A supply chain sustainability innovation framework and evaluation methodology

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Abstract – Sustainability is hinged on innovation. The importance of sustainable innovation management in sustainable supply chain management (SSCM) cannot be underestimated. Studies on SSCM have emphasized the need for sustainable innovation in achieving sustainability but none provide deep insights to sustainable innovation management in SSCM implementation. This lack of research depth stimulates this study to identify and investigate criteria for sustainable supply chain management innovation advancement. This paper proposes a sustainable innovation criteria framework for investigating sustainable supply chains in manufacturing companies. To exemplify the applicability and efficiency of the proposed framework, a sample of five Indian manufacturing companies are used to evaluate and prioritize the sustainable innovation management criteria, using the 'best-worst' multi-criteria decision-making (BW-MCDM) model. The criteria weights for all companies from BWM are aggregated, averaged and used for ranking. The respondent managers viewed 'financial availability for innovation' as the most important sustainable innovation sub-criteria. The results of the study will inform industrial managers, practitioners and decision-makers on which criteria to focus on during the implementation stage, to increase sustainability in manufacturing supply chains, and further advance corporate and supply chain sustainable development. The framework may also serve as a theoretical construct for future empirical study on sustainable supply chain innovation in the manufacturing sector. This paper sets the stage for further research in sustainable innovation practices in the manufacturing sector and its supply chains.

1. Introduction

Environmental and human system damage, the consequences of industrial activities since industrial revolution, is a rising global concern (Chen, 2008; Kusi-Sarpong et al., 2015). The debate on sustainable development has grown exponentially and received increasing attention in the sustainability and supply chain management arena (Seuring & Müller, 2008a; Fahimnia et al., 2015). Increasing public awareness, stricter government regulatory requirements, and market

pressure have forced many firms to integrate sustainability into their supply chains (Bai et al., 2017; Kusi-Sarpong et al., 2016a & b). Several policy interventions have been implemented to remedy such damage, but these initiatives are unfortunately mostly internally focused; limiting the scope of addressing comprehensive industrial sustainable management concerns (Chen, 2008). Managing these sustainability issues effectively requires an extended perspective beyond a focal firm to include supply chain partners (Isaksson et al., 2010; Kusi-Sarpong at al., 2015). Sustainable supply chain management (SSCM) can be described as managing organizational supply chains to maximize *profitability*, improve the *social* wellbeing of its stakeholders and reducing negative *environmental* impacts (Hassini et al., 2011).

For example, the manufacturing sector as a product system, relates directly and indirectly to economic wealth creation, impact on the natural environment and social systems along the product's life cycle (Kusi-Sarpong et al., 2015, Warren et al., 2001). Responding to these multi-stakeholder pressures and concerns (Badri Ahmadi et al., 2017b) is important for sustainable development progress.

Achieving sustainable development will require the implementation of sustainable innovations (Boons et al., 2013; Horbach, 2005). Sustainable innovation can be defined as introducing novel, or modifications in, production processes, techniques, systems, organizations and products to lessen environmental damage. These innovations should also provide similar or greater value with improved economic, social and organizational performance (Hafkesbrink & Halstrick-Schwenk, 2005; Horbach, 2005). Firms can develop innovation strategies for addressing and improving sustainability within their manufacturing processes and supply chains (Cai and Zhou, 2014; Isaksson et al., 2010; Seuring & Müller, 2008a). Sustainable Supply Chains are also

associated with certain risks, which need to be addressed through risk mitigation strategies or through sustainable innovations (Gouda and Saranga, 2018).

Several studies have proposed sustainable supply chain management frameworks (see Ansari and Kant, 2017; Chardine-Baumann et al., 2014; Dubey et al., 2017; Esfahbodi et al., 2016; Fabbe-Costes et al., 2014; Genovese et al., 2017; Gopal & Thakkar, 2016; Li & Mathiyazhagan, 2018; Mathivathanan et al., 2018; Paulraj et al., 2017; Sauer & Seuring, 2017) and have emphasized the importance of sustainable innovation in SSCM (Boons et al., 2013; Costantini et al., 2017; de Vargas Mores et al., 2018; Gao et al., 2017; Gupta and Barua, 2017; Isaksson et al., 2010; Hall, 2001; Verghese & Lewis, 2007; Zailani et al., 2015). No studies have specifically attempted to develop sustainable innovation implementation criteria for sustainable supply chains nor have investigated these criteria within an industrial setting. To advance theoretical and practical understanding and address the gap in the literature, this paper proposes a comprehensive sustainable innovation criteria framework for sustainable supply chains. This study further investigates this framework within the Indian manufacturing context providing practical insights and guidelines for implementation. A novel multi-criteria decision-making (MCDM) model called the 'best-worst method' (BWM) (Rezaei, 2015; 2016) is utilized to aid in this investigation.

This study targets the Indian manufacturing sector and their supply chains due to their recent and future growth potential (Mehta & Rajan, 2017). The manufacturing sector is one of the fastest growing in India with revenue potential reaching US$ 1 trillion by 2025. Yet, technological improvement and organizational practices in manufacturing processes and methods have not matched this industry's increasing growth, hence, few investments have been made. There is also a need for enhancing sustainable performance in Indian manufacturing supply chains. An

important step to achieve this goal is by introducing sustainable innovations and practices into their supply chains. This study aims to aid in this effort.

The objectives of this study are as follows:

(1) To identify sustainable innovation criteria to propose a sustainable innovation decision framework for sustainable supply chains in the context of manufacturing sectors;

(2) To determine the relative importance (weights) of the supply chain sustainability innovation criteria, and;

(3) To further theoretical; managerial/practical and country understanding of sustainability innovation especially within the supply chain context.

To achieve these objectives, this paper initially reviews the sustainable supply chain management and green/sustainable innovation management literature. This initial review identifies sustainable innovation criteria that will initially populate the sustainable supply chain innovation criteria framework; which is then further refined using practitioner and expert opinion. The BWM tool is developed and applied in evaluating the proposed framework within five selected Indian manufacturing companies. Within this evaluation, the paper determines the relative importance weights of the criteria and prioritizes them to provide an implementation path according to their levels of impact to overall organizational sustainability.

The contributions of the paper are multifold and include: (1) identifying and developing a multi-level innovation criteria framework of sustainable supply chains in the manufacturing sector; (2) proposing a novel MCDM method for investigating sustainable supply chain innovation criteria and; (3) applying this methodology using empirical data in the context of the Indian manufacturing sector.

The remainder of this paper is organized as follows. Theoretical background of sustainable supply chain management and sustainable innovation management criteria are presented; with research gaps and highlights given in Section 2. In Section 3, the proposed research methodology is presented, and a practical application and evaluation of the framework is provided in Section 4. In Section 5, the results analysis and discussion are presented and academic/theoretical, managerial/practical and country implications given in Section 6. Finally, the conclusion, limitations and future research directions are elaborated in Section 7.

2. Theoretical Background

2.1 Sustainable supply chain management

Sustainable supply chain management is supply chain planning and decision making that incorporates economic, social, and environmental sustainability dimensions (Ahi & Searcy, 2013). The integration of sustainability initiatives into organizational supply chain operations derive from social pressures, stricter government policy, corporate image, growing public awareness and market pressures (Esfahbodi et al., 2016; Tseng at el., 2015).

Sustainable supply chain initiatives support manufacturing companies and industries in their sustainable development. A growing body of literature has investigated sustainable supply chain management from different perspectives (see Fahimnia et al., 2015). Sustainability has been defined into three broad categories, environmental, economic, and social dimensions (Carter and Rogers, 2008). Organizations can achieve sustainability by integrating these three dimensions and need to go beyond organizational boundaries, include strategize supplier operations transparency, risk management, and improve stakeholder engagement (Carter and

Rogers, 2008). Recycle, reuse, and reduce for material saving are also important practice criteria for SSCM in manufacturing organizations (Su et al., 2016).

Social sustainability of supply chains has also been gaining traction. Eight refined social criteria, aided by the best-worst method, were investigated in an Iranian manufacturing context. Results indicated that, 'contractual stakeholders influence', was the most important criteria for social sustainability implementation followed by 'work safety and labor health' and 'Training education and community influence' in that order (Badri Ahmadi et al., 2017a). Transparency in work, social responsibility towards society, and better working conditions have also been established as important factors for SSCM support (Lim et al., 2017).

2.2 Sustainable Innovation criteria of manufacturing supply chains

Innovation is essential for corporate and supply chain sustainability development and implementation (Schaltegger and Wagner, 2011; Klewitz and Hansen, 2014). Sustainable innovation can be defined as new or modified processes, techniques, practices, systems and products to reduce social and environmental harm (Kemp et al., 2001; Beise and Rennings, 2005). This definition takes into account product and production process changes (De Marchi, 2012). Recycling, waste management, green efficiency, green design and concerns essential to reduce environmental and social impact of organizational products should also be considered in organizational sustainability innovations. The term green and sustainable innovation has been used interchangeably in the literature, with similar theoretical underpinnings (Hall, 2002; Wagner, 2008; Klewitz and Hansen, 2014; Gupta and Barua, 2017). Deeper insight is therefore required for better understanding of these concepts.

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Sustainable and green innovation antecedents and characteristics have been studied over the years with a number of findings. Stakeholder engagement, internal and external stakeholders, are important for promoting sustainable innovation in organizations (Ayuso et al., 2011). Drivers for sustainable innovation include strong business networks, seeking to build competitive advantage, R&D organizational support, cost savings, subsidies and tax cuts, compliance with regulations and customer demand (Vasilenko and Arbačiauskas, 2012). Applying sustainable innovations can also benefit organizations a number of ways (outcomes) that make the business case including reducing costs, improving profits and social image of the organization (Aguado et al., 2013). Sustainable innovations can also be industry specific. For example, in the chemical industry, cost reduction, improved feed stock, improved yields and broadly increasing market share occurred from building sustainability into innovations. Risk management, such as in the chemical industry, is also an important aspect for sustainability innovations. Organizations that do not include social factors into their process innovations are at more risk than others (Iles and Martin, 2013).

Broadly, knowledge management and learning have also played important roles in sustainability innovation. Systematic reviews of literature and qualitative studies (De Medeiros et al. 2014; Medeiros, et al. 2016) recently showed that knowledge on government regulations, inter-organizational collaboration, fulfilling customer needs, innovation learning, technology and R&D investments are essential for greening innovations. Content analysis reviewing literature from 1991 - 2016 (Tariq et al., 2017) revealed various attributes of sustainable innovation including market factors, stakeholders' pressure, technological factors, collaborations and networking factors, organizational factors and social, cultural and ethical factors. All these

dimensions, as in much literature, for green innovation result in economic and financial, market and environmental performance outcomes.

Building dynamic capabilities and the resource-based perspective can help explain various drivers and factors in sustainable innovation (Mousavi and Bossink, 2017). Entrepreneurial capabilities to gather knowledge related to environmental policies and technologies; transforming opportunities into meaningful innovative processes and products; and reconfiguration to achieve strategic fit through realignment of resources according to requirements, have all been identified as ways for building and adjusting sustainability capabilities.

Based on a review of literature, some introduced in this section, and several rounds of discussion with industrial managers, sustainable innovation of manufacturing supply chains are categorized into three broad dimensions including economic, environmental and social and are further classified into 20 sub-criteria as summarized in Table 1.

Table 1 Main Criteria and Sub-criteria for sustainable innovation

Main Criteria	Sub-Criteria	Short Descriptions	Supporting Literature
Economic (EC)	Sustainable product cost reduction (EC1)	Organizations ability to reduce product cost through sustainable innovation practices and to provide products at lower costs.	Berkel, 2007; Lee, 2008; Bai and Sarkis, 2010; Chiou et al., 2011; Mathiyazhagan et al., 2013; Sarkis and Dhavale, 2015; Govindan et al., 2016; Luthra et al., 2017; Jia et al., 2018; Zhu et al., 2018
	Financial availability for innovation (EC2)	Innovative approaches for securing funding from various financial institutions to carry out sustainable innovation practices.	Jenkins and Yakovleva, 2006; Mathiyazhagan et al., 2013; Govindan et al., 2016
	Return on investment and investment recovery of products (EC3)	Recovery of resources (financial) invested in sustainable practices through various activities such as reuse, recycling, selling of scrap and waste material.	Zhu and Sarkis, 2004; Franke et al., 2006; Zhu et al., 2008; Wooi and Zailani, 2010; Kapetanopoulou and Tagaras, 2011; Lee et al., 2014; Li and Mathiyazhagan, 2018; Mathivathanan et al., 2018
	Enhanced sustainability value to customers (EC4)	Provision of greater value to customers either by reducing price or enhancing functions of products.	Gupta and Barua, 2017

	Investment in R&D for sustainable products (EC5)	Amount of financial resources invested as a proportion of total budget to complete research to support sustainable products production.	Horbach, 2008; Halila and Rundquist, 2011; Testa et al., 2011; Horbach et al., 2012; Zailani et al., 2012; Calik and Bardudeen, 2016; Ansari and Kant, 2017
	Designing sustainable products to reduce material consumption and cost (EC6)	Organizational effort to design products to reduce material consumption and hence product cost in a sustainable production manner.	Moffat and Auer, 2006; Gonzalez et al., 2008; Tseng and Chiu, 2012; Calik and Bardudeen, 2016; Govindan et al., 2016; Zhu et al., 2018
Environmental (EN)	Inter- and Intra-organization collaboration (EN1)	Collaboration between different organizational functions and amongst organizations to share resources and technologies to produce green and sustainable products.	Messeni Petruzzelli et al., 2011; Quist and Tukker, 2013; Bocken et al., 2014; Cai and Zhou, 2014; Tariq et al., 2017; Taylor and Vachon, 2018; Mathivathanan et al., 2018
	Technical expertise availability and investment in R&D for green practices (EN2)	Availability of technical expertise and research facilities to manage and complete green and sustainable practices in organizations.	Kammerer, 2009; Rennings and Rammer, 2009; Lin and Ho, 2011; Horbach et al., 2012; Shen et al., 2013; Triguero et al., 2013; Kannan et al., 2014; Dangelico, 2016; Tariq et al., 2017; Das, 2018; Li and Mathiyazhagan, 2018
	Green logistics capabilities development (EN3)	Organizations capabilities to package, label and transport products in an environmentally friendly manner.	Rao and Holt, 2005; Zhu et al., 2008; Liu et al., 2011; Wang et al., 2012; Kannan et al., 2014; Hashemi et al., 2015; Jabbour et al., 2015; Luthra et al., 2017; Golini et al., 2017; Mathivathanan et al., 2018
	Green manufacturing and operational capabilities development (EN4)	Adoption of innovative manufacturing practices to minimize energy consumption and waste in production.	Zhu et al., 2008; Nelson and Winter 2009; Tsai et al., 2012; Triguero et al., 2013; Maruthi and Rashmi, 2015; Somsuk and Laosirihongthong, 2016; Ansari and Kant, 2017
	Environment management commitment and initiatives (EN5)	Implementation and adoption of various environmental policies and standards in organizations.	Zhu and Sarkis, 2006; Simpson et al., 2007; Lin and Juang, 2008; Wagner, 2008; Tsai et al., 2012; Inoue et al., 2013; Shen et al., 2013; Lee et al., 2014; Hashemi et al., 2015; Somsuk and Laosirihongthong, 2016; Tariq et al., 2017; Das, 2018
	Designing products to reduce their impact on environment (EN6)	Organization product design to reduce environmental impact including using environmental friendly materials for products for easier disposal at end of life.	Moffat and Auer, 2006; Wagner, 2008; Tseng, 2011; Tseng and Chiu, 2012; Govindan et al., 2013; Bai and Sarkis, 2014; Kannan et al., 2014; Hashemi et al., 2015; Ansari and Kant, 2017
	Conducting regular environmental audits (EN7)	Repeated auditing in organizations to ensure compliance with environmental standards.	Mahmood et al., 2013; Kannan et al., 2014; Hassan et al., 2016; Somsuk and Laosirihongthong,

			2016; Mathivathanan et al., 2018
Social (SC)	Implementation of socio-eco policies in organizations for sustainability (SC1)	Implementation and enforcement of socio-environmental standards and policies by organizations.	Pickman , 1998; Horbach, 2008; Demirel and Kesidou, 2011; Horbach et al., 2012; Yabar et al., 2013; Govindan et al., 2016; Tariq et al., 2017
	Quick response to high customers and market demand for sustainable products (SC2)	Organizational responsiveness to customers and market demand and, awareness regarding benefits of using environmentally-friendly and green products.	Kammerer, 2009; Zhou et al., 2009; Artiach et al., 2010; Horbach et al., 2012; Lin et al., 2013; Chiou et al., 2011; Zhu et al., 2012; Mondéjar-Jiménez et al., 2015; Golini et al., 2017; Tariq et al., 2017
	Enhancing social image of the organization (SC3)	Efforts companies put in place for enhancing their image in the market by producing environmentally-friendly products.	Noci and Verganti, 1999; Rennings, 2000; Kammerer, 2009; De Marchi, 2012; Tariq et al., 2017; Zhu et al., 2018
	Responding to stakeholders pressure for green and sustainable products (SC4)	Response to pressure created from various stakeholders such as customers, employees, shareholders, suppliers and competitors to produce green and sustainable products.	Horbach, 2008; Demirel and Kesidou, 2011; Berrone et al., 2013; Yabar et al., 2013; Amore and Bennedsen 2016; Doran and Ryan, 2016; Tariq et al., 2017
	Corporate social responsibility initiatives (SC5)	Organizational developments and implementation of general ethical policies towards social and green initiatives.	Wagner, 2010; Chang, 2011; Tariq et al., 2017; Ansari and Kant, 2017
	Cultural, social values and norms (SC6)	Values and beliefs of organizations or individuals, where the benefit of society is considered important over individual interest.	Rothenberg and Zyglidopoulos, 2007; Montalvo, 2008; Chiarvesio et al., 2015; Huang and Li, 2015; Jia et al., 2018
	Occupational health, safety and rights of the employees (SC7)	Refers to health, safety and rights of the employees and organizations efforts to improve these conditions in a sustainable manner.	Bai and Sarkis, 2010; Ageron et al., 2012; Wang et al., 2012; Sarkis and Dhavale, 2015; Calik and Bardudeen, 2016; Badri Ahmadi et al., 2017b; Luthra et al., 2017; Golini et al., 2017; Das, 2018; Jia et al., 2018; Mathivathanan et al., 2018; Zhu et al., 2018

2.3 Research gaps and highlights

Most studies regarding sustainability have focused on sustainable supply chain management (Bai and Sarkis, 2010; Amindoust et al., 2012; Govindan et al., 2013; Azadi et al., 2015; Sarkis and Dhavale, 2015; Trapp and Sarkis, 2016; Ahmadi et al., 2017; Luthra et al., 2017; Golini et al., 2017; Das, 2018; Taylor and Vachon, 2018). There is limited focus on sustainable

innovation (Hellström, 2007; Ayuso et al., 2011; Ozaki, 2011; Watson and Sauter, 2011; Vasilenko and Arbačiauskas, 2012; Iles and Martin, 2013; Calik and Bardudeen, 2016; Mousavi and Bossink, 2017; Tariq et al., 2017).

These limited sustainable innovation studies either present sustainable innovation systematic literature reviews or conceptual frameworks. Only one study was identified that empirically develop scales to measure supply chain sustainable innovation (Calik and Bardudeen, 2016). There is a lack of robust empirical studies on sustainable supply chain innovation criteria, especially in manufacturing settings. Studies related to prioritizing these criteria for guiding general implementation, especially from emerging economy nations, is non-existent.

This study explores and evaluates a comprehensive and unified criteria framework for manufacturing supply chain sustainable innovation by prioritizing criteria using the best worst method in the Indian manufacturing organization context.

2.4 Finalization of the evaluation criteria

The literature review is initially conducted to identify and select potential criteria. Past green and sustainable innovation studies are reviewed with twenty-five criteria identified.

These criteria were then tabulated and put forward to the five industry managers for elimination consideration based on a simple "Yes" (acceptance) and "No" (rejection); or for the addition of missing criteria. Researchers agreed on a minimum of four "Yeses" received by a criterion as an affirmative vote to maintain a criterion. No further additions were made. After the evaluation analysis, twenty criteria received four or more "Yes" votes reaffirming their importance to be part of the sustainable innovation criteria framework. The managers were further requested to categorize these criteria under the economic, environmental and social

based criteria. After three rounds of group/panel reviews and discussions (deliberations) with one of the researchers and all five industrial managers with the aid of previous criteria categorizations information, sub-criteria categorization consensus was constructed with the final listing and categories summarized in Table 1.

3. Research Methodology

The multiple case study research approach is applied in this study to gain insight into the subject matter. Many studies (e.g. Seuring, 2008; Lee, 2009) utilize case study research to investigate diverse subjects and uses bounded contextually rich data to investigate a specific phenomenon (Barratt et al., 2011).

Manufacturing supply chain sustainable innovation is a multi-criteria concept. Evaluating this multiple criteria framework within a multiple case study situation can benefit through MCDM application as a methodological tool. The 'best-worst' method (BWM) (Rezeai, 2015) is used in this case. This intuitive, yet robust, MCDM approach for evaluating various criteria provides some advantages to this subject area; where it has not been applied to this specific situation. The required information for BWM and the BWM method are overviewed initially.

3.1 The Best-worst method

MCDM techniques are utilized for complex problems; problems typically with tradeoffs. Decision makers in these environments may face selection of the 'best' alternative from among many alternatives. Many MCDM techniques exist. MCDM approaches have been especially prevalent for addressing complete sustainable supply chain management and sustainable supplier selection problems (e.g. see Brandenburg et al., 2014 and Govindan et al., 2015 for broad reviews). Fuzzy DEA (Azadi et al., 2015); grey system and rough sets (Bai & Sarkis, 2010); AHP and

IGRA (Badri Ahmadi et al., 2017b); AHP (Cucchiella et al., 2017) are some recent efforts of utilizing MCDM techniques for sustainable supply chain evaluation.

These models tend to lack consistency among alternatives (Rezaei, 2015). BWM overcomes these problems. BWM has some advantages including requiring fewer decision maker inputs for obtaining overall weights and rankings of the variables; and the aforementioned consistency. AHP, one of the most popular approaches for MCDM, was compared to BWM and Rezaei (2015) found BWM's results were more consistent when compared to AHP. BWM requires significantly smaller datasets and expert inputs since comparisons are completed between best alternative/criterion and given alternatives/criteria; along with comparisons between given alternatives/criteria and worst alternative/criterion. BWM saves expert time and ease for calculations enabling consistent results. This MCDM technique, like any other, has some limitations. It depends solely on the judgment of experts selected for the study; this reliance on a group of experts and may result in some bias. To overcome this limitation, we have tried to involve experts from different industries and different backgrounds. Another limitation is the number of experts used. There is still different opinions about the number of experts that are sufficient for MCDM analysis. However, there are many authors that have used 5 or fewer experts for MCDM including Dou et al., 2014; Govindan et al., 2015; Gupta, 2016, Gupta and Barua, 2017; 2018; Kannan et al., 2009; Shaw et al., 2012; Wu et al., 2012. Most recently, Rezaei et al. (2018) in their paper on evaluating quality of baggage handling at airports, made it clear that only 4-10 experts are required for achieving reliable data for MCDM analysis. Another widely used MCDM evaluation technique is DEA, which is also very sensitive to its data set; results can change significantly if a decision making unit (DMU) or criteria is dropped.

Due to its advantages, BWM has been utilized for an increasing number of MCDM based studies; many of which relate to this study. Ranking of enablers of technological innovation in manufacturing enterprises (Gupta and Barua, 2016); supplier segmentation (Rezaei et al., 2015; Bai et al., 2017); green supplier selection (Rezaei et al., 2016; Gupta and Barua, 2017); innovation and efficiency of university – industry projects (Salimi and Rezaei, 2016); ranking energy efficiency alternatives and other sustainability technology (Gupta et al., 2017; Ren et al., 2017); and evaluating airport services and operations (Gupta, 2017; Rezaei et al., 2017); to name a few related studies. None have explicitly integrated manufacturing supply chain innovation studies, as this study does.

General steps involved in this technique include (Rezaei, 2015; Rezaei, 2016):

Step 1: Finalization of decision criteria.

The finalized decision criteria are denoted as $\{c_1, c_2, \ldots, c_n\}$ for n main criteria.

Step 2: Determination of best and worst criteria among main as well as sub criteria.

Step 3: On a 9-point scale of 1 to 9, where 1 means equal preference and 9 means extreme preference, determine the preference of the best criterion over all other criteria. The best-to-others (BO) vector can be represented as:

$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$, where a_{Bj} indicates the preference of the best criterion B over criteria j; $a_{BB} = 1$.

Step 4: Determine the preference of all other criteria over the worst criterion using a 9-point scale of 1 to 9. The others-to-worst (OW) vector can be represented as:

$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$, Where a_{jW} indicates the preference of the criteria j over the worst criterion W; $a_{WW} = 1$.

Step 5: Calculate the optimal weights ($w_1{}^*$, $w_2{}^*$, ..., $w_n{}^*$).

Determine weights of criteria such that the maximum absolute differences for all j are minimized over the following set $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$.

A minimax model can be formulated as:

$$\min \max j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$$

Subject to:

$$\sum_j w_j = 1$$

$w_j \geq 0$, for all j $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (1)

Model (1) can be solved by converting it into the following linear programming problem model:

$$\text{Min } \xi^L$$

Subject to:

$$|w_B - a_{Bj}w_j| \leq \xi^L, \text{ for all j}$$

$$|w_j - a_{jW}w_W| \leq \xi^L, \text{ for all j}$$

$$\sum_j w_j = 1$$

$w_j \geq 0$, for all j $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (2)

Solving the linear model (2), will result in optimal weights ($w_1{}^*$, $w_2{}^*$, ..., $w_n{}^*$) and optimal value ξ^L. Consistency (ξ^L) of comparisons also needs to be determined. A value closer to 0 is more desired for consistency (Rezaei, 2016).

4. Practical application and evaluation

This multi-case field study used five case manufacturing companies from Indian manufacturing sectors. Case Company 1 is an automobile company and has been in operation for

four decades. Case Company 2 is an automobile company that has been in operation for over 20 years and has pan-India presence. Case company 3 is an electric component manufacturer. Case Company 4 is a plastics manufacturer. Case Company 5 is an electric and electronic component manufacturer.

All the companies in this sample were selected because they have organizational goals to reduce environmental impact of their products using innovative technologies. Furthermore, all the companies were ensured to have a minimum of ten years of operational experience. Senior and upper level managers from each company participated in both sustainable innovation criteria refinement and response to the BWM questionnaire. The participants were given a short presentation regarding the objectives of the study. The various objectives and criteria of sustainable innovation finalized in the previous phase were presented to the respondents along with the details of each criteria. The respondents were then asked to rate first main criteria on the scale of 1 to 9 (scale mentioned in appendix). The respondents were asked to first identify the best criterion and thereafter conduct a pairwise comparative rating of the best to other criteria. Similarly they were asked to identify the worst criterion and rate other criteria with respect to the worst criterion. A similar approach was applied for all the sub criteria. All the five respondents were asked to rate the criteria individually and later the average of weights obtained from the ratings of each respondents were taken to arrive at the final ranking of sub criteria as well as main criteria.

The Case Company 1 respondent is a Senior Manager of R&D and New Product Development and is responsible for evaluating the technical feasibility of projects, identifying new product development opportunities, designing of new products and technical changes in

product design. He is an engineering graduate and has been working for the company for about 11 years. The Case Company 2 respondent is a manager of Strategy, Marketing and Market Development, and is responsible for assessing the market situation and demands, customer needs and marketing the products and explaining the benefit of the products to customers. He holds a graduate degree in marketing and has been associated with the company for the over 7 years. The Case Company 3 respondent is a Senior Manager of Plant Operations and Production and is responsible for managing the operations related to the shop floor and also managing the resources required for production. He is also responsible for the greening initiatives of the company. He is an engineering graduate and has been associated with company for about 10 years. The Case Company 4 respondent is a Senior Manager of Product Development and is responsible for incorporating new technologies into the product and processes. He is also responsible for the innovation related activities of the company. He is a graduate in engineering and has been associated with the company for about 8-9 years. The Case Company 5 respondent is a Senior Manager Operations and Planning and is responsible for the production related activities and also member of the company's team for incorporating green practices into the system. He holds a graduate degree in Industrial Engineering and has been associated with the company for 12-13 years.

Representatives from each company were asked to select the best and worst criteria from among all the main criteria. This step occurred after initial factors refinement in previous stages. They were asked to provide their preference ratings of the best main criterion over the other main criteria; preference ratings of all the main criteria over the worst criterion were also

determined. The best and worst criteria identified by experts/representatives of all case companies are shown in Table 2.

Table 2. Best and Worst criteria identified by managers of case companies

Sustainable innovation criteria	Determined as Best by managers	Determined as Worst by managers
Economic (EC)	3, 4	
EC1		
EC2	1, 2, 3, 5	
EC3		
EC4		1, 2, 3, 4, 5
EC5	4	
EC6		
Environmental (EN)	1, 2, 5	
EN1		1
EN2	1, 2, 4, 5	
EN3		4
EN4	3	
EN5		
EN6		
EN7		2, 3, 7
Social (SC)		1, 2, 3, 4, 5
SC1		5
SC2	1, 2, 3, 4, 5	
SC3		
SC4		
SC5		3
SC6		1, 2, 6
SC7		

The ratings for the best main criterion over the other main criteria and the other main criteria over the worst criterion for the case company 1 respondent are shown in Table 3. Here for all the pairwise comparisons of different criteria, a scale for Best Worst Method (See Appendix) used by Rezaei et al. (2014) and Gupta (2017) was also adopted. In Table 3, for example, Environmental (EN) criterion (best criterion) is considered "moderately more important" over Economic (EC) criterion, hence rated 3 by respondent manager at the intersection of EN and EC. At the intersection of EN and EN, an automatic rating of 1, which means, "equally important" is provided. Similarly, at the intersection of EN and Social (SC), EN is considered "very strongly more important" over SC criterion, hence rated 7 by the respondent manager. The second part of the table provides rating of other criteria with respect to worst criterion in a similar manner as above.

Table 3. Main criteria comparison for case company 1

BO	Economic (EC)	Environmental (EN)	Social (SC)
Best criterion: *Environmental (EN)*	3	1	7

OW	Worst criterion: *Social (SC)*
Economic (EC)	3
Environmental (EN)	7
Social (SC)	1

The case company 1 respondent was asked to evaluate the sub-criteria under each main criterion in a similar manner using a 9-point scale of 1 to 9 as above. The comparison scores of sub-criteria under economic, environmental and social main criteria are shown in Tables 4 – 6 below:

Table 4. Pairwise comparison for Economic sub-criteria for case company 1

BO	EC_1	EC_2	EC_3	EC_4	EC_5	EC_6
Best criterion: EC_2	4	1	7	9	5	3

OW	Worst criterion: EC_4
EC_1	3
EC_2	9
EC_3	2
EC_4	1
EC_5	2
EC_6	3

Table 5. Pairwise comparison for Environmental sub-criteria for case company 1

BO	EN_1	EN_2	EN_3	EN_4	EN_5	EN_6	EN_7
Best criterion: EN_2	9	1	5	2	4	3	8

OW	Worst criterion: EN_1
EN_1	1
EN_2	9
EN_3	3
EN_4	4
EN_5	2
EN_6	3
EN_7	2

Table 6. Pairwise comparison for Social sub-criteria for case company 1

BO	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7
Best criterion: SC_2	6	1	2	4	8	9	5

OW	Worst criterion: SC_6
SC_1	2
SC_2	9
SC_3	4
SC_4	3
SC_5	2
SC_6	1
SC_7	2

After the pairwise comparison of each of the main criteria and sub-criteria by the respondent, the next step is determining the main criteria and sub criteria weights. Using formulation (2), the main criteria and sub-criteria weights for Case Company 1 are summarized in Table 7.

Table 7. Weights of Main and sub criteria for Case Company 1

Main Criteria	Local Weights Main Criteria	Sub-Criteria	Local Weights Sub-Criteria	Global weights	Ranking
Economic (EC)	0.236	EC1	0.127	0.030	10
		EC2	0.480	0.113	3
		EC3	0.073	0.017	14
		EC4	0.050	0.012	15
		EC5	0.102	0.024	12
		EC6	0.169	0.040	7
Environmental (EN)	0.673	EN1	0.039	0.026	11
		EN2	0.387	0.261	1
		EN3	0.084	0.057	6

Main Criteria	Local Weights Main Criteria	Sub-Criteria	Local Weights Sub Criteria	Global weights	Ranking
		EN4	0.191	0.128	2
		EN5	0.105	0.071	5
		EN6	0.140	0.094	4
		EN7	0.053	0.035	9
Social (SC)	0.091	SC1	0.075	0.007	18
		SC2	0.420	0.038	8
		SC3	0.203	0.018	13
		SC4	0.112	0.010	16
		SC5	0.056	0.005	19
		SC6	0.043	0.004	20
		SC7	0.090	0.008	17

Each case company respondent rated the main and sub-criteria. After obtaining the ratings from each company, criteria weights were simply averaged. The averaged weights are summarized in Table 8.

Table 8. Aggregate weights of Main and sub-criteria for all case companies

Main Criteria	Local Weights Main Criteria	Sub-Criteria	Local Weights Sub Criteria	Global weights	Ranking
Economic (EC)	0.425	EC1	0.150	0.064	6
		EC2	0.407	0.173	1
		EC3	0.076	0.032	11
		EC4	0.049	0.021	14
		EC5	0.163	0.069	4
		EC6	0.154	0.066	5
Environmental (EN)	0.483	EN1	0.057	0.027	12
		EN2	0.348	0.168	2
		EN3	0.078	0.038	10
		EN4	0.241	0.116	3
		EN5	0.100	0.048	8
		EN6	0.123	0.060	7
		EN7	0.054	0.026	13
Social (SC)	0.092	SC1	0.078	0.007	18
		SC2	0.424	0.039	9
		SC3	0.176	0.016	15
		SC4	0.109	0.010	16
		SC5	0.065	0.006	19
		SC6	0.057	0.005	20
		SC7	0.093	0.009	17

5. Results analysis and discussion

The outcomes, summarized in Table 8, provide some initial strategic managerial guidance insights. The first major observation is that general environmental criteria (EN) category seems

to be the highest ranked for developing sustainability innovation in manufacturing supply chains. This finding first tells us that these companies view sustainability from an environmental aspect, or at least driven by environmental policies and philosophies. Secondly, it is surprising that the environmental factors take precedence, even for sustainability innovation, given that the major drivers of most organizations remain economic; some of these results may have been influenced by respondents who were active in greening initiatives in their organizations.

The top ten sustainable innovation sub-criteria by ranking are: EC2>EN2>EN4>EC5>EC6>EC1>EN6>EN5>SC2>EN3. "Financial availability for innovation (EC2)" has the highest sustainable innovation criterion global weight of 0.173; whereas "cultural, social values and norms (SC6)" has the lowest sustainable innovation criteria global weight of 0.005.

In addition, "Technical expertise availability and investment in R&D for green practices (EN2)" and "Green manufacturing and operational capabilities development (EN4)" are ranked second and third respectively in order of priority, whereas "Investment in R&D for sustainable products (EC5)" and "Designing sustainable products to reduce material consumption and cost (EC6)" happens to be the fourth and fifth respectively in order priority. This outcome may be argued that, EC2 is the most promising, critical, important and influential sub-criterion for fostering successful sustainable supply chains when these organizations attempt to implement sustainable innovation initiatives. That is to say, the respondent managers may view 'financial availability for innovation', as an important initiative that may need to be present to support other initiatives.

For example, organizational technical expertise and investment in R & D for green practices (ranked second on the list), if available may only be useful, or will only be possible to

develop when there are some resources, and in this case, resources for supporting innovative green practices and sustainable product development activities. Investments in research and development (R & D), again, reaffirming the critical need for financial availability prior to and in support of the development of other sustainable innovation sub-criteria. In a similar situation, the development of green manufacturing and operational capabilities (ranked third on the list) will require the prior existence and need of financial availability to help fund for example the purchases of parts and components for upgrading and replacing existing traditional manufacturing systems to build the needed capabilities. This result means these manufacturing organizations consider sustainable innovation from an economic sustainability perspective. This interpretation may mean that the initiatives and programs implemented by these manufacturing organizations towards sustainability may have been focused on economic sustainability; hence the emphasis placed on financial/economic innovation criteria. Another interpretation is that sound financial standing and resources will effectively support the overall sustenance of the sustainable innovation program.

The socio-cultural value and norms initiative (ranked twentieth on the list) may be viewed as less economically beneficial when innovating for sustainability, as a cost center, and not offering any economic benefits to other programs. The country and industry may be less reliant on social initiatives when attempting to address sustainability issues, hence may explain the reason for the lower ranking of 'Cultural, social values and norms' and overall, the sub-criteria under the social dimension. The implication of this result to the manufacturing industry is that, EC2 among others would require the greatest and urgent managerial attention to aid in achieving a desirable sustainable outcome. This outcome does complement and in consistent with a

number of previous studies. For example, financial constraints may hold back sustainable innovation as firms cannot innovative if they're not financial sound, since most if not all, innovations start with research and development (R & D) activities which comes with significant investment cost element (Canepa & Stoneman, 2007; Hyytinen & Toivanen, 2005; Savignac, 2008). Another reason may be that the managers and companies are more concerned with greening initiatives and may define sustainability as an environmental issue. This interpretation is reinforced by some managers' involvement in 'greening' initiatives, implying an environmental focus to sustainability in these organizations.

Among the top ten ranked sustainable innovation sub-criteria are four out of the six economic dimensions including: EC1, EC2, EC5 and EC6; five out of the seven environmental criteria including: EN2, EN3, EN4, EN5 and EN6; and one criterion (SC2) of the social dimension. This empirical results, evidently supports the fact that, fostering successful organizational sustainable innovation implementation programs arises from economic and environmental perspectives and initiatives. Thus, social sustainability issues are relatively less influential when it comes to sustainable innovation in manufacturing sectors. This observation can be made from the results in Table 8 which shows that, "quick response to high customers and market demand for sustainable products (SC2)", is the only sub-criteria among the top ten, with six out of the seven social dimension sub-criteria including: SC1, SC3, SC4, SC5, and SC6, ranked the lowest (ranked 18, 15, 16, 19, 20 & 17 respectively) among the twenty sustainable innovation sub-criteria.

These results are reaffirmed by the outcome depicted in Table 7 for case company 1, which also ranked same set of social sustainable innovation sub-criteria as the lowest among all

sub-criteria. From a practical perspective; this may mean the economic and environmental dimension activities such as "financial availability for innovation" exists and financial availability and stability has already been achieved. Social sustainability innovation practices and criteria may be interpreted as non-core activities of these organizations and managers. When innovating for sustainability they are either not incentivized or are less capable of focusing on these initiatives.

6. Research implications and managerial feedback

6.1 Academic, managerial and country implications

The results from this study do have several implications for research and practice.

Academically, this study advances the supply chain sustainability literature by further investigating innovation in manufacturing organization sustainable supply chains. It extends previous studies that only focus on green innovation initiatives to broader sustainability dimensions. The study introduces sustainability innovation initiatives as an important aspect of sustainable supply chain management. The conceptualization of the sustainable innovation framework strengthens the theoretical foundation for evaluating, controlling and monitoring sustainable supply chain innovation in manufacturing sectors. These constructs may prove valuable for broader theoretical investigations for more complete evaluation of innovation within the organizational sustainability literature.

From a practical perspective, managers and policy makers may encourage broader adoption of sustainable innovation initiatives by targeting sub-criteria that are highly ranked (e.g. top ten ranked) as an initial step. These "lower hanging fruit" initiatives may gain the organizational and political support for a sustainable supply chain innovation implementation program. Another option, if organizations wish to build social sustainability, is focusing and

investing in the lower ranked social dimension sub-criteria, which seem to be either more immature or less reinforced initiatives. The results may provide initial insights into a sequential implementation path.

The study's results do inform and provide options for industrial managers and decision-makers on which sub-criteria to focus during implementation. It may also indicate which initiatives they may delay, as a way to introduce systematically, the sustainable innovation activities. In this study, although the results are specific to a given industry in an emerging economy nation, the outcome may be applicable to other emerging economies and contexts, reaffirming its usefulness.

Implications for India and its manufacturing sector also exist. The India manufacturing sector may face more economic and environmental pressures when compared to social pressures. Thus, their foundational activities for sustainable supply chain innovation implementation programs are still in the very early stages, overall for environmental sustainability. Additionally, organizations may not have the necessary resources to adopt and implement sustainable innovations simultaneously; and so may have to choose amongst a set of sustainable innovation activities. Maximizing performance outcomes in a resource constrained environment is the goal of most industries; this modeling effort and results can help set the foundation for prioritizing. In many cases greening, or environmental initiatives, may have 'win-win' opportunities that can provide simultaneous economic and environmental benefits; whereas social sustainability initiatives may not have as many visible 'win-win' opportunities. It may require creative insights from managers to see value in social innovations; and there is need

for more support or external pressures to mature. Shared value contexts for sustainability innovations in supply chains need to expand based on this preliminary study.

It is therefore important for manufacturing organizations to be given some useful guidance from theoretical knowledge and evaluation of sustainable innovation. This paper's approach can and does provide some initial guidance for managing implementation of sustainability innovation in manufacturing supply chains. Overall, it is clear that, Indian manufacturing companies believe they should first develop/build a very good financial base as an initial step for successful sustainable supply chain innovation, eventually addressing environmental and socio-cultural issues.

6.2 Managerial feedback

In order to validate and further interpret the study results; feedback was sought from managers of three different companies from the ones involved in this study. Three managers provided feedback. The respondent managers were from three different backgrounds. The first respondent is an Environmental Manager for a leading automobile company; the second respondent is a Senior Manager- Finance in an automobile company and, the third respondent is a Manager for Production, Planning and Control in an electronics industry. The industrial managers were presented with Table 1, which contains the various main and sub-criteria, and also with Table 8, that had the final aggregated results which presents the weights and corresponding rankings of the criteria.

The Environmental Manager confirmed the results and further stated that, he strongly believes that environmental factors are the major drivers for sustainable innovation in the supply chain. In fact, the manager is of the opinion that developing green manufacturing capabilities is

very important for attaining the overall goal of sustainable supply chain management. He also reaffirms "availability of finance for innovation" in his response as an important criterion.

The Senior Manager-Finance, perceived economic criterion as the best among all the other criteria and is of the opinion that investment in research will lead to more innovations and will help reduce material consumption and cost, if products are designed considering sustainability aspects. Surprisingly, The Manager for Production, Planning and Control also considered environmental criterion as the most important criterion.

Although, the respondent managers' feedback confirmed the results of the study, they were all of the opinion that environmental and economic criteria are of equal importance as exhibited in our results and in Table 8. It is worth noting that these responses may be due to social desirability. A more critical examination through having them perform a more analytical evaluation could get around this issue, but was not completed at this time.

They did show concern with the low weights of the Social criterion in the study as they believe that although in comparison with Economic and Environmental criteria, social criterion is generally viewed as less important. But their impression was this factor shouldn't have received such low weights (9.2%), in its overall contribution to sustainability. They were also of the opinion that separate in depth studies of each sector may provide further insight. Overall, the respondent managers were satisfied with the results and confirmed were what they expected.

7. Conclusion and future research

The manufacturing sector faces serious sustainability issues throughout their supply chains, and in particular, in emerging economies, such as India. Sustainable innovation is one of the ways to help overcome these sustainability issues. This study has introduces a sustainable

innovation criteria framework to deal with the sustainable innovation issues within the Indian manufacturing sector. The Best Worst Method (BWM) is applied to aid in ranking the sustainable innovation criteria. The results from this exploratory evaluation showed that the industrial managers viewed "financial availability for innovation" as the most important and critical sub-criteria to foster sustainable supply chain management and sustainable development followed by 'technical expertise availability and investment in R&D for green practices' and 'green manufacturing and operational capabilities development'. It was also evident that, 'Cultural, social values and norms' was the lowest ranked criterion.

Although this study does have a number of contributions, there exist some limitations and concerns. These limitations do provide useful and additional opportunities for future and further studies into the subject. Given that only a few managers from the Indian manufacturing sector provided inputs, generalizations cannot be made. The study is a snap-shot in time, and much broader empirical and longitudinal investigation to determine if the sustainable innovation criteria importance may change over time is required. However, given the homogeneity of the respondent managers, we can be certain about particular activities and concerns in relation to sustainable innovation of Indian's manufacturing companies and its manufacturing sector. We suggest future researchers to utilize other MCDM techniques together with our sustainable manufacturing supply chain innovation framework, to investigate the criteria weights, and compare the results of the two models. As this study involved three different types of manufacturing organizations including automobile, plastic and electrical and electronics, therefore generalizing results for one particular sector may be difficult. Future studies can involve

a bigger data set from any two type of industries and performing comparative analysis of results

of these two industries.

Clearly, sustainable innovation of manufacturing supply chains in emerging economies is

a subject that merits and requires further research. We believe this paper sets an initial stage for

further and future research investigation and practical application of sustainable innovation of

manufacturing supply chains.

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Appendix

Scale for Best Worst Method								
Equally important	Equal to moderately more important	Moderately more important	Moderately to strongly more important	Strongly more important	Strongly to very strongly more important	Very strongly more important	Very strongly to extremely more important	Extremely more important
1	2	3	4	5	6	7	8	9