4879	0.6176	0.7128
S5	0.6460	0.8109	0.8196
S6	0.6443	0.6472	0.7599
S7	0.6732	0.7026	0.7818
S8	0.6997	0.7505	0.8009
S9	0.7903	0.7510	0.7156
S10	0.7481	0.7503	0.7142
S11	0.8415	0.8277	0.8355
S12	0.8090	0.7926	0.8505
S13	0.8088	0.7924	0.8016
S14	0.5538	0.7276	0.8188
S15	0.6732	0.7721	0.8348
S16	0.8556	0.5887	0.8013
S17	0.7906	0.8111	0.8576
S18	0.6734	0.7028	0.8013

Phase (d): To prioritize ES strategies

Step 10: Prioritizing strategies by analyzing the efficiency scores of all strategies using CCR DEA:

To prioritize the ES strategies, the last step was to analyze the impact values with the help of CCR data envelopment analysis (CCR DEA). For this, each strategy was considered a Decision Making Unit (DMU). The CCR DEA model used was output oriented where the output values are intended to be maximized, as mentioned earlier. In the DEA method, it is preferable to enhance the output criteria and vice versa. In this study, the impact values of 18 strategies on two PM factors (flexibility and customer responsiveness) were considered as outputs of DEA and the impact values on remaining factor (cost) were considered as input of DEA as it is desired to be kept as low as possible. By undergoing the optimization problem each time with changing equality constraints in MATLAB, as mentioned in 3.2, the efficiency score in [1, ∞] range for each strategy was determined and are provided in Table 6.

Table 1: Efficiency scores of ES strategies found with DEA

Symbol	Strategy name	Efficiency Score	Rank
S1	Pollution prevention through recycling & reuse	1.0445	5
S2	Usage of eco-efficient material	1.1268	13
S3	Usage of materials recycled from the disposed components in the production process	1.0453	6
S4	Usage of non-pollutant gas as a source of energy	1.2032	15
S5	Collaboration with R&D department for eco-innovation	1.0201	2
S6	Selecting suppliers committed to adopt and certify ISO 14001:2015	1.1286	14
S7	Proper disposal of components	1.097	11
S8	Source-based emission reduction	1.0708	10
S9	Mileage reduction for freight transport	1.0668	8
S10	Reduction in relative energy consumption with respect to competing companies	1.103	12
S11	Material savings and better utilization of by-products	1	1
S12	Renewable energy technologies (ventilation and energy use in buildings)	1	1
S13	Recovery and utilization of residual energy and heat	1.0407	4
S14	Usage of eco-friendly production technology and equipment	1.0474	7
S15	Elimination of hazardous waste at source level	1.0273	3
S16	Better utilization of process-generated scrapped items	1	1
S17	Introducing application of big data	1	1
S18	Continuous monitoring of data related to plant emissions to control hazardous situations before occurring	1.0703	9

Each efficiency score actually represented a numerical value indicating how efficiently a strategy could work to improve the overall SC performance, which was our prime objective. Efficiency values for output-oriented CCR DEA model are obtained equal to or greater than 1 in the [1,∞] scale. Values equal or close to 1 indicated greater competency of the strategy for achieving maximized SC performance. Values greater than 1 indicated the inefficiency of the strategies. Thus the ranking of those 18 strategies was achieved based on their efficiency scores and it was given in the rightmost column of Table 6.

6 Results and Discussions

In this section, the insights of the research findings will be discussed about other related research works. The logic behind selecting the prioritized strategies will also be discussed here. Another important thing to point out, before starting discussion about the research findings, is that the experts' response collection was one of the vital tasks to come to a conclusion in this prioritization problem. The respondents' subjectivity or biased views can be a major problem which could ultimately result in inaccurate results. We have organized one to one interview, randomized questions and answer options, made questions easily understandable and used interval scale questions to reduce response biases.

As can be seen in Table 6, four strategies simultaneously achieved the first rank. Those four strategies are: S11 (Material savings and better utilization of by-products), S12 (Renewable energy technologies), S16 (Better utilization of process-generated scrapped items), and S17 (Introducing application of big data). The second ranked strategy was S5 (Collaboration with R&D department for eco-innovation). S11, S12, S16, S17, and S5 were the top five strategies based on their efficiency scores. Figure 4 shows all the strategies versus their efficiency scores plotted and the relative gap between each strategy's efficiency with the average efficiency score.

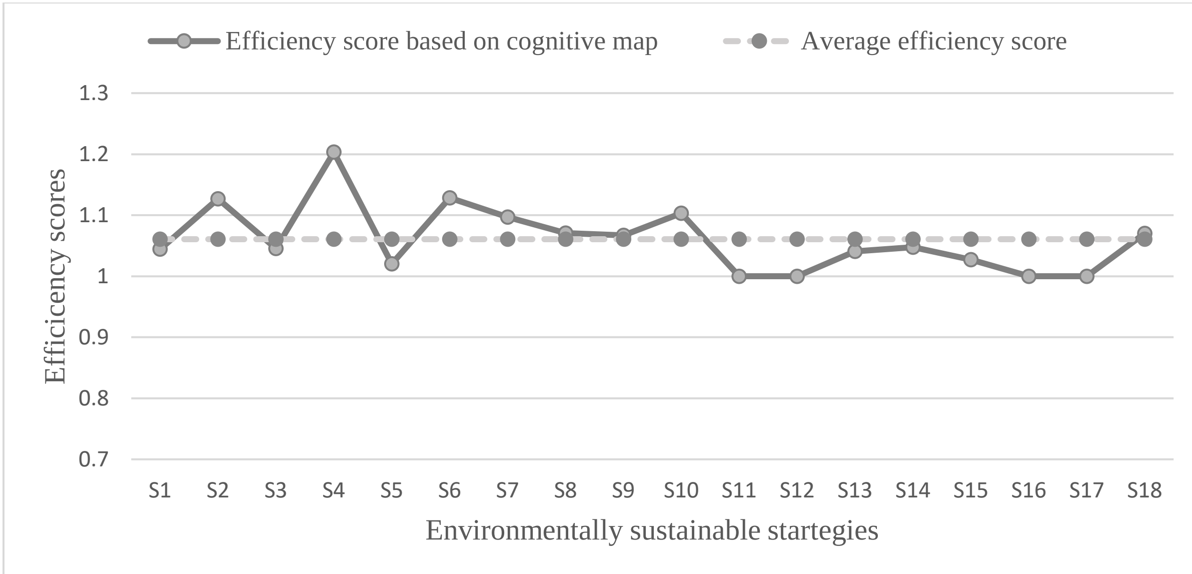

Figure 4: Individual and average efficiency scores of ES strategies

'Introducing application of big data' (S17) was ranked the number one strategy among all strategies. Even though Bangladesh is a developing country, it is the right time to introduce state-of-art data management system in industries because the advantages are of huge significance especially considering the amount of investments (Brinch & Brinch, 2018). Ren, Gao, et al., (2015) prioritized 'developing new and sustainable technologies as strategies' for promoting the development of the hydrogen economy in China. The need to 'upgrade technology' was prioritized in the work of Mangla et al., (2015)and Mangla et al. (2017), Prakash and Barua (2015) based their case studies on an Indian poly-plastic manufacturer, an ancillary auto manufacturer, and the Indian electronic industry, respectively. So, big data could potentially be the best and most upgraded technology for efficiently achieving environmental sustainability.

'Material savings and better utilization of by-products' (S11), 'Renewable energy technologies' (S12), and 'Better utilization of process generated scrapped items' (S16) were all equally ranked in the top strategies with 'Introducing Application of big data' (S17). These three strategies (S11, S12, S16) are the most practical and economically viable solutions for environmental sustainability (Naidoo & Gasparatos, 2018). The practices of 'reduction of material waste and better utilization of by-products' and 'reduction of energy waste' were prioritized to achieve sustainability by the studies of Prakash and Barua (2015) and Naidoo and Gasparatos (2018), based on their case studies on the Indian electronic industry and the retail sector, respectively, and thus strengthens the logic for S11 and S12 being prioritized strategies in this study. Ahmed et al., (2016) identified ‘recycling’ as the best compromise for a sustainable alternative for End of Life Vehicle management, which further supports S11 and S16 being prioritized strategies. Moreover, 2 of the 4 top prioritized strategies (S11, S16) have coherence with the CE concept. CE concept implementation ensures better output with less expense and quantity of materials (Reichel et al., 2016; Masi et al., 2017; Fonseca et al., 2018; MacArthur, 2013; Lieder & Rashid, 2016), and thus it is believed to be one of the most important validations of the results of this study. This result ultimately expresses the implications of CE for emerging economies. Among these three strategies, most have already been implemented by the company under study, but their implementation needs to be spread throughout the entire SC network. This will result in the initiation of most of the other strategies (recycling, using eco-efficient material, using eco-friendly technologies, eliminating hazardous wastes, reducing relative energy consumption), indirectly resulting in improvement in the overall SC (cost reduction and increase of flexibility and responsiveness).

‘Collaboration with R&D department for eco-innovation’ (S5) was ranked as the second ES strategy. Goyal et al. (2015) found ‘research development and pollution prevention’ as the most important practices in the manufacturing sector among their 12 identified corporate sustainability practices. Advancing research has been declared as a major solution to overcoming barriers to a sustainable shale gas revolution in China in the research of (Ren, Tan, et al., 2015). The work of Ren, Tan, et al., (2015), Mangla et al., (2015), Mangla et al. (2017), and Prakash and Barua, (2015) also identified collaboration with R&D as a key practice for achieving sustainability. As most of the manufacturing companies in Bangladesh still lag in the field of Research and Development, the implementation of ES strategies cannot be fully possible. Every company has their own unique product lines and markets, so implementing generalized strategies throughout the SC network without proper lab works or innovations would not yield quality results. It is not enough to simply implement strategies without innovative thinking. Eco-innovation is the most effective way to reduce environmental losses (Costantini et al., 2016). In a country like Bangladesh, a company may not be in the best situation to undergo basic scientific research but its R&D department should still focus on product and process development strategies for environmental sustainability.

A number of studies had results that differed from those in this study. One example is in the study of Goyal et al. (2015) who had a prioritized practice as ‘Pollution prevention’. The ‘refinement of subsidies’, ‘seeking tax allowances from governments’, ‘improving skills’, ‘increasing top management commitment and support of lower and middle level managers’, and ‘developing outsourcing policies’ were the prioritized strategies suggested in the research works of Ren, Tan, et al., (2015), Mangla et al., (2015), Mangla et al. (2017), and Prakash and Barua (2015). Dooley, (2016) gave emphasis on systematic innovation (product stewardship) rather than heavy technological innovation for environmental sustainability of low-velocity industries. The probable reasons for the differing priorities of these studies could be the variations in industries and organizations selected for the case study, differences in methodology used, and emphasis on more managerial aspects.

The top five out of 18 strategies were recommended for implementation in the company under study because of the limitations of assets (resources, skills, and technologies) they possess. Most manufacturing companies in Bangladesh have these limitations which impedes them from applying many of the ES strategies. Considering the current assets and future policies of the case study company, it is recommended they prioritize these top five ES strategies.

Although there are limitations of assets, focusing on these five strategies should not mean that the other 13 strategies are not considered. As discussed earlier, correlation among these strategies indicated that implementation of one strategy indirectly initiates the implementation of the correlated strategies. Further, this research outlined which strategies would most promisingly impact the PM factors, based on those correlations. Therefore, the decision to primarily focus on these top five strategies makes a lot of sense.

These results will vary based on each company, industry, and timeframe. So, different companies and industries will have different shortlists of prioritized ES strategies when following the same research methodology. This is because when the 3 inputs (W, A^0, t matrix) are fed into the EDR they produce the value of impact of each strategy on the PM factors. If the same research methodology was applied for different industries, the ‘weight matrix $[w_{ij}]$’ would have been modified as the cause-effect relationships of strategy-strategy and strategy-performance factor pairs varies from industry to industry. When applied for different companies, the ‘initial concept state matrix A^0’ would change as current levels of effort toward environmental sustainability varies from company to company. Finally, the result would also vary with different timeframes to improve the same company. This is because, with a longer timeframe, a higher quality of work with a more suitable collection of ES strategies would be developed and thus alter the order of the 'target matrix'$[t_j]$.

7 Conclusions

Throughout the world, achieving environmental sustainability is perceived as a top priority because it is directly related to the survival of mankind. Manufacturing companies are one of the major contributors to the presently degraded state of the environment. Renowned companies are now coming forward and committing to be strategic to ensure minimal harm is caused to the environment. But all companies must be conscious of their impact on the environment to survive in todays' market and satisfy their stakeholders by improving the overall performance of their supply chains. For companies with limited resources and capabilities, it is extremely challenging to be an environmentally friendly company without being strategic. Therefore, it is necessary to develop ES strategies. This research provides a basic, but specific, methodology to choose the strategies best suited for a given manufacturing company. This methodology is designed to work best in practical fields. While being easy to implement, it also captures the complicated relationships between the strategies and within the overall SC.

7.1 Research Implications

FMCGs (e.g., non-durables like toiletries, soap, cosmetics, teeth cleaning products, shaving products, as well as detergents, glassware, light bulbs, batteries, paper products, and plastic goods) are products purchased frequently at relatively cheap prices (Deliya, 2012). Because of the high volume sale and discarding nature of FMCGs, the rejected (by both consumer and SC members) components from the FMCG sector are a major concern as environmental pollution (Padmanabhan, 2016). As a result, FMCG companies in developed and developing countries have increasing concern for finding remedies to reduce their impact on the environment (Morel & Kwakye, 2012; Wanninayake & Randiwela, 2018). A number of researchers [USA and Sweden

(Morel & Kwakye, 2012); Sri Lanka (Wanninayake & Randiwela, 2018), India (Nagaraju & Thejaswini, 2014), Pakistan (Abbasi & Hassan, 2013)] considered consumer perception and organizational performance only. This study attempts to give strategic solutions for environmental pollution for FMCGs of an emerging economy considering the overall SC.

This study presents a new decision-making approach featuring FCM with EDR and DEA into the prioritization of ES strategies. In addition, this study is simple to follow as it uses the learning algorithm. Company professionals may find this research easy to implement into their overall SC network. In doing so, the study provides theoretical contributions related to environmental sustainability.

7.2 Limitations

One of the major limitations of this study is the unavailability of properly structured data. In this research, the EDR learning algorithm played a significant role, but EDR is a variant of the neural network which requires properly structured data for accurate results. Due to the lack of availability of historical data, the primary data source for this research was the knowledge and experience of experts in the related field. Although EDR reduces dependence on the perceived subjective knowledge, state-of-art data would enhance the accuracy of the result. Moreover, due to avoiding over-complexity, the PM factors were limited to three. There is a trade-off between the simplicity of the methodology and the accuracy of the result, still, the number of PM factors were enough to achieve results accurate enough to determine the most practical solution. To reduce complexities in survey responses, causal relationships between some strategies and PM factors were assumed to be zero. This assumption decreases the accuracy of the result to a certain amount, but was acceptable as based on time limitations of the highly-paid experts. Finally, results will vary based on company, industry, and timeframe, because the cause-effect relationship among strategies and their impact on PM factors varies from industry to industry. Also, with a longer timeframe, a higher quality of work with a more suitable collection of ES strategies likely will be developed. Thus, with industry and timeframe shifts, results on prioritization of ES strategies will change. Future researchers are encouraged to explore a way to circumvent this limitation. This research should be replicated over time, and extended to other organizations and other countries.

7.3 Future Research Direction

As environmental degradation issues are the most burning topics about which the whole world is concerned, the amount of research into environmental sustainability will naturally grow tremendously in the future. The possible extension of this research would be to apply this methodology in more diverse organizations than only the manufacturing sector. Another future scope would be to apply other decision-making techniques to compare or merge results obtained from these approaches. Different novel MCDM techniques e.g., DEMATEL in association with uncertainty theories (e.g., interval type 2 fuzzy sets, IFSs, 2-tuples), ANP-DEMATEL and other innovative and effective combination of the MCDM techniques such as ANP, DEMATEL, ISM, Interpolative Boolean Algebra can be used to compare the results and to improve the findings.

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APPENDIX A: QUESTIONNAIRES FOR DETERMINING WEIGHT MATRIX

Each of the question mentioned belonging to the 2 categories of questionnaire mentioned below is actually a multiple choice grid type questions (an approach to present multiple questions within one interrogative sentence). Please fill each row of each multiple choice grid type questions by either filling or ticking the preferred circles.

Category 1 Questionnaire (To determine weights of Strategy-Strategy pair):

Determination of Extent of Cause-effect Relationship between a Pair of Strategies for Environmental Sustainability:

Cause-effect relationship between 2 Strategies e.g., i & j indicates if the strategy i is implemented, how much influence the strategy j carries for it. For example, if strategy 'Pollution Prevention through recycling & reuse' is implemented, it will obviously have an impact on the strategy 'Usage of recycled material in production process'. And you have to just give answer considering this scenario that what will be the extent of this impact.

1. If the strategy 'Pollution Prevention through recycling & reuse' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Usage of materials recycled from the disposed components in production process	O	O	O	O	O
Selecting suppliers committed to adopt and certify ISO 14001:2015	O	O	O	O	O
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O

Material savings and better utilization of by-products	O	O	O	O	O
Better utilization of process-generated scrapped items	O	O	O	O	O

2. If the strategy 'Usage of eco-efficient material' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Usage of materials recycled from the disposed components in production process	O	O	O	O	O
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O
Material savings and better utilization of by-products	O	O	O	O	O
Usage of eco-friendly production technology and equipment	O	O	O	O	O
Elimination of hazardous waste at source level	O	O	O	O	O

3. If the strategy 'Usage of materials recycled from the disposed components in production process' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O
Material savings and better utilization of by-products	O	O	O	O	O
Better utilization of process-generated scrapped items	O	O	O	O	O

4. If the strategy 'Usage of non-polluting fuel as source of energy' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Source based emission reduction	O	O	O	O	O
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O
Recovery and utilization of residual energy and heat	O	O	O	O	O

5. If the strategy ‘Collaboration with R&D department for eco-innovation’ is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Pollution Prevention through recycling & reuse	O	O	O	O	O
Usage of eco-efficient material	O	O	O	O	O
Usage of materials recycled from the disposed components in production process	O	O	O	O	O
Usage of non-polluting fuel as source of energy	O	O	O	O	O
Source based emission reduction	O	O	O	O	O
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O
Material savings and better utilization of by-products	O	O	O	O	O
Renewable energy technologies (Ventilation and energy use in buildings)	O	O	O	O	O

Recovery and utilization of residual energy and heat	O	O	O	O	O
Usage of eco-friendly production technology and equipment	O	O	O	O	O
Elimination of hazardous waste at source level	O	O	O	O	O
Better utilization of process-generated scrapped items	O	O	O	O	O
Continuous monitoring of data related to plants' emission to control hazardous situations before occurring	O	O	O	O	O

6. If the strategy 'Selecting suppliers committed to adopt and certify ISO 14001:2015' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Pollution Prevention through recycling & reuse	O	O	O	O	O
Source based emission reduction	O	O	O	O	O
Reduction in relative energy consumption with	O	O	O	O	O

respect to competing companies					
Elimination of hazardous waste at source level	O	O	O	O	O

7. If the strategy 'Proper disposal of components' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Pollution Prevention through recycling & reuse	O	O	O	O	O
Source based emission reduction	O	O	O	O	O
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O
Elimination of hazardous waste at source level	O	O	O	O	O

8. If the strategy 'Source based emission reduction' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Collaboration with R&D department for eco-innovation	O	O	O	O	O

Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O
Elimination of hazardous waste at source level	O	O	O	O	O

9. If the strategy ‘mileage reduction for freight transport’ is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Usage of non-polluting fuel as source of energy	O	O	O	O	O
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O
Elimination of hazardous waste at source level	O	O	O	O	O

10. If the strategy ‘Reduction in relative energy consumption with respect to competing companies’ is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Usage of non-polluting fuel as source of energy	O	O	O	O	O

Elimination of hazardous waste at source level	O	O	O	O	O

11. If the strategy 'Material savings and better utilization of by-products' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Pollution Prevention through recycling & reuse	O	O	O	O	O
Usage of materials recycled from the disposed components in production process	O	O	O	O	O
Proper disposal of components	O	O	O	O	O
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O
Better utilization of process-generated scrapped items	O	O	O	O	O

12. If the strategy 'Renewable energy technologies' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High

Source based emission reduction	O	O	O	O	O
Recovery and utilization of residual energy and heat	O	O	O	O	O

13. If the strategy 'Recovery and utilization of residual energy and heat' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Source based emission reduction	O	O	O	O	O
Elimination of hazardous waste at source level	O	O	O	O	O

14. If the strategy 'Usage of eco-friendly production technology and equipment' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Usage of non-polluting fuel as source of energy	O	O	O	O	O
Proper disposal of components	O	O	O	O	O
Source based emission reduction	O	O	O	O	O
Reduction in relative energy consumption with	O	O	O	O	O

respect to competing companies					
Material savings and better utilization of by-products	O	O	O	O	O
Recovery and utilization of residual energy and heat	O	O	O	O	O
Elimination of hazardous waste at source level	O	O	O	O	O
Continuous monitoring of data related to plants' emission to control hazardous situations before occurring	O	O	O	O	O

15. If the strategy ‘Elimination of hazardous waste at source level’ is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Proper disposal of components	O	O	O	O	O
Reduction in relative energy consumption with respect to competing companies	O	O	O	O	O

16. If the strategy ‘Better utilization of process-generated scrapped items’ is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Pollution Prevention through recycling & reuse	O	O	O	O	O
Usage of materials recycled from the disposed components in production process	O	O	O	O	O
Proper disposal of components	O	O	O	O	O

17. If the strategy 'Introducing application of big data' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Pollution Prevention through recycling & reuse	O	O	O	O	O
Usage of materials recycled from the disposed components in production process	O	O	O	O	O
Proper disposal of components	O	O	O	O	O

18. If the strategy 'Continuous monitoring of data related to plants' emission to control hazardous situations before occurring' is implemented, how much impact do you think each of the following strategies will carry?

	Negligible	Low	Moderate	High	Very High
Usage of non-polluting fuel as source of energy	O	O	O	O	O
Proper disposal of components	O	O	O	O	O
Source based emission reduction	O	O	O	O	O
Elimination of hazardous waste at source level	O	O	O	O	O

Category 2 Questionnaire (To determine weights of Strategy-Performance factor pair):

Determination of the extent of impact of each strategy on the performance measurement factors of supply chain:

1. What kind of impact do you think the strategy 'Pollution prevention through recycling & reuse' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

2. What kind of impact do you think the strategy ‘Usage of eco-efficient material' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

3. What kind of impact do you think the strategy ‘Usage of materials recycled from the disposed components in production process ' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

4. What kind of impact do you think the strategy ‘Usage of non-polluting fuel as source of energy' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

5. What kind of impact do you think the strategy 'Collaboration with R&D department for eco-innovation' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

6. What kind of impact do you think the strategy 'Selecting suppliers committed to adopt and certify ISO 14001:2015' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

7. What kind of impact do you think the strategy 'Proper disposal of components' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O

Increasing responsiveness	O	O	O	O	O

8. What kind of impact do you think the strategy ‘Source based emission reduction' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

9. What kind of impact do you think the strategy ‘Mileage reduction for freight transport' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

10. What kind of impact do you think the strategy ‘Reduction in relative energy consumption with respect to competing companies' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O

Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

11. What kind of impact do you think the strategy 'Material savings and better utilization of by-products' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

12. What kind of impact do you think the strategy 'Renewable energy technologies (Ventilation and energy use in buildings)' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

13. What kind of impact do you think the strategy 'Recovery and utilization of residual energy and heat' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive

Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

14. What kind of impact do you think the strategy 'Usage of eco-friendly production technology and equipment' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

15. What kind of impact do you think the strategy 'Elimination of hazardous waste at source level' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

16. What kind of impact do you think the strategy 'Better utilization of process–generated scrapped items' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

17. What kind of impact do you think the strategy 'Introducing application of big data ' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

18. What kind of impact do you think the strategy 'Continuous monitoring of data related to plants' emission to control hazardous situations before occurring' has on the following factors?

	Strongly Negative	Slightly Negative	No Impact	Slightly Positive	Strongly Positive
Decreasing cost	O	O	O	O	O
Increasing flexibility	O	O	O	O	O
Increasing responsiveness	O	O	O	O	O

APPENDIX B: DETAILS OF THE RESPONDENTS

Table B1: Profile of Respondents

Background	Belonging University or Company Name	Affiliation
Academic	Bangladesh University of Engineering and Technology	Faculty of Institute of Appropriate Technology
Corporate	Lafarge Holcim Bangladesh Ltd., Bangladesh	Executive in Health & Safety
Academic	Ahsanuallah University of Science and Technology, Bangladesh	Faculty of Mechanical and Production Engineering
Corporate	British American Tobacco Bangladesh	Former Team Leader, EHS
Corporate	British American Tobacco Bangladesh	Environmental, Health, and Safety EHS Officer
Corporate	Runners Automobiles, Bangladesh	Environmental, Health, and Safety EHS Officer
Corporate	Energypac Engineering Ltd., Bangladesh	Former Deputy Manager - Supply Chain

APPENDIX C: WEIGHT MATRIX WITH SHORT DESCRIPTION OF ES STRATEGIES AND PM FACTORS

Table C1: Weight matrix representing cause-effect relationships among strategies and PM factors

	S1 Pollution prevention	S2 Use of eco-eff. Mat.	S3 Use of recycled mat.	S4 Use of non-pollutant gas	S5 Collabo-ration with R&D	S6 Selection of aware suppliers	S7 Component disposal	S8 Emission reduction	S9 Mileage reduction	S10 Consumed energy reduction
S1- Pollution prevention	0	0	0	0	0.75	0.46	0.71	0	0	0
S2- Use of eco-eff. Mat.	0	0	0	0	0.79	0	0	0	0	0
S3- Use of recycled mat.	0.75	0.54	0	0	0.63	0	0	0	0	0
S4- Use of non-pollutant gas	0	0	0	0	0.75	0	0	0.71	0.58	0.71
S5- Collaboration with R&D	0	0	0	0	0	0	0	0	0	0
S6- Selection of aware suppliers	0.67	0.58	0.63	0.50	0.63	0	0.63	0.71	0.46	0.58
S7- Component disposal	0	0	0	0	0	0	0	0	0	0
S8- Emission reduction	0	0	0	0.79	0.58	0.46	0.46	0	0	0
S9- Mileage reduction	0	0	0	0	0	0	0	0	0	0
S10- Consumed energy reduction	0.46	0.63	0.50	0.54	0.58	0.54	0.50	0.50	0.46	0
S11- Mat. & byproduct utilization	0.79	0.50	0.83	0	0.63	0	0	0	0	0
S12- Renewable energy tech.	0	0	0	0	0.75	0	0	0	0	0
S13- Residual energy utilization	0	0	0	0.71	0.54	0	0	0	0	0
S14- Eco-friendly production tech.	0	0.71	0	0	0.75	0	0	0	0	0
S15- Harmful waste elimination	0	0.58	0	0	0.58	0.42	0.50	0.75	0.29	0.54
S16- Scrap utilization	0.79	0	0.71	0	0.58	0	0	0	0	0.71
S17- Big data application	0	0	0	0	0	0	0	0	0	0
S18- Continuously emission monitoring	0	0	0	0	0.58	0	0	0	0	0
P1- Cost	0.4	-0.2	0.6	-0.6	-0.1	-0.1	0	0.1	0.5	0.3
P2- Flexibility	0.5	0	0.2	-0.2	0.6	-0.1	0.1	0.3	0.3	0.3
P3- Responsiveness	0.4	0.3	0.4	0.1	0.6	0.3	0.4	0.5	0.1	0.1

Table C1 (cont.): Weight matrix representing cause-effect relationships among strategies and PM factors

	S11 Mat. & byproduct utilization	S12 Renew-able energy tech.	S13 Residual energy utilization	S14 Eco-friendly produc-tion tech.	S15 Harmful waste elimina-tion	S16 Scrap utiliza-tion	S17 Big data applica-tion	S18 Continuously emission monitoring	P1 Cost	P2 Flexi-bility	P3 Respon-siveness
S1- Pollution prevention	0.75	0	0	0	0.54	0	0	0	0	0	0
S2- Use of eco-eff. Mat.	0	0	0	0	0	0	0	0	0	0	0
S3- Use of recycled mat.	0.75	0	0	0	0	0.79	0	0	0	0	0
S4- Use of non-pollutant gas	0	0	0	0.58	0	0	0	0.71	0	0	0
S5- Collaboration with R&D	0	0	0	0	0	0	0.83	0	0	0	0
S6- Selection of aware suppliers	0.58	0	0	0.63	0.58	0	0.71	0.71	0	0	0
S7- Component disposal	0.63	0	0	0.67	0.63	0.83	0.42	0.67	0	0	0
S8- Emission reduction	0	0.67	0.58	0.50	0	0	0.75	0.58	0	0	0
S9- Mileage reduction	0	0	0	0	0	0	0	0	0	0	0
S10- Consumed energy reduction	0.63	0	0	0.58	0	0	0.75	0	0	0	0
S11- Mat. & byproduct utilization	0	0	0	0.63	0	0	0.83	0	0	0	0
S12- Renewable energy tech.	0	0	0	0	0	0	0	0	0	0	0
S13- Residual energy utilization	0	0.79	0	0.71	0	0	0.75	0	0	0	0
S14- Eco-friendly production tech.	0	0	0	0	0	0	0.42	0	0	0	0
S15- Harmful waste elimination	0	0	0.46	0.50	0	0	0.75	0.50	0	0	0
S16- Scrap utilization	0	0	0	0	0	0	0.50	0	0	0	0
S17- Big data application	0	0	0	0.67	0	0	0	0	0	0	0
S18- Continuously emission monitoring	0	0	0	0	0	0	0.75	0	0	0	0
P1- Cost	0.8	0.6	0.6	-0.4	0	0.9	0.50	0	0	0	0
P2- Flexibility	0.7	0.5	0.5	0.2	0.4	-0.3	0.60	0.1	0	0	0
P3- Responsiveness	0.7	0.8	0.5	0.6	0.7	0.5	0.85	0.5	0	0	0