Sustainable supplier selection based on industry 4.0 initiatives within the context of circular economy implementation in supply chain operations

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Abstract – This study proposes a decision framework based on industry 4.0 initiatives within circular economy implementation to evaluate and select sustainable suppliers. In this context, sustainable supplier selection, industry 4.0, and circular economy have emerged as key topics of the contemporary operations management debate. The mix method approach of combining literature review and industrial expert's inputs was adopted to identify four main categories and twenty-one sub-categories relevant to the supplier selection decision. A multi-criteria decision-making support tool composed of the 'best-worst method' (BWM) and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) was applied to aid in the evaluation and selection of a sustainable supplier in Pakistan's textile manufacturing company. The BWM approach was first applied to determine the relative importance weights, and then, VIKOR used to rank the suppliers. The findings of the study suggest that, the Pakistan's textile manufacturing company places much emphasis and importance on "Technological and Infrastructure (TI)" with weight of 0.356 and "a positive organizational culture towards implementation of industry 4.0 and circular economy initiatives" (OG3) with global weight of 0.139 when embarking on such decisions, and ranked supplier 2 as the top sustainable supplier. Managerial and post-selection benchmarking negotiations and future research directions are also introduced.

***Keywords*:** Circular economy; Industry 4.0; Sustainable supply chains, Sustainable supplier selection; Best Worst method; VIKOR.

1. Introduction

Supplier selection plays an integral part of organization's overall supply chain decision. The supplier selection decision is a strategic decision that helps organizations to minimize cost, achieve high quality products and services, and minimize risk (Feng & Zhang, 2017; Panagiotidou, et al., 2017; Pascual, et al., 2017). In any supply chains, the procurement department is responsible for procuring the right product or service to the right place at the right time – in the right quantity, in the right condition or quality, and from the right supplier at the right price (Grant, Lambert, Stock & Ellam 2006; Monczka et al. 2011). Selecting the right supplier (s) to work with is one important vehicle for achieving supply chain performance (Khan et al., 2018). With the increasing awareness and interest of stakeholders towards sustainability and sustainable products, organizations have started to integrate sustainability considerations into their supply chain operations (Wollmuth & Ivanova, 2014; Nguyen, 2016). One approach to achieving sustainability objective is by integrating and considering environmental, social, and economic criteria (Hopwood et al., 2005; Lozano, 2008; WCED, 1987) when selecting sustainable suppliers. Most recently, the concept of circular economy has also been introduced focusing on environmental and socio-economic issues (Witjes and Lozano, 2016) with the objective of transforming wastes (non-value added) into resources (value added).

The use of advanced technology has already made significant impact in our society (Kazantsev et al, 2018). This industrial revolution, termed as digital economy, has played an important role in aiding information sharing, knowledge transfer, and communications between different players within supply chain network (Ciocoiu 2011, Gromoff et al. 2012). Due to shorter product life cycle, customized demand, flexibility in production, effective and efficient utilization of resources, there is the need for industrial revolution in supplier selection and manufacturing (Lasi, et al., 2014). Moreover, shorter product life cycle requires responsive manufacturing system, which can only be possible/achievable through the use of advanced technology.

Industrial revolution has significant advantages on overall supply chain performance. It provides benefits for all major functions of supply chains from planning, to sourcing, make, and delivering. Literature has acknowledged its benefits including helping in meeting market requirements with high quality and within promised delivery date (Hofmann and Bick 2015, Müller et al. 2017); ability to customized products and its tracking and traceability (Weyer et al. 2015, Kagermann 2015, Khan and Turowski 2016, Ivanov et al. 2017, Li 2017, Hofmann and Rüsch 2017); and in designing responsive supply chain to minimize batch size (Chandra and Kumar 2000). The current industrial revolution, Industry 4.0, makes supply chain more resilient to minimize the effect of internal and external disruptions by benefiting from data analytics (Prajogo and Olhager 2012). Moreover, it helps to minimize inventory level and improves customer service level (Lee et al. 2015). Industry 4.0 helps to better monitor and provide the involvement of local supply-base, making supply chains more sustainable than ever before (Müller et al. 2017).

Circular economy (CE) and industry 4.0 are relatively new concepts within the context of sustainable supply chain (SSC) and rarely applied in practice successfully (Nguyen, 2016). The future of supply chains is dependent on circular economy and gaining maximum benefits from industry

4.0. It is affirm by the different survey reports such as PwC that 81% of the purchasing managers' surveyed in German industrial companies anticipated Purchasing 4.0 to follow Industry 4.0 (PwC, 2014). Similarly, a study carried out by BME (Bundesverband Materialwirtschaft, Einkauf und Logistik) thus, the 'German Association for Supply Chain Management, Procurement and Logistics', stated that around 37% of German companies have already implemented Industry 4.0 elements within their supply chains (Gottge and Menzel, 2017). Industry 4.0 has an ability to help improve communication, transparency, and makes data available within sustainable supplier selection process (Spina, et al., 2013; Glock & Hochrein, 2011). Therefore, it is essential for decision makers to take advantage of industry 4.0 technologies within their supplier selection decision process to gain these benefits.

Even though the concept of Industry 4.0 and CE has been examined by a number of researchers in the past separately, however, little attention has been given to integrate them within the context of sustainable supplier selection. In order to achieve the benefits of integrating Industry 4.0 and CE within sustainable supplier selection, it is essential for organizations to align their supplier selection process and decision within its context. To advance theoretical and practical understanding and help close the literature gap, this paper introduces a comprehensive CE-based Industry 4.0 criteria framework for sustainable supplier selection decision. The study further investigate this framework within the Pakistan textile manufacturing context providing practical insights and guidelines for implementation. This investigation is aided by an integrated multi-criteria decision-making support tool composed of the 'best-worst method' (BWM) and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) method.

The study targets the Pakistan textile manufacturing industry as the case industry for investigating the subject because it is the largest manufacturing industry in Pakistan and the 8th largest exporter of textile commodities in Asia (Ravi Magazine, 2015). In addition, it is the 4th largest producer of cotton, 3rd largest spinning capacity in Asia after China and India, and contributes 5% to the global spinning capacity (Stotz, 2015). The sector contributes 8.5% to Pakistan's GDP and employs about 45% of the total labour forces (38% of the manufacturing workers) in the country (Tahir, 2013). Yet, this sector is one of the serious polluters in Pakistan and lacks the necessary infrastructure to aid the transitioning towards sustainability. This study is aimed at setting the foundation and providing some tools and guidelines to support managers and policy makers to this transition.

Therefore, the objectives of this paper are to:

i) Identify and refine CE based Industry 4.0 initiatives within sustainable supply chain operations for developing a sustainable supplier selection criteria framework.

ii) Evaluate a set of suppliers based on the proposed integrated CE based Industry 4.0 initiatives/criteria framework and rank them according to their levels of involvement in these initiatives.

The contributions of this study are three-folds. First, it contributes to the three streams of literature including circular economy, industry 4.0 and sustainability by proposing a unified framework that integrates these three concepts into a sustainable supplier selection decision. Second, it investigates this framework within an industrial setting providing a practical managerial guidelines and another perspective of the literature, contributing to theory development. Finally, the focus of this study on Pakistan and its textile manufacturing industry is another contribution helping build up studies from emerging economy nation's perspective.

The rest of the study is organized as follows. Literature background and framework development are discussed in Section 2. In Section 3, the methodological approach employed for the study is presented. The case study and results are presented in Section 4. In Section 5, the discussion, and conclusion of the paper is given.

2. Literature background and framework development

2.1 Sustainable supply chains and management

Sustainable supply chains (SSC) seek to minimize negative ecological effects, wasted resources, and provide cost savings throughout the supply chain, from raw material acquisition to final use and product end-of-life (Gimenez and Sierra, 2013; Hsu et al., 2013; Gouda and Saranga, 2018). Sustainable supply chain management is defined as "The management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements" (Seuring and Müller, 2008, p. 1700). Sustainable supply chain management (SSCM) takes into consideration the triple bottom-line (TBL) dimensions of economic, social, and environmental sustainability approach when planning and making decisions regarding the supply chains (Badri Ahmadi et al., 2017; Kusi-Sarpong et al., 2018a; Khan et al., 2018).

Sustainability considerations and integration into the supply chains are driven by stricter governmental policies, increasing public awareness, social activism and pressures, corporate brand and image, and market and customer pressures (Badri Ahmadi et al., 2017; Esfahbodi et al., 2016; Fabbe-Costes et al., 2014; Tseng at el., 2015). Organizations have also integrated sustainability into their supply chains as a means of managing their supply chain risks such as environmental damages and labour disputes, which may results in supply chain disruptions (Gouda and Saranga, 2018). For example, in China, Walmart invested in environmental and social sustainability practices to minimize supply chain disruption from its 60,000 suppliers (Denend and Plambeck, 2007).

Supplier's operations can affect the reputation of the buying firms or even causes severe supply chain disruptions (Tong et al., 2018). For example, supplier's employee strike actions, legal disputes, accidents, natural disasters, spills etc. can have detrimental impact not only on the brand/corporate image but also on the financial health of the buying firm in terms of loss of sales etc (Speier et al. 2011; Ivanov et al. 2017; Hendricks and Singhal 2003). Therefore, both the buying and supplying firms are required to integrate and manage sustainability in their operations in a coordinated manner to improve the overall supply chain sustainability. More specifically, multinational organizations are expected to extend their sustainability initiatives to include their suppliers especially those in the emerging economies (e.g. introducing sustainable sourcing), for upscaling and advancing the goal of achieving sustainable supply chains.

Cooperation between supply chain partners in the form of effective communication is essential for effective SSCM. Not only are upstream and early pressures important, but environmental management systems, designing green products, packaging and recycling of products are also critical for achieving sustainability related goals (Eltayeb et al., 2011; Zailani et al., 2012). A number of additional important enablers for broader sustainability in production and supply chains include: adoption of safety standards, green practices, economic welfare of community, safety and health and stability of employees (Diabat et al., 2014).

Broader sets of enablers can be categorized into four main dimensions such as ‘sustainable plan’, ‘communities for sustainability’, ‘sustainable operational process control’ and ‘sustainable certificates and growth’ and can be further sub-categorized into 22 sub-enablers (Su et al., 2016). Knowledge management factors and dimensions also may support SSCM. For example, knowledge sharing, joint knowledge creation, information technology, and knowledge storage are all important for supporting communication among partners (Lim et al. 2017), and contributes to jointly development of sustainability practices (Kusi-Sarpong et al., 2016a, b; Kusi-Sarpong et al., 2015). These jointly developed sustainability initiatives along the supply chains, ultimately benefits all involving supply chain partners by reducing supply chain risks and disruptions hence advancing the supply chain sustainability goal (Foerstl et al., 2010; Hofmann et al., 2014; Taylor and Vachon, 2018). Social responsibility towards societal issues and better working conditions (e.g. work health and safety) have also been established as important sustainability initiatives for supporting SSCM (Badri Ahmadi et al., 2017; Lim et al., 2017).

2.2 Sustainable supplier selection

Over the last couple of years, sustainable supplier selection (SSS) has played a major role in the overall supply chain (SC) performance and crucial for any organization (Schöll, 2017). SSS has attracted many researchers and practitioners attention over the last years (Dubey et al., 2017; Turker and Altuntas, 2014) and is considered a focus issue (Esfahbodi et al, 2016; Vahidi et al, 2018). In literature, many authors have studied SSS as a core decision of SSCM (Zhang et al., 2014). Previously, SSS studies heavily focused on environmental and economic sustainability criteria (see Baskaran et al, 2012; Freeman and Chen, 2015; Sarkis and TaTalluri, 2002; Verma and Pulman, 1998; Sen et al, 2008). However, recent studies have started to incorporate the TBL-based sustainability perspective into the sourcing decisions (Elkington, 1998; Kleindorfer et al., 2005). The incorporation of all three sustainability dimensions (TBL) helps to increase organizations sustainability performance and reducing overall operational risks (Campbell, 2007; Cegarra-Navarro et al., 2016; Dubey et al., 2017; Schaltegger, 2011). Brandenburg et al. (2014) and Lueg and Radlach, (2016) both emphasized the need to select suppliers based on all sustainability aspects. In addition, Zhang et al. (2015) argued that supplier selection model should not only include the green and economic aspects, but should incorporate the broader TBL concept of sustainability in the supplier selection process. However, Ulutas et al. (2016)

highlighted that the integration of qualitative and quantitative sustainability criteria in supplier evaluation is limited in the literature.

More recently, many quantitative models have been developed by several authors considering mainly environment and economic sustainability dimensions (see Brandenburg et al., 2014; Zhang et al., 2015; Lueg and Radlach, 2016; Taticchi, 2015). Similarly, many authors (see Zhang et al., 2014; Taticchi, 2015) have also started to develop quantitative models that focus on environment and social aspects. Most of these quantitative models incorporate multiple criteria decision-making (MCDM) techniques, mathematical programming (MP) techniques and artificial intelligence (AI) techniques (Chai et al., 2013; Govindan et al., 2015; Ho et al., 2011). Additionally, integrated methods has also been used in SSS models such as AHP-Entropy-TOPSIS (Freeman and Chen, 2015), a DEMATEL-TOPSIS (Orji and Wei, 2014), and an AD-AHP (Zhang et al., 2014).

2.3 Circular economy and industry 4.0

Circular economy is the process of transforming supply chain operations from the linear model to circular production/business model where used/waste materials and components are reintroduced into the supply chain in a close-loop system through reusing, recycling, remanufacturing, repair and refurbishing as a means of recapturing value and minimizing negative impacts (Batista et al., 2018; Mangla et al., 2018; Schroeder et al., 2018; Yang et al., 2018; Jakhar et al., 2018). The shift to and implementation of circular business model requires the continuous monitoring and improvement of products lifecycle, hence the need for supporting technologies (Rizos et al., 2016; De Angelis et al., 2018). The introduction of circular economy business model and initiatives by manufacturing companies also requires changes to their manufacturing processes, some of which may include the addition of new technologies such as smart technologies which can be developed through Internet/wireless technologies to help protect and control environmental impacts (Lee et al., 2015; Reinhard et al., 2016; Schumacher et al., 2016). In achieving this goal, one important tool that have become most popular among organizations due to its advantages in manufacturing processes as well as environmental protection is Industry 4.0 (Moktadir et al., 2018). The term (concept of) Industry 4.0 refers to the fourth industrial revolution which is based on Internet technologies (such as Internet of Services - IoS, Internet of Things – IoT, Industrial Internet (II) and Cyber Physical System – CPS and Artificial Intelligent - IT) enabled industrial automation to create smart products, a smart production, and smart services (Wollschlaeger et al., 2017; Davies, 2015; Lee and Lee, 2015; Lee et al., 2015, 2014; Rüßmann et al., 2015).

Industry 4.0 has greatly influenced manufacturing companies operations and decisions (Ford, 2015; Reinhard et al., 2016; Fatorachian and Kazemi, 2018). For example, Internet of Service (IoS), internet of thing (IoT), and Cyber Physical System – CPS, a part of Industry 4.0 initiatives, facilitate and support the adoption of new technologies by manufacturing firms to aid in the automation of their manufacturing process (Moktadir et al., 2018) and help manage supply chain relationships and supporting or improving other sustainability initiatives (Bai et al., 2017a). A broader initiative may include the use of wireless sensor connections/technologies to support manufacturing and operational process automation, seamless interoperability and connectivity between devices, systems, services, disparate networks (Condry and Nelson, 2016) to enhance manufacturing operational efficiency and productivity by adopting automation and cleaner technology (Wang and Wang, 2016). These devices and machines with such kind of connectivity can be moved and connected with greater ease with no restricting cables which ensures resilient with real-time and reliability capabilities (Wollschlaeger et al., 2017; Bibby and Dehe, 2018). One interesting features of Industry 4.0 (e.g. IoT) is the use of Internet-enabled devices as end points for accessing industrial data (Condry and Nelson, 2016).

2.4 Identification of potential CE based Industry 4.0 criteria

To integrate Industry 4.0 within circular economy implementation in sustainable supplier selection process, there is the need to identify appropriate set of criteria that can guide the selection. Many sustainable supplier selection studies have been completed in the literature (see Jain and Khan, 2017; Jain and Khan, 2016; Dweiri et al., 2016; Khan and Al-Hosani, 2016; Cheaitou and Khan, 2015; Khan, Dweiri, and Jain 2016; Kusi-Sarpong et al., 2018b), yet none of these considered the use of industry 4.0 initiatives within the circular economy implementation more explicitly to guide the selection. Criteria determination is a very imperative step in the selection process as it serves as the basis for selecting the right supplier. Most of the previous sustainable supplier selection studies based their decisions on mainly the conventional environmental, social and economic elements of sustainability. However, with the advent of fourth industrial revolution and emerging trends of circular economy, it is essential for organizations and decision makers to incorporate all these elements of sustainability in their decisions. Thus, it is important for organizations to incorporate criteria related to Industry 4.0 within circular economy implementation when making sustainable supplier selection decisions. In this study, an attempt is made, for the very first time, to capture Industry 4.0 initiatives within circular economy implementation towards sustainable supply chain operations in a unified framework. The search keywords that was used to summarise these potential sustainable supplier selection criteria based on industry 4.0 initiatives within circular economy implementation are as followed: "sustainable supplier selection", Industry 4.0 and sustainable supplier selection", circular economy and sustainable supplier selection", "Industry 4.0 and sustainable supply chain", "circular economy and sustainable supply chain", and "sustainable supplier selection and sustainable supply chain" from Scopus, google scholar, science direct, and web of science.

However, the criteria captured through the extensive literature review are subjected to several rounds of review by supply chain experts to propose a final framework. This framework is further utilized alongside a proposed methodology composed of BWM and VIKOR for guiding sustainable supplier selection decision-making in a Pakistan's textile manufacturing company.

2.5 Research gaps and highlights

Some studies have occurred on circular economy and Industry 4.0 business models and initiatives and their implementations but none have until now, investigated the selection of sustainable suppliers based on Industry 4.0 business models and initiatives within circular economy implementation context. This has warranted and motivated this study. For example, and in terms of circular economy, Mangla et al (2018) investigated the challenges of implementing circular supply chain from an Indian manufacturing industry perspective whereas Agyemang et al (2018) investigated drivers and barriers to circular economy in the Pakistan's automobile manufacturing industry. In another two similar studies, Geng and Doberstein, (2008) and Geng et al. (2012) presented the current situation and measures being implemented in China for the long-term promotion of circular economy and further identified a series of barriers and challenges to the implementation of the concept in China (Geng and Doberstein, 2008). In terms of Industry 4.0, Moktadir et al. (2018) investigated the challenges to industry 4.0 implementation in the leather industry of Bangladesh whereas Hofmann and Rüsch, (2017) investigated Industry 4.0 implementation initiatives and scenarios in the context of logistics management. A literature survey has also occurred to identify the barriers that challenges and enablers that promotes small businesses in their transition to a circular economy (Rizos et al., 2016). In a more recent study, de Sousa Jabbour et al. (2018) conducted an advocacy study proposing a roadmap to enhance the application of circular economy principles in organisations by means of Industry 4.0 approaches for the integration of Industry 4.0 and the circular economy.

These are some latest examples of studies that have occurred and are relevant to circular economy and Industry 4.0 and a combination of both but clearly depicting the lack of studies on selection of sustainable suppliers considering their Industry 4.0 initiatives within a circular economy contextual implementation. To aid in addressing this literature gap, this study proposes a sustainable supplier selection framework drawing on existing literature, and experts input for investigating and selecting sustainable suppliers based on their levels of involvement in Industry 4.0 initiatives within circular economy implementation from a case context of Pakistan textile manufacturing industry. In this study, the circular economy-Industry 4.0 based sustainable supplier selection criteria framework is initially assessed and ranked using a multi-criteria decision making (MCDM) tool named the 'best-worst method' (BWM), and these criteria relative weights are further integrated into the VIKOR model to overcome VIKOR's limitations of requiring additional information about the criteria weights.

3. Methodology

The study adopted the case study approach (Yin, 2017) to investigate the subject. The study uses Pakistan textile manufacturing company managers to evaluate and select a suitable sustainable supplier based on CE based industry 4.0 criteria within sustainable supply chain operations. The methodological process follows a three-phase approach (see Appendix 1). The first phase of this methodology focuses on the refinement of the potential criteria through discussion with experts. These criteria were those identified earlier through extensive literature review. The second phase consists of the ranking of the final CE based Industry 4.0 criteria listing for sustainable supplier selection in sustainable supply chain operations through best worst method. The final and third phase involves the use of the VIKOR method to evaluate and rank the suppliers based on their levels of involvement in those criteria in the second phase. Numerous MCDM techniques are available in literature to rank criteria as well as alternatives such as AHP, ANP, DEMATEL, ELECTRE, TOPSIS etc. (Aragonés-Beltrán et al., 2014; Govindan et al., 2014;

Gupta and Barua, 2016a; Bai et al., 2017a,b; Leong et al., 2017; Sangaiah et al., 2017). Among these, AHP is the most widely used MCDM technique for ranking of the criteria due to its ease of use. However, this study utilizes a MCDM technique called best-worst method to rank the criteria because this methodology utilizes fewer pairwise comparisons and subsequently lesser data in comparison to AHP. Also, the best-worst methodology gives better and more consistent results in comparison to AHP (Rezaei, 2015). To rank the suppliers, VIKOR methodology is used. VIKOR has the advantage of providing an optimized solution in case of complex and conflicting situations and in cases where criteria have different units of measurement. It provides optimized solution that is closest to the ideal solution using compromise priority approach (Opricovic and Tzeng, 2004; Wu and Liu, 2011; Rostamzadeh et al., 2015).

The various methodological phases are explained below:

3.1 Obtaining weights of criteria using BWM

BWM is one of the latest MCDM technique being used nowadays by many researchers worldwide such as Gupta and Barua, 2016b (technological innovation enablers ranking); Rezaei et al., 2016 (green supplier selection); Gupta and Barua, 2017 (green supplier selection); Gupta, 2017 (airport evaluation based on service quality). Others include Salimi and Rezaei, 2017 (evaluating firms RandD performance); Gupta and Barua, 2018 (barriers to green innovation in SMEs); van de Kaa et al., 2017a (selection of biomass technology); van de Kaa et al., 2017b (selecting electric vehicle); Abadi et al., 2018 (evaluation of medical tourism strategy); Gupta, 2018 (GHRM criteria evaluation); Kusi-Sarpong et al., 2018a (sustainable innovation framework);

Rezaei et al., 2018 (quality assessment of airport baggage handling); van de Kaa et al., 2019 (analysing the various competing technologies); Wang et al., 2019 (analysis of energy related risks); Zolfani and Chatterjee, 2019 (analysis of sustainable design). The steps for BWM as given by Rezaei (2015; 2016) are explained below:

Step 1: Selection of criteria for supplier selection

Through literature review and supply chain experts' opinion, the criteria are finalized for analysis as stated in subsection 4.1.

Step 2: Each expert/manager is asked to identify the best and worst criteria among the finalized criteria for both the main category and sub category criteria.

Step 3: Thereafter, preference rating of the best to other criteria is obtained from each expert/managers using a scale of 1 to 9 (see appendix 3).

Step 4: Similarly, other to worst criteria preference rating is also obtained from each of the expert/manager using a scale of 1 to 9 (see appendix 3).

Step 5: Optimized weights (w_1^*, w_2^*, ...,w_n^*) for all the criteria are obtained using following steps.

The objective is to obtain the weights of criteria/attributes so that the maximum absolute differences for all j can be minimized for $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$. This minimax model will be obtained:

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

$$\text{s.t.} \sum_j w_j = 1$$

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

Model (1) when transformed into a linear model, gives better results, the model is shown below:

$\min \xi^L$

s.t.

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

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

$\sum_j w_j = 1$

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

Model (2) can be solved to obtain optimal weights (w_1^*, w_2^*,......., w_n^*) and optimal value ξ^L.

Consistency (ξ^L) of criteria/attribute comparisons close to "0" is desired (Rezaei, 2016).

3.2 Ranking the alternatives using VIKOR

VIKOR method as introduced by Opricovic (1998) has the advantage of providing optimized solutions in case of complex and conflicting situations and in cases where criteria have different units of measurement. It provides an optimized solution that is closest to the ideal solution using compromise priority approach. The VIKOR methodology is currently widely applied by researchers in various contexts such as Liu et al., 2012 (FMEA risk evaluation); Chang, 2014 (hospital service evaluation); Rostamzadeh et al., 2015 (GSCM practices evaluation). Others include Awasthi and Kannan, 2016 (green supplier selection); Mohsen and Fereshteh, 2017 (Failure mode risk analysis); Zhao et al., 2017 (Supplier selection); Gupta, 2018 (ranking of airlines based on service quality); Abdel-Baset et al., 2019 (Sustainable supplier selection); Ma et al., 2019 (Assessment of bike sharing service quality); Sharma et al., 2019 (Software vulnerability prioritization). The steps for VIKOR methodology are discussed below:

Step 1: The first step is to obtain a pairwise matrix of criteria and alternatives using the scale mentioned in appendix 9.

Step 2: Thereafter, using equation (3) the average decision matrix is obtained,

$$F = \frac{1}{k}\sum_{k=1}^{k} F_k \qquad (3)$$

Step 3: Using equations (4) and (5) the best f_b^* and the worst f_b^- values of all the criteria, b = 1, 2,....n are obtained,

$$f_b^* = Max\ (f_{ab}) \qquad (4)$$

$$f_b^- = Min\ (f_{ab}) \qquad (5)$$

Where f_b^* is the positive ideal solution and f_b^- is the negative ideal solution for the bth attribute.

Step 4: Compute the S_a and R_a values for a = 1, 2, ...m using equations (6) and (7).

$$S_a = \sum_{b=1}^{n} W_b\ [\ (f_b^* - f_{ab})/(f_b^* - f_b^-)] \qquad (6)$$

$$R_a = Max_b\ [W_b\ (f_b^* - f_{ab})/(f_b^* - f_b^-)] \qquad (7)$$

Where S_a and R_a are the distance of ath alternative from positive ideal solution and negative ideal solution respectively and W_b represents the weights of the criteria.

Step 5: Using equation (8) compute the scores for Q_a.

$$Q_a = v\left(\frac{S_a - S^*}{S^- - S^*}\right) + (1 - v)\left(\frac{R_a - R^*}{R^- - R^*}\right) \qquad (8)$$

Where $S^{-} = Max_a S_a,\ S^{*} = Min_a S_a, R^{-} = Max_a R_a, R^{*} = Min_a R_a\ and\ v$ denotes the weightage of maximum set utility which is between 0-1 and is taken as 0.5 in this study as used in Gupta (2017).

Step 6: Using Q_a values alternatives are ranked.

Step 7: Alternatives are ranked based on minimum Q_a values obtained subject to simultaneously satisfying two conditions:

Condition 1: Q(A(1)) is chosen if Q(A(2)) – Q(A(1)) ≥ 1/n-1 where A(2) is the alternative that has got the second rank in the analysis and n is the total alternatives.

Condition 2: Q(A(1)) also obtains the first rank according to both S_a and R_a values.

Step 8: Alternative that obtained a minimum score in Q_a is ranked first.

4. Case study and results

The proposed CE-based Industry 4.0 sustainable supplier selection framework is utilized within a case textile manufacturing company in Pakistan, represented as "company ABC" henceforth. Company ABC is a textile manufacturing company with a monthly production of 3.2 million meters of denim fabric and 1.5 million garments which reflect their commitment to the textile industry. Company ABC have a staff strength of 14,000 and uses state of the art laundries for denim wet processes to get an edge over their counterparts. Today, company ABC is known for its vertically integrated set-up that caters for all processes from manufacturing, fabric, to the final garment. Company ABC have a focus on procuring the finest quality cotton, making use of high-end sophisticated technology and deploying dedicated resources that are skilled with adequate expertise to meet local and international standards. Presently, company ABC takes pride in being considered one of the premium and leading players in the Denim Textile and Apparel industry of Pakistan. Aiming to achieve increasing sustainable performance, company ABC is embarking on selecting a highly performing supplier based on a set of CE-based Industry 4.0 criteria among a set of 'top category' of suppliers from their supply-base.

For the purpose of criteria finalization, three supply chain experts not necessarily from company ABC were selected and presented with the criteria identified through literature review. One of these experts is a CEO of a leading logistic company, the second expert is a Director, Supply chain of an e-commerce company, and third expert is manager, supply chain at a manufacturing company. All three experts have over 15 years' of experience. For the criteria ranking, 5 managers from within the case company were selected based on their direct involvements in similar decisions and decision-making processes and were asked to conduct a pairwise comparison of the finalized criteria. The details of these five managers are summarized in Table 1.

Table 1 Managers from case company involved in the decision-making process

Manager	**Position**	**Role**	**Working Experience**
1	Asst. Planning Manager	Develop daily production plan	2
2	Procurement Manager	Sourcing and purchasing	3
3	Production Manager	Implement daily production plan	7
4	Quality Manager	Implement quality control and assurance policies	12
5	Warehouse Manager	Issuance and receiving of material and goods	15

For the evaluation and selection of the sustainable supplier, five suppliers of company ABC were selected. The managers were asked to provide their ratings to these suppliers based on the finalized criteria in previous phase. The details of suppliers selected for evaluation in the case is summarized in Table 2.

Table 2 Supplier Characteristics

Supplier	**Location**	**Year of Establishment**	**Work Force Size**	**Turnover (Rs. / Year)**
Supplier 1	Korangi Industrial Area	1985	1200	65000000
Supplier 2	Port Qasim	2012	650	43000000
Supplier 3	S.I.T.E Area	2002	1000	13000000
Supplier 4	Pakistan Textile City	2007	450	26000000
Supplier 5	North Karachi Industrial Area	1999	200	19000000

4.1 Finalization of the evaluation criteria

Extensive literature review and modified-Delphi method are used to finalize the criteria on CE-based Industry 4.0 for sustainable supplier selection within company ABC. After a detailed literature review, twenty one criteria were identified. These criteria were then presented to experts to finalize the criteria. After several rounds of deliberations and discussion with supply chain experts, the experts agreed with the selected criteria and did not suggest any change. These criteria were then categorized into four main categories for the purpose of evaluation and ranking, again, with inputs from the supply chain experts. The final listing and their categorizations can be found in Table 3.

Table 3 Main and Sub category criteria of CE-based Industry 4.0

Main Category	Sub Category	Brief description	Supporting Literature
Organizational (OG)	Top management support and dedication towards industry 4.0 and circular economy implementation (OG1)	This refers to the support and enthusiasm by top management and leaders to adopt and implement Industry 4.0 and related technologies.	Savtschenko et al., 2017; Shamim et al., 2017; Jabbour et al., 2018a; Luthra and Mangla, 2018
	Financial wellbeing and availability for implementing Industry 4.0 within circular economy (OG2)	Availability of sufficient funds to procure, adopt and implement Industry 4.0 technologies within circular economy.	Theorin et al. 2017; Nicoletti, 2018; Luthra and Mangla, 2018
	A positive organizational culture towards implementation of Industry 4.0 and circular economy initiatives (OG3)	Developing a culture where people in the organization are open to adoption of technologies and new methods for sustainable management and circular economy through Industry 4.0.	Rizos et al., 2016
	Training and awareness on Industry 4.0 trends and capacity building (OG4)	Providing training to the employees of the organization and developing organizations capabilities in order to implement Industry 4.0 within circular economy.	Despeisse et al., 2017; Jabbour et al., 2018a
	Readiness for organizational change to adopt Industry 4.0 for circular economy (OG5)	Making employees aware of the benefit of adoption of Industry 4.0 within circular economy to avoid resist the change in adoption of associated new technologies.	Jabbour et al., 2018a
	Efficient Industry 4.0 Project Management (OG6)	This refers to the management of Industry 4.0 initiatives through project managers. The integration of Industry 4.0 technologies with environmentally sustainable manufacturing decisions would be implemented via improvement projects, requiring effective project teams to be organised.	Jabbour et al., 2018a
Regulatory and Institutional (RI)	Government support and policies to favour Industry 4.0 & circular economy (RI1)	Government policies which include tax exemption, subsidized loans and assistance to adopt latest advanced technologies by the industries.	Rizos et al., 2016; BRICS Business Council, 2017; Luthra and Mangla, 2018
	Research & Development initiatives for Industry 4.0 adoption in circular economy (RI2)	Developing research facilities at the organization which facilitate the reuse and recycling activities through use of Industry 4.0 technologies.	Schmidt et al., 2015; Hermann et al., 2016; Luthra and Mangla, 2018
	Strategic alignment between organizations capabilities and sustainability goals (RI3)	This refers to linking organization's structure and resources related to Industry 4.0 technologies with the environmental and sustainability related goals that	Jabbour et al., 2018a

		the organization wants to achieve through adoption of Industry 4.0 and circular economy.	
	Following global standards and data sharing protocols (RI4)	Adopting and following standards and protocols in data transfers in adopting sustainability oriented modern information interface technologies in business networks.	Branke et al., 2016; Luthra and Mangla, 2018
Technological and Infrastructural (TI)	Smart manufacturing and Cyber-Physical Production Systems (TI1)	This comprises of smart machines, warehousing systems and production facilities that have been developed digitally and benefit from end-to-end ICT-based integration.	Kang et al. 2016; Davis et al. 2012; Kagermann, 2015
	Proper IT enabled infrastructure to support Industry 4.0 technologies (TI2)	Proper IT infrastructure is most essential for adoption and implementation of Industry 4.0 technologies and tracking product return in circular economy. IT infrastructure includes high speed internet connectivity, technologies to store and process large amount of data etc.	Bedekar, 2017; Luthra and Mangla, 2018; Moktadir et al., 2018; Jabbour et al., 2018b
	Availability of and proficiency in data collection and management tools and techniques like RFID, Environmental IoT (TI3)	This refers to use of different data collection tools like RFID tags, sensors, scanners etc. for real-time data collection and monitoring within the circular supply chain. It also refers to ability to decipher and use that data for achieving sustainability goals.	Zhao et al. 2013; Pagoropoulos et al., 2017; Jabbour et al., 2018b
	Information heuristics to enable data capturing for 'design for environment' and sustainable consumption/production (TI4)	This refers to proper information management and data capturing techniques so that suitable designing of the products can be done in future to enable sustainable production.	Despeisse et al., 2017
	Smart ICT-based networking (TI5)	This enables the use of fewer resources more efficiently. E.g. fitting start-stop functions on machinery to cut energy consumption significantly.	Kagermann, 2015
	Big data technologies (TI6)	This enables real-time monitoring and improve the automation level of power systems where implemented.	Peng et al. 2015
	Smart scheduling and control (TI7)	Using data driven techniques and advanced decision architecture to perform scheduling and control operations in a supply chain.	Zheng et al., 2018

Supply chain collaboration (SC)	Supply chain partners pressure and demand to adopt Industry 4.0 and circular economy (SC1)	This refers to pressure from various stakeholders on sustainably use of products by reusing, refurbishing and remanufacturing with Industry 4.0 tools.	Rizos et al., 2016
	Sustainable product lifecycle management to ensure circularity (SC2)	This uses IoT to make devices to interact among themselves to promote environment benefits such as CO2 emissions or environment impacts reduction.	Framling et al. 2013
	Assuring data security throughout circular supply chain (SC3)	In Industry 4.0 the physical systems are connected to digital data and platforms for data exchange and storage. With large amount of organizations data available on cloud, it is essential to protect that data from different threats so that Industry 4.0 related technologies are successfully adopted.	Moktadir et al., 2018
	Collaborative network for Industry 4.0 within a circular supply chain (SC4)	This refers to collaborations among various industry for sharing technologies, machinery, collaborative R&D etc. related to Industry 4.0.	Camarinha-Matos et al., 2017

4.2 Criteria weights calculation using best-worst method

Once the criteria for the study are finalized, the next step is to calculate weights of the criteria using BWM methods. Five managers from the case company (see details in Table 1) were asked to identify best and worst criteria among main category criteria as well as subcategory criteria. The best and worst criteria identified by different managers are shown in Appendix 2.

After obtaining the best and worst criteria by each manager, all the managers were again asked to give preference rating of best to others and others to worst criteria for main category criteria as well as subcategory criteria using the scale in Appendix 3. The preference rating obtained from manager 1 for main category criteria is shown in Appendix 4.

Similarly, all the managers were also asked to rate the sub-criteria as done for the main category criteria. The preference rating given by manager 1 for subcategory criteria is shown in Appendices 5-8.

In the same way the ratings of all the main criteria and sub criteria were obtained from manager 1, the remaining four managers were also asked to provide their ratings on all the criteria. After obtaining all the ratings from the five managers, the next step was to obtain the weights of all the criteria using equation (2). The individual weights obtained after solving equation (4) and taking their averages for both main and sub categories criteria for all five managers responses, were then aggregated using a multiplicative operator in desirability index table and the final results is presented in Table 4.

Table 4 Aggregated weights of Main and sub-criteria for all the managers

Main Criteria	Weights of Main Criteria	Sub Criteria	Weights of Sub Criteria	Global Weights	Ranking
Organizational (OG)	0.332	OG1	0.173	0.057	6
		OG2	0.105	0.035	12
		OG3	0.417	0.139	1
		OG4	0.114	0.038	10
		OG5	0.137	0.046	7
		OG6	0.055	0.018	18
Regulatory and Institutional (RI)	0.234	RI1	0.308	0.072	4
		RI2	0.468	0.110	3
		RI3	0.156	0.037	11
		RI4	0.068	0.016	19
Technological and Infrastructural (TI)	0.356	TI1	0.328	0.117	2
		TI2	0.163	0.058	5
		TI3	0.090	0.032	13
		TI4	0.087	0.031	15
		TI5	0.079	0.028	17
		TI6	0.128	0.046	8
		TI7	0.124	0.044	9
Supply Chain Collaboration (SC)	0.077	SC1	0.062	0.005	21
		SC2	0.390	0.030	16
		SC3	0.413	0.032	14
		SC4	0.135	0.010	20

4.3 Ranking of suppliers using VIKOR method

After obtaining the criteria weights in phase 2, the next phase involves ranking of some selected suppliers' w.r.t weights of these criteria. VIKOR methodology discussed in section 3 is used to aid the ranking of these suppliers. All the managers were asked to provide their preferential ratings for each supplier using the scale in appendix 9. The ratings given by manager 1 for each supplier w.r.t to the evaluation criteria are shown in Appendix 10.

Similarly, all the managers are asked to rate the suppliers w.r.t the evaluation criteria. The average rating of all the managers obtained using equation (3) is presented in Appendix 11. Using equations (4) and (5) the maximum and minimum values of criteria are also obtained and are shown in Appendix 11 (see rows 8 & 9 respectively).

Further, using equations (6), (7) and (8), the values of S, R and Q are calculated and is shown in Appendix 12. The suppliers are ranked on the basis of their Q values. The supplier having lowest Q value is selected as best supplier subject to satisfying two conditions as mentioned in step 7 of phase 3 of methodology. Here supplier 2 (SP2) obtains the first rank as it has lowest Q value and also satisfies both conditions i.e. $Q(SP4) - Q(SP2) \geq 1/(5-1)$ and also Q(SP2) obtains the first rank according to both R and S values as shown in Table 5.

Table 5 Ranking of alternatives for R, S and Q values

	S	Rank	R	Rank	Q	Rank
SP1	0.849	5	0.117	4	0.864	5
SP2	*0.315*	*1*	*0.058*	*1*	*0.000*	*1*
SP3	0.401	3	0.139	5	0.580	4
SP4	0.397	2	0.091	3	0.282	2
SP5	0.542	4	0.088	2	0.395	3

5. Discussion and conclusion

Sustainable supplier selection is one of the most critical decisions by organizations when seeking to achieve sustainable supply chains and advancing sustainable development. Selection of the best/optimal supplier among a set of potential suppliers taking into considering multiple criteria is an imperative activity and decision for organizations, especially those in the manufacturing and production industries where not all activities can be and are undertaken in-house. The use of multi-criteria decision-making (MCDM) tools are useful for aiding such kind of strategic decisions. Many tools have been introduced and applied for such decisions, yet each do have their limitations and are context specific in their effectiveness. In this paper, to aid in addressing some contextual limitations of some MCDM tools and their applications, we integrated some MCDM tools comprising of BWM and VIKOR methods and utilized it to investigate CE-based Industry 4.0 sustainability supplier evaluation and selection.

The paper introduced a comprehensive CE-based Industry 4.0 criteria framework for investigating and supporting sustainable suppliers selection decision. This study share some similarities with some of the recent studies such as Guo et al (2017) and Zhou and Xu (2018), in which the authors evaluated and selected sustainable suppliers. The lack of implemented suppliers' sustainability performance measures within sustainable supplier selection decisions has been reported in the literature (See Bhattacharya et al., 2014; Dubey et al., 2016; Tacchichi et al., 2015). Therefore, the proposed framework consisting of four main categories and twenty-one sub-categories can help in selecting suppliers by considering industry 4.0, sustainability, and CE. This framework was then applied to a Pakistani textile manufacturing company with inputs from 5 of their top management members (managers) aided by the integrated BWM and VIKOR methodology for evaluating and ranking of five suppliers in terms of their levels of involvement in Industry 4.0 initiatives within circular economy implementation.

The empirical results of the study can be found in Tables 4 and 5. From Table 4, it can be seen that the top three sub-criteria that the managers of company ABC considered much importance during the evaluation include, “A positive organizational culture towards implementation of Industry 4.0 and circular economy initiatives (OG3)” with global weight of 0.139; “Smart manufacturing and Cyber-Physical Production Systems (TI1)” with global weight of 0.117; and “Research & Development initiatives for Industry 4.0 adoption in circular economy (RI2)” with global weight of 0.110. Among these, OG3 happens to be the topmost and foundational sub-criteria, as a mind-set shift (Gupta, 2018) from a linear to the implementation of Industry 4.0 and circular economy initiatives is a very imperative step every organizations need to achieve should they want to realize higher sustainability performance.

Table 5 depicts the Q values of the five potential suppliers with their respective ranking. As can be seen, supplier 2 is ranked the topmost suppliers with Q value of 0.00 (the lower the Q value the better). Supplier 4, 5, 3 and 1 follows respectively. Although supplier 2 is considered the optimal supplier according to this result, and is recommended to the Pakistani textile manufacturing company for contracting, unfortunately, there are some criteria that supplier 2 was not well rated. Hence, the Pakistani textile manufacturing company may consider having specific post-selection negotiations with this supplier for potential improvements in these lower rated criteria, using other suppliers as benchmark (Bai et al., 2019).

5.1 Managerial and post-selection benchmarking negotiations

In this section, the paper illustrates how managers from the case company can utilize the results obtained from this study for supporting post-supplier selection negotiations with the selected supplier for future improvements. As an example, using data from Appendix 11, we can see that supplier 2 has the best rated performance criteria among the five suppliers for the first three criteria (under the main organizational category), namely: "Top management support and dedication towards industry 4.0 and circular economy implementation" (OG1), "Financial wellbeing and availability for implementing Industry 4.0 within circular economy" (OG2) and "A positive organizational culture towards implementation of Industry 4.0 and circular economy initiatives" (OG3). This signifies that, no further negotiations is required with supplier 2 for these three performance criteria. However, it is observed that supplier 3 (under the main organizational category) has the highest rated performance criteria among the five suppliers for the 4th and 5th criteria, namely: "Training and awareness on Industry 4.0 trends and capacity building" (OG4) and "Readiness for organizational change to adopt Industry 4.0 for circular economy" (OG5); and suppliers 4 has the highest rated performance criteria among the five suppliers for 6th criteria, "Efficient Industry 4.0 Project Management" (OG6). For these two criteria (OG4 and OG5), supplier 3's performance ratings can be utilize as a benchmark measurement for other suppliers. Therefore, the Pakistani textile manufacturing company can as part of their post-supplier selection project, can consider negotiating with supplier 2 to focus on improving the performance of these two criteria. In the same way, supplier 4's performance rating can be considered as a benchmark measurement for other suppliers and so the case company can negotiate with supplier 2 to initiate some steps to improve this performance criteria. Many of these are observed among the remaining categories and similar step can be taken by managers for improvement negotiations.

Given the possibilities of interactions and trade-offs among performance criteria, care must be taken not to compromise the overall performance of supplier 2. Overall, this depicts that compensatory assessment may allow for some poor performing outcomes to occur; therefore setting a minimum value expectations may be necessary to guarantee better overall performance on criteria.

5.2 Implications for management sciences professionals

Management sciences discipline is concern with the identification, extension and unification of scientific knowledge pertaining to process and substance of management (Kendall et al., 1982). This study has some relevant implications for management sciences professionals especially for those within the case country. These implications come from two perspectives: (1) the perspective of the proposed analytical framework, and (2) the perspective of the integrated BWM-VIKOR decision-support model. The application and implementation of these tools and techniques to solve managerial and technical problems within the case company recognizes well the behavioral and socio-economic realities of management practice in organizations.

This study provides a framework for management sciences professionals in developing economies such as Pakistan to help identify suitable criteria for sustainable supplier selection within the context of circular economy based on Industry 4.0 initiatives. The basic framework can be applied across different industries in the developing countries. By evaluating and ranking these selected criteria, this study primarily helps management sciences professionals to identify which criteria are more important over the others for supporting sustainable supply chain management decisions within the context of circular economy based on Industry 4.0 initiatives. This evaluation is extended to the selection of a sustainable supplier based on these criteria. Similar industries in developing countries can incorporate this framework for selecting a suitable sustainable supplier for partnership.

Methodologically, the integration of the tools (BWM and VIKOR methods) into a unified model, though not novel, its application to the case country and company is novel and can be considered as a contextual applicability extension of the model, thus, contributing to the decision making application. The application of the tools and the outcome of the theoretical framework showed that the model is beneficial. This expounds on the issue of theoretically, multiple criteria approaches are valuable when considering sustainability concerns. Thus, this study reaffirms the importance of the multi-criteria models used in the study, given management sciences professionals the confidence to adopt and apply multi-criteria models to sustainable supplier selection decision in specific and sustainability decisions in general.

Overall this study provides an analytical framework and multi-criteria model for management sciences professionals who act as decision mediators or even decision makers to help them make *more effective and informed decisions* (Fahimnia, et al., 2019) concerning sustainable criteria and sustainable suppliers' performance leading to overall sustainability improvement of the organization.

5.3 Limitations and future research directions

This study employs a framework for sustainable supplier selection based on Industry 4.0 within the context of circular economy. The work is novel in its approach and methodology selection but still has some limitations. First, this study uses a case study of Pakistan and generalizing results for other developing countries can be a major challenge. Also, a total of 21 criteria were identified through literature review and managerial inputs, there can be other criteria which might have been left behind either due to non-applicability of those criteria in this particular case or due to manager's bias. Further studies can involve exploring more criteria for supplier selection and testing the framework in various other developing countries. This study involved four main criteria, however for sustainable supplier selection social criteria are also equally important, future studies can look into this aspect by taking social criteria along with other criteria for sustainable supplier selection based on Industry 4.0 criteria within a circular economy implementation. Lastly, this study has used MCDM techniques including BWM and VIKOR for ranking the criteria and alternatives. These MCDM techniques (BWM and VIKOR) have their shortcomings. Both methodologies require data from experts/managers, and so it is essential to choose the right set of experts/managers for data collection. In addition, the research problem should be well explain to these experts/managers in detailed before collecting data. Furthermore, according to Zeng et al. (2013), VIKOR methodology sometimes gives less consistent results for normalized data.

As we know many of these criteria are interrelated and depends on each other, so future studies must attempt to explore this relationship by adopting techniques such as ISM, DEMATEL, and SEM for getting robust results.

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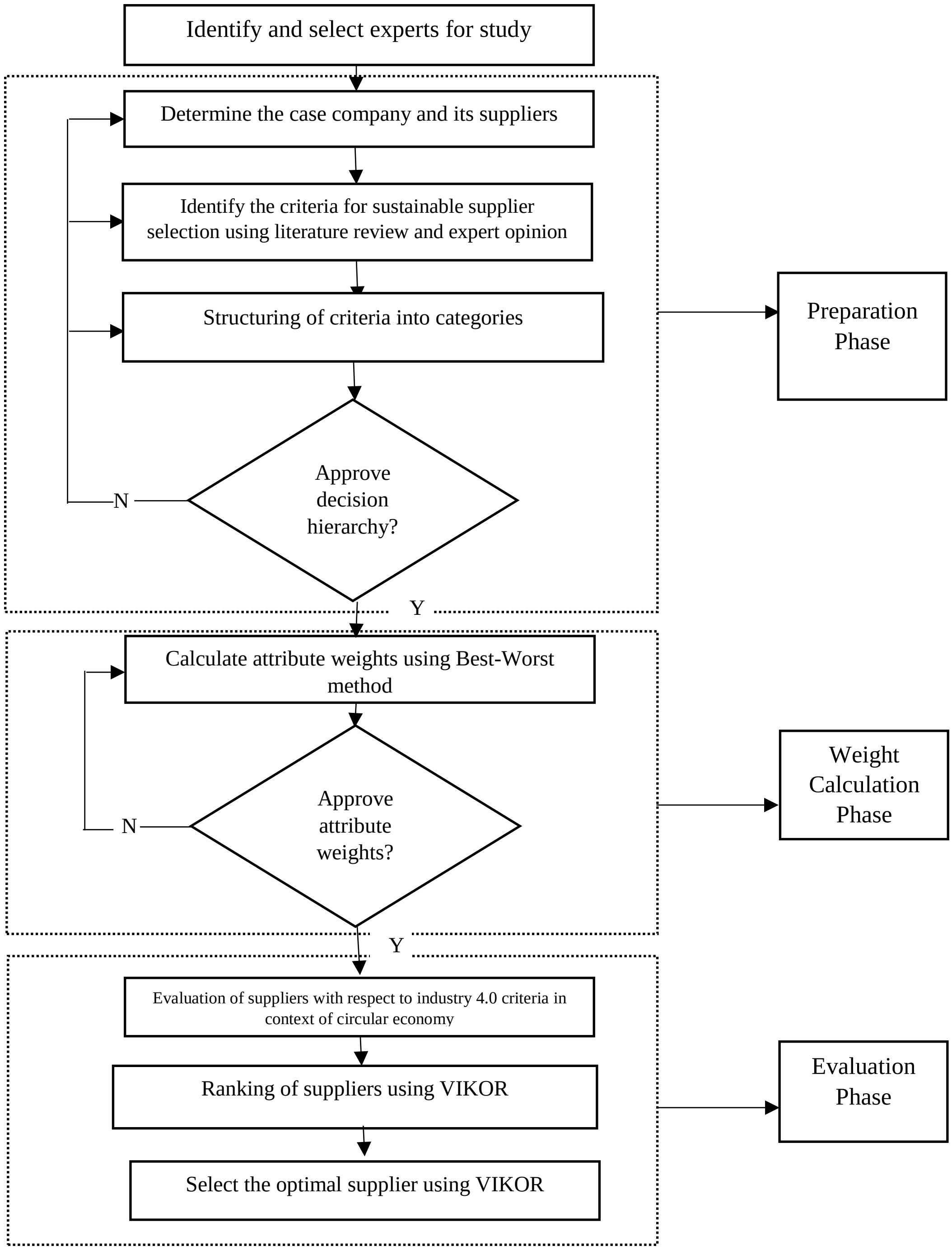
Appendices

Appendix 1 Schematic diagram for phases of methodology



Appendix 2 Best and Worst green evaluation criteria identified by managers

Criteria	Determined as Best by managers	Determined as Worst by managers
Organizational (OG)	3, 5	
OG1		
OG2		
OG3	1, 2, 3, 4	
OG4		
OG5	5	4
OG6		1, 2, 3, 5
Regulatory and Institutional (RI)	**4**	3
RI1	4, 5	
RI2	1, 2, 3	
RI3		
RI4		1, 2, 3, 4, 5
Technological and Infrastructural (TI)	1, 2	
TI1	1, 2, 3, 5	4
TI2	4	
TI3		
TI4		1, 2
TI5		5
TI6		
TI7		3
Supply Chain Collaboration (SC)		1, 2, 4, 5
SC1		1, 2, 3, 4, 5
SC2	3, 5	
SC3	1, 2, 4	
SC4		

Appendix 3 Linguistic scale for pairwise comparison for best worst methodology

Scale for Best worst methodology								
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**

Appendix 4 Main category criteria comparison manager 1

BO	*Organizational (OG)*	*Regulatory and Institutional (RI)*	*Technological and Infrastructural (TI)*	*Supply Chain Collaboration (SC)*
Best criteria: ***Technological and Infrastructural (TI)***	7	4	1	9

OW	Worst criteria: ***Supply Chain Collaboration (SC)***
Organizational (OG)	3
Regulatory and Institutional (RI)	2
Technological and Infrastructural (TI)	9
Supply Chain Collaboration (SC)	1

Appendix 5 Pairwise comparison of Organizational (OG) sub criteria by manager 1

BO	***OG1***	***OG2***	***OG3***	***OG4***	***OG5***	***OG6***
Best criterion: ***OG3***	7	6	1	5	8	9

OW	Worst criterion: ***OG6***
OG1	3
OG2	2
OG3	9
OG4	4
OG5	2
OG6	1

Appendix 6 Pairwise comparison for Regulatory and Institutional (RI) sub criteria by manager 1

BO	***RI1***	***RI2***	***RI3***	***RI4***
Best criteria: ***RI2***	3	1	3	6

OW	Worst criteria: ***RI4***
RI1	3
RI2	7
RI3	4
RI4	1

Appendix 7 Pairwise comparison for Technological and Infrastructural (TI) sub criteria by manager 1

BO	***TI1***	***TI2***	***TI3***	***TI4***	***TI5***	***TI6***	***TI7***
Best criterion: ***TI1***	1	4	5	9	7	7	6

OW	Worst criterion: ***TI4***
TI1	9
TI2	4
TI3	2
TI4	1
TI5	2
TI6	3
TI7	3

Appendix 8 Pairwise comparison for Supply Chain Collaboration (SC) sub criteria by manager 1

BO	***SC1***	***SC2***	***SC3***	***SC4***
Best criteria: ***SC3***	9	7	1	6

OW	Worst criteria: ***SC1***
SC1	1
SC2	2
SC3	9
SC4	3

Appendix 9 Linguistic scale for pairwise comparison for VIKOR methodology

Scale for VIKOR methodology	
Linguistic variables	**Importance rating**
Least Important	1
Moderately Important	2
Strongly Important	3
Very Strongly Important	4
Extremely Important	5

Appendix 10 Rating of Suppliers by Manager 1

	OG1	OG2	OG3	OG4	OG5	OG6	RI1	RI2	RI3	RI4	TI1	TI2	TI3	TI4	TI5	TI6	TI7	SC1	SC2	SC3	SC4
SP1	2	3	3	1	4	4	1	4	1	1	1	3	2	2	3	1	2	3	1	1	3
SP2	4	3	4	3	4	1	2	5	3	2	1	1	3	1	2	4	5	1	3	3	1
SP3	4	2	4	5	5	3	1	4	2	5	2	3	4	3	4	1	5	3	1	3	2
SP4	4	2	2	4	4	3	2	3	1	3	2	1	3	2	5	1	4	4	1	1	1
SP5	4	3	3	2	2	3	2	5	2	1	3	3	5	3	2	4	3	4	4	1	3

Appendix 11 Aggregated rating of alternatives by all the managers

	OG1	OG2	OG3	OG4	OG5	OG6	RI1	RI2	RI3	RI4	TI1	TI2	TI3	TI4	TI5	TI6	TI7	SC1	SC2	SC3	SC4
SP1	1.6	2.8	2.8	2	3	2.8	1.4	2.2	2.6	2.6	2.2	2.8	2.6	2.6	2.6	1.4	2	3	2.2	1.8	2.6
SP2	3.6	4	3.8	3	3.6	1.8	3.2	3.4	2.6	2.2	2.6	1.6	3.4	2.4	3	3.2	3.6	1.8	2.4	3.4	2.2
SP3	3	2.6	2.6	4.2	4.4	2	2.4	3.4	3	3.6	3	2.4	2.4	3.2	3	2	3.6	2.6	2.4	2.8	2
SP4	3.6	3.4	3.4	3.4	3.6	3.4	2.6	2.4	2.8	2.6	2.4	2.8	2.8	2.6	3.8	2.8	4.2	3.6	3.6	3.2	1.6
SP5	2.6	3	3.2	2.8	2.4	2	1.8	3.2	2.4	2	2.4	3	3.8	2.4	2.4	2.8	2.6	3.4	3	3.2	2.6
f_b^*	3.6	4	3.8	4.2	4.4	3.4	3.2	3.4	3	3.6	3	3	3.8	3.2	3.8	3.2	4.2	3.6	3.6	3.4	2.6
f_b^-	1.6	2.6	2.6	2	2.4	1.8	1.4	2.2	2.4	2	2.2	1.6	2.4	2.4	2.4	1.4	2	1.8	2.2	1.8	1.6

Appendix 12 S, R and Q values for alternatives

	S	**R**	**Q**
SP1	0.849	0.117	0.864
SP2	0.315	0.058	0.000
SP3	0.401	0.139	0.580
SP4	0.397	0.091	0.282
SP5	0.542	0.088	0.395
	$S^{-} = 0.849$	$R^{-} = 0.139$	
	$S^{*} = 0.315$	$R^{*} = 0.058$	