**A Framework for** **Assessing Sustainability in Multi-tier Supply Chains using Empirical Evidence and Fuzzy Expert System**

**Abstract**

This study investigates various factors for assessing sustainability in Multi-tier Supply Chains (MtSCs) using a hybrid approach consisting of an empirical study and fuzzy expert system. After an extensive literature review, four research questions were formulated and a questionnaire designed. From its distribution, 152 responses were collected from the textile industry. Exploratory Factor Analysis (EFA) was employed to determine the most effective factors that could contribute to the evaluation of extensive aspects of sustainability in MtSCs as well as recognize the importance of constructs. The categorized constructs based on their importance included “Environmental issues”, “Economic issues”, “Policy and governance”, “Participation”, “Social issues”, “Transparency” and “Leadership and support”. A comprehensive rating for evaluating sustainability by indicating a readiness score and linguistic variables for each construct was developed in the form of a “fuzzy expert system”. The developed fuzzy expert system was applied in an Iranian textile company to assess its readiness status as a case application. The results indicated that the company had the highest and lowest readiness in “Transparency” and “Environmental issues” with total readiness scores of 2.65 and 0.17 respectively. The finding recommends that the company should pay more attention to environmental issues such as making a cutback on utility consumption and increasing recycled materials. The framework’s validity was measured around 90% based on the satisfaction of experts’ judgments, which enables the framework to be applied in different industrial settings. Theoretically, the findings contribute to the Resources-Based View (RBV) theory, with a focus on the sustainability of MtSCs, by unveiling a comprehensive set of factors for assessing sustainability and recognizing external and internal strategic resources that lead firms to sustainable competitive advantages.

***Keywords:*** Multi-tier Suppliers, Sustainability, Exploratory Factor Analysis, Fuzzy Inference Engine, Resources-Based View Theory, Emerging economy

**1.** **Introduction**

Governmental regulatory and people awareness have exerted compelling pressures on lead firms to consider sustainability in their decisions and operations (Ghadge et al., 2019; Kusi-Sarpong et al., 2019). It is not just a matter of reactions to such high pressure, numerous benefits are lying in sustainability initiatives to build up competitive advantages against rivals. Lead companies are prone to instability not stemming from their operations but also suppliers and partners’ behaviour within the supply chain (Tuni et al., 2020; Sauer and Seuring, 2019). Poor provision of raw materials by suppliers to lead firms may cause delivery of poor products to customers, which leads to poor reputation and lower revenue as the outcome (Bai et al., 2019). The unstable suppliers’ behaviour from strike actions to the use of poor raw materials might result in serious repercussions for lead companies such as production loss and diminishing reputation (Bai et al, 2019; Ghadge et al., 2019). For instance, the famous lead company Nestle was boycotted by its customers due to the unstable behaviour of its supplier, i.e. Sinar Mas, for cutting down rainforest to expand available land for palm oil production (Sauer and Seuring, 2019; Hartmann and Moeller, 2014). Zara Company also faced up enraged customers for releasing toxic waste into rivers by its suppliers (Hartmann and Moeller, 2014). Customers never distinguish between lead company and suppliers. They tend to hold the lead company accountable for doing any wrong actions within its SC, which causes a “chain liability effect” (Bai et al., 2019; Hartmann and Moeller, 2014).

Since Suppliers provide raw materials and services to lead firms, their behaviours and actions are so important to lead companies for reaching sustainability and competitive advantages against competitors (Bai et al., 2019; Ghadge et al., 2019). Suppliers’ behaviours have a knock-on effect on the performance of a lead company. Thus, there is a dire need for a lead company to provide a regular and constant assessment of suppliers’ performance within the SC for mitigating the negative impact of suppliers’ behaviour (Bai et al., 2019).

Since the early 2000s, Sustainable Supply Chain Management (SSCM) has received high attention from academicians and industrialists. SSCM delineated as addressing organizational supply chain aimed at increasing profitability, improving social well-being, and mitigating destructive environmental impact (Kusi-Sarpong et al., 2019). Sustainability is fulfilled with the interconnection of three main pillars of economic, environmental, and social issues (Orji et al., 2020). Striking up a balance between these three concepts assures organizational sustainability (Sarkis et al., 2019). Lead companies put their process, activities, and products to provide more environmentally friendly services and products to customers. While social and economic aspects of sustainability pay attention to keeping the company’s reputation and increasing revenue respectively (Jia et al., 2019; Gong et al., 2018). In a way, SSCM has turned into a trending theme and dozens of research papers have highlighted the importance of such topics (Jia et al., 2019; Gong et al., 2018).

The high participation of various actors in the supply chain has led to the complexity of sustainability in supply chain management. It is highly required to exceed the dyadic perspective from first-tier suppliers and a lead firm (Mejías et al., 2019). The expansion of scope means that the lead company should consider more than one-tier suppliers to reach sustainability (Jabbour et al., 2019; Sarkis et al., 2019). The wider concentration on first-tier suppliers requires considering the behaviour and performance of downstream suppliers and partners to avoid compromising lead company reputation, on account of the poor performance of low-tier suppliers (Sarkis et al., 2019).

Over the past few years, the focus on SSCM has shifted from lead company and first-tier suppliers to sub-suppliers, suppliers, and lead company (Jia et al., 2019; Gong et al., 2018). The vast majority of the existing sustainability-based papers have studied the relationships between the lead company, direct suppliers, and customers (Sarkis et al., 2019). However, the existing research on the assessment of the supplier’s sustainability performance for more than first-tier suppliers is significantly rare and a significant number of papers have concentrated on single-tier supplier rather than upstream suppliers (Tuni et al., 2020; Sarkis et al., 2019). The most published papers with the title of sustainability in MtSCs concentrates on developed countries and abstains from creating a framework in relationship with emerging economies and developing countries. There is a profound lack of multi-tier perspectives allocated to the context of emerging economies (Govindan et al., 2021; Luján-Ornelas et al., 2020). The concept of sustainability has been practised in different industries such as food and furniture (Venkatesh et al., 2020). The textile industry is one of the most important sectors across the world where everyone is involved with it, to some extent (Jia et al., 2019). Thus, there is a dire need to assess sustainability within the textile industry.

SSCM is the coordination of material and information flow while considering triple –bottom –lines of sustainable development such as economic, social, and environmental issues. These practices are divided into two dimensions including assessment (e.g., monitoring) and collaboration (e.g., training) (Grimm et al., 2018). Recent papers have highlighted the importance of the two dimensions in Multi-tier Supply Chains (MtSC) (Grimm et al., 2018; Grimm et al., 2016).

Reaching sustainability in MtSCs requires constant and systematic monitoring of behaviour and communication of sub-suppliers, suppliers, customers, and staffs. Such valuable information and report are considered intangible and strategic resources for reaching sustainable competitive advantage as per the RBV theory (Nardo and Veltri, 2013). However, many focal companies are suffering from limited monitoring and traceability of external and internal actors including suppliers, customers, and staffs in MtSCs (Bai et al., 2019). They are strongly challenging to find an appropriate method to expand their visibility regarding the behaviour and operations of downstream suppliers for being equipped with practical information as intangible strategic resources (Meqdadi et al., 2020; Nardo and Veltri, 2013).

Following the extensive literature review, four research questions were formulated as:

*RQ1.* How can a framework for assessing the readiness status of sustainability within MtSCs in the context of the textile industry for emerging economies be developed?

*RQ2.* What are the most effective comprehensive sets of critical factors for assessing the readiness status of the three main pillars of sustainability within MtSCs?

*RQ3.* How can the quantitative value of readiness for sustainability’s pillars for case studies at an MtSCs level be calculated?

*RQ4.* How can the vagueness of subjective factors of sustainability pillars within MtSCs for making the result more realistic be calculated?

Following the research questions, the research objectives are:

* To develop a framework for assessing the readiness status of sustainability within MtSCs in the textile industry and within the specific context of emerging economies.
* To determine the most effective comprehensive sets of critical factors for evaluating the readiness status of the sustainability pillars within MtSCs.
* To calculate the quantitative readiness value of sustainability pillars for MtSCs case studies.
* To select an appropriate method for modelling the uncertainty of subjective factors.

The study provides the following unique contributions to reaching sustainability in MtSCs:

* Proposing a novel framework for assessing broader dimensions of the three main pillars of sustainability in MtSCs.
* Introducing a comprehensive set of factors for assessing the broader aspects of sustainability in MtSCs.
* Contributing to the RBV theory through a meticulous assessment of behaviours and relationships of suppliers and downstream suppliers as strategic resources for performing more efficiently and reaching competitive advantages.
* Conducting an empirical study to categorize the most impactful factors into different constructs.
* Designing a novel expert system based on experts’ knowledge for making the framework applicable and measurable for assessing the readiness status of sustainability in MtSCs for the textile-manufacturing case study as well as providing practical pieces of advice to policy makers.
* Using fuzzy sets theory to capture the inherent ambiguity of subjective factors and constructs in the expert system.

The paper is comprised of six sections. The next section explains the main concept of MtSCs, RBV theory and recognizes the most relevant studies. The third section introduces the research methodologies including empirical study and fuzzy expert system. The fourth section applies the framework for a case study to assess the readiness status of factors and check the suitability and applicability of the framework. The fifth section denotes the results and discusses the theoretical and practical implications. The sixth section is allocated for the research conclusion.

**2. Literature Review**

In this section, the concept of Sustainable Supply Chain Management and MtSCs explained then the most relevant studies were recognized. Following an extensive literature review, the most common research methodologies and the context of case studies were determined. Finally, the research gaps are introduced accordingly.

**2.1. Overview of Sustainable Supply Chain Management**

Sustainable Supply Chain Management (SSCM) is involved in addressing information and materials through the entire supply chain following social, environmental and economic attributes as well as practising cooperation between companies along the supply chain (Bai et al., 2019; Jia et al., 2019). The definition has highlighted the importance of economic, environmental, and social aspects and having cooperation between actors while fulfilling the stakeholders’ needs not just a lead company (Bai et al., 2019). SSCM helps the company to alleviate the negative impact of SC operations and enhance the performance efficiency based on economic, environmental, and social perspectives (Gong et al., 2019). Sustainable supply chain initiatives help manufacturing companies and industries to accelerate sustainable development (Kusi-Sarpong et al., 2019). It is concluded that all pillars of sustainability including social, environmental, and economic issues should be considered to develop SSCM (Khan et al., 2018). SSCM has received trajectory attention from industrialists and academicians because customers, governmental agencies and regulatory entities are fully aware of economic, environmental, and social issues, which affect a firm’s operations (Khan et al., 2018). Different papers have studied sustainable supply chain from different dimensions (Kusi-Sarpong et al., 2019; Gong et al., 2018). The research interest in SSCM has changed from focusing on a lead company and first-tier supplier to considering more actors in the entire supply chain such as suppliers of that supplier. Despite becoming a hot theme among researchers, there are a few studies to explore sustainability at an MtSCs level (Gong et al., 2018).

**2.2. Resource-Based View Theory**

The theory suggests that companies should possess different resources to improve their competitive advantages (Li et al., 2020). The theory is considered as an important strategy for companies to make competitive advantages against rivals including human, capital, technology, equipment, and information resources. The resources are divided into two categories such as tangible (company’s physical infrastructure) and intangible (technology and information) (Khan et al., 2020). The RBV theory believes that resources should have specific features, including being valuable, rare, inimitable, and non-substitutable to reach sustainable competitive advantages (Ismail and Latiff, 2019). By having such features, companies can sustain their position in the market and can outdo competitors. Indeed, it is so challenging for companies to sustain their competitive advantages because they are most likely to follow up competitors’ footsteps and avoid recognizing and exploiting their tangible and intangible resources (Ismail and Latiff, 2019).

In this research, lead firms are equipped with the main drivers of sustainability in MtSCs as an intangible strategic resource (information) to have a better vision of suppliers’ behaviour and practices. Such valuable information enables managers to exceed their perspective to better-monitoring low-tier supplier’s behaviour aimed at making the right decision for reaching higher sustainable competitive advantages.

**2.3. Multi-tier Supply Chain Studies and Research Gaps**

Since the lead firms never operate and compete solely as a single entity in the supply chain, the conventional concept of the supply chain has faced up to big transformation. supply chain no longer defines as comprised of a focal company, suppliers, and customers (Gong et al., 2018). The complexity of cooperation between various suppliers and focal companies leads to transcending supply chain boundaries by considering more actors including a lead firm, its suppliers, suppliers of those suppliers, customers, and customers of those customers (Sarkis et al., 2019; Tachizawa and Wong, 2014).

The vast majority of previous studies mostly avoids considering sustainability in MtSCs. They mostly concentrate on first-tier suppliers for assessing sustainability in supply chain management (Lechler et al., 2020; Sawik, 2020). A few studies have been conducted to investigate the sustainability in MtSCs since 2014 (Ghadge et al., 2019; Hartmann and Moeller, 2014). To identify the most relevant studies, a systematic literature review was conducted based on one of the most prestigious scientific databases of academic research, i.e. Scopus database. The attributable reasons for selecting this database included high precision citations and covering more than 2,000 periodicals (Jabbour et al., 2019). The following keywords including “Sustainability OR Sustainable” AND “Multi-tier OR Multitier” AND “Supply Chain” were searched in “Title” and “Abstract”, and “Keyword” sections. The initial search results returned 57 papers including scientific articles, review papers, conference papers, and book chapters. After reviewing the abstracts and manuscripts, those which considered at least one aspect of the sustainability pillars (including economic, social and environmental issues) within MtSCs (whether second, third or further tiers) were considered as the most relevant studies and selected for further analysis. Table 1 shows the most relevant studies:

**Table 1.** The most relevant studies

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Study** | **Research description** | **Sustainability Pillars**  | **Research Methodology** | **Case Study** | **Applied Theory** | **Factors** |
| Tuni et al. (2020) | The study proposes an integrative empirical study to strike up a balance for sustainability pillars. | Environmental and Social pillars | Empirical study | Machinery Industry | None | -Material consumption-Land occupation-Water consumption-Energy consumption-Solid waste |
| Sauer and Seuring (2020) | The research proposes a framework for identifying and assessing the challenges of sustainability in MtSCs. | Environmental and Social pillars | Delphi method | Mineral Industry | Exploratory theory | -Creating demands for more sustainability-Governance structure-Socio and environmental issues-Cooperation |
| Venkatesh et al. (2020) | The paper investigates the main drivers of social sustainability in MtSCs from suppliers’ perspective. | Social pillar | Empirical study | Apparel Industry | Mid-level theory | -Lead company governance-Strategic partnership between suppliers and sub-suppliers-Price pressure-Transparency-Institutional pressure |
| Adesanya et al. (2020) | The research investigates how sustainability can be improved by Supplier Relationship Management (SRM). | None | Empirical study | Tobacco Industry | None | -Ethical standards-Top-level management commitment-Traceability system based on specific KPI-Incentive and penalties policy-Training-Code of conduct  |
| Fraser et al. (2020) | The study highlights the significant role of transparency as the prerequisite of developing sustainability. | None | Empirical study | Automatic Industry | None | -Trust-Knowledge sharing and organizational learning-System traceability-Increasing information transparency |
| López andRuiz-Benítez (2020) | The study investigates the effect of applying different sustainable strategies (such as lean, green, and resilient) in single tier and MtSCs. | Social, Economic and Environmental pillars | Empirical study | Aerospace Industry | None | -Cost of material purchasing, -Cost of energy consumption, -Fee for waste management, -Transportation cost-Production cost, Air emission-Liquid waste-Solid waste, -Toxic materials-Environmental incidents, Recycled materials-Energy consumption, -Worker’s motivation-Health working-Worker’s skills-Worker’s retribution |
| Mena and Schoenherr (2020) | The study explores the contagion effect of green sustainability in MtSCs. | Environmental pillar | Empirical study | Machinery, computer, electronic equipment, metal, food, tobacco, and Chemical Industries | Institutional theory | -Coercive mechanism by lead firm-Coercive mechanism by customers  |
| Sancha et al. (2019) | The paper investigates the significant role of nexus suppliers in providing higher sustainability for low-tier suppliers. | Environmental pillar | Empirical study | Electronic Industry | Nexus supplier theory | -Strong tie with suppliers-High visibility by lead firm |
| Mejias et al., (2019) | The study signifies the critical role of the traceability management system in assessing the suppliers’ performance for reaching higher sustainability within MtSCs. | Environmental and Social pillars | Multi-Criteria Decision Making (MCDM) | Fashion Industry | Multi-tier supply chain theory | -Social issues-Environmental issues-Supplier management |
| Jia et al. (2019) | The study highlights the concept of leadership in enhancing sustainability in MtSCs. | None | Empirical study | Food and furniture Industry | Multifactor leadership theory | -Leadership-Governance mechanism-Supply chain structure-Supply chain learning |
| Hannibal and Kauppi (2019) | The study uses the information processing theory to discuss how a third party can reduce social sustainability uncertainty. | Social pillar | Empirical study | Food industry | Information processing theory | -Freedom of association-Forced labour -Child labour-Abuse and harassment-Fair remuneration,-Health and safety-Traceability-Participation and transparency-Working hours-Solidarity |
| Gong et al. (2019) | The research has investigated how sustainability capabilities can enhance SSCM | Environmental pillar | Empirical study | Different Industries | Stakeholder theory | -Customer’s awareness-Stakeholder’s involvement-Sustainability capability |
| Darvish et al. (2019) | The research assesses the effect of operational decisions on economic and environmental aspects | Environmental and economic pillars | Mathematical formulation (Branch-and-cut algorithm) | None | None | -Decreasing the total cost-Minimizing distance-Minimizing emission |
| Grimm et al. (2018) | The research investigates the interrelationship of the Critical Success Factor regarding the trust and commitment in MtSCs. | None  | MCDM method  | Food Industry | Critical Success Factor theory | -Commitment-Trust-Supply know-how-Little geographical distance-Little cultural distance-Participation and involvement-Complying with sustainability standards |
| Gong et al. (2018) | The study investigates how multinational corporates coordinate their internal and external resources to learn sustainability. | None | Empirical study | Food and furniture Industry | Resource Orchestration Perspective (ROP) theory | - Supply chain structure-Governance mechanism- Supply chain learning |
| Awashti et al. (2018) | The research proposes a framework for selecting the most sustainable supplier and sub-supplier | Economic, Environmental and social pillars | Fuzzy hybrid MCDM method | None | None | -Economic, Quality of relationship, Environmental issues, Social issues-Global risk |
| Agyemang et al. (2018) | The research identifies and analyzes the most critical barriers to implement green sustainability in MtSCs. | Environmental pillar | Grey MCDM method  | Cashew Industry | None | -Top-level management commitment-Financial cost and constraints-Traceability system, Poor supplier’s commitment-Willingness of suppliers to exchange information-Low customer’s demands for green production-Low level of customer’s awareness -Certainty of economic benefits-National regulation and policy-Non-governmental agencies and NGO supports |
| Grimm et al. (2016) | The study explores the management of sub-suppliers regarding the compliance with cooperating social standards | Environmental and social pillars | Empirical study | Electronic and Food Industry | Institutional theory and resource dependence theory | -Public attention-Perceived risk of not complying with corporate social standards-Power channel to use punitive or incentive mechanism for sub-suppliers |
| Tachizawa and Wong (2014) | The study does an extended literature review to recognize the most effective factors to manage the sustainability of MtSCs. | Environmental pillar | Systematic literature review | None | None | -Power of lead firm to affect the suppliers-Stakeholder pressures-Industry type-Criticality of materials-Dependency of the lead firm and suppliers-Geographical distance-Knowledge resources |

The extensive literature review denotes that supply chain researchers have mostly put their efforts into assessing sustainability for direct or first-tier suppliers. They neglected the important role of sub-suppliers or lower-tier suppliers in enhancing sustainability for the supply chain network. As shown in Table 1, the most relevant studies regarding the sustainability of MtSCs has been published since 2014. The theme has received the highest attention by researchers in 2019 and 2020 such that the vast majority of papers have been published over this period, which makes the concept a trending topic.

Sustainability is comprised of three main pillars including economic, social, and environmental issues. The vast majority of studies considers limited numbers of sustainability pillars. The studies intend to concentrate on one or two pillars of sustainability for assessing the relevant factors. Tuni et al. (2020) consider environmental and social pillars concurrently for striking up a balance in sustainability. Venkatesh et al. (2020) focus on determining the drivers of social sustainability in MtSCs. Environmental and social pillars are the most pronounced in the previous studies while the economic pillar has received less attention. However, there are only two studies considering the three main pillars of sustainability within MtSCs simultaneously (Lopez and Ruiz-Bentez, 2020; Awashti et al., 2018).

The data collection and application of the proposed framework were carried out for developed countries and researchers intend to consider case studies and research context in developed countries (Govindan et al., 2021). Ventakesh et al. (2020) consider that social sustainability studies are mostly conducted within developed countries and there is a serious lack of researches in emerging economies.

The previous studies have collected data and applied the suggested framework for a specific industry. For instance, Sauer and Seuring (2020) have proposed a novel framework for identifying and assessing the challenges of sustainability in MtSCs in the mineral industry. Sancha et al. (2019) have investigated the significant role of nexus suppliers in providing higher sustainability for the electronic industry. The studies indicate that the suggested framework is applicable for a specific industry and cannot be extended for other industries. According to Luján-Ornelas et al. (2020), sustainability is a context-related concept, which means that its meaning depends on the context in which it is used. In layman’s terms, the useful definition should be created under a specific context. The textile industry is one of the most significant productive industries and everybody is engaged with the industry to some extent (Luján-Ornelas et al.,2020). The textile industry is one of the most influential manufacturing sectors in the global economy. On the flip side, it is one of the most polluting industries. The industry is comprised of very sophisticated supply chains that exert severe social challenges (Luján-Ornelas et al., 2020). Several studies have focused on assessing the sustainability of single-tier supply chains within the textile industry (Shiwanthi et al., 2018) but no studies have focused on the sustainability of MtSCs in this industrial sector. Thus, one of the main research gaps is:

* Absence of a potent framework for assessing the readiness status of sustainability pillars in MtSCs for the textile industry in emerging economies.

Additionally, the studies have proposed different factors for assessing the main pillars of sustainability. For instance, Tuni et al. (2020) and Sauer et al. (2020) both have focused on the important role of environmental, and social issues of sustainability. The first study highlights water, material and energy consumption as the main factors for the assessment of sustainability while the second study suggests governance policy and cooperation as the relevant factors. It is inferred that the sustainability concept is open to a variety of interpretation and the researchers still have difficulties unveiling a comprehensive set of factors for assessing sustainability within each pillar in MtSCs. The second important research gap is:

* Absence of a comprehensive set of critical factors for assessing the readiness status of sustainability pillars within MtSCs.

The vast majority of the researchers preferred to use the empirical study to recognize the potential association between selected factors and determine their preference within MtSCs (Adesanya et al., 2020; Grimm et al., 2016). Additionally, few papers have applied mathematical-based methods such as Multi-Criteria Decision Making (MCDM) to determine the priority and cause-effect relationship of factors in a network (Agyemang et al., 2018; Awashti et al., 2018). The outcome suggests a high practical implication for policymakers to pay attention to more important factors in enhancing sustainability. For instance, Agyemang et al. (2018) have used DEMATEL method to explore the cause-effect of factors for economic pillar. Awashti et al. (2018) have used the hybrid MCDM method to prioritize the factors in all three pillars of sustainability. The suggested frameworks are unable to be applied for potential case studies to determine the readiness status of factors and sustainability pillars aimed at informing managers regarding the readiness of their enterprise. The third research gap is:

* Absence of a framework for calculating the quantitative readiness value of sustainability pillars for MtSCs case studies.

Most of the suggested factors for the assessment of sustainability pillars are subjective and contain a high level of uncertainty. For instance, Adesanya et al. (2020) have proposed a framework for assessing sustainability in MtSCs. Top-level management is proposed as one of the factors, which is overwhelmed with ambiguity. The study has used Empirical study to evaluate its impact on SC, which is unable to capture the inherent vagueness of subjective factors. The next research gap is:

* Absence of proposed method for capturing existing vagueness in subjective factors of sustainability pillars in MtSCs.

**3. Research methodology**

The paper proposes a unique research methodology comprised of two main phases including an Empirical Study and Fuzzy Expert System.

An empirical study was conducted to make sure that all the selected factors were suitable for assessing the sustainability of MtSCs and had a strong effect on the concept of sustainability within MtSCs. Due to a high number of factors and differences between them, categorizing the factors facilitated their understanding and ease at further analysis. Therefore, the Exploratory Factor Analysis (EFA) method was applied to limit the factors and group them into limited constructs.

To make the construct applicable to different potential case studies, an expert system was proposed to make the categorized factors measurable for real phenomena. An expert system was proposed to measuring the readiness status of sustainability of each construct based on linguistic variables. Moreover, due to the existing ambiguity within some of the factors, the Fuzzy sets theory was proposed to capture the inherent vagueness. Figure 1 illustrates the main research methodology steps:

**First Step (Empirical study and Exploratory Factor Analysis):** Ensuring the effectiveness of the selected factors and categorizing them into limited groups.

**Second Module (Fuzzy Expert System):** Making the factors applicable for measuring the readiness status of sustainability of MtSCs.

**Figure 1.** Research methodology main steps

 In the first phase, the empirical study was applied to make sure that the selected factors had a strong impact on the sustainability of MtSCs. The empirical study was made of four steps, including designing a questionnaire, validating the questionnaire, data collection, and data analysis. The result determined the most effective factors on sustainable MtSCs as well as their categorization into limited numbers of constructs. In the second phase, a fuzzy expert system was designed for each construct, which was extracted from the first phase. The fuzzy expert system was proposed to make the framework applicable and practical for assessing the readiness status of the sustainability pillars in MtSCs in different case studies. Figure 2 shows the research methodology framework in detail:

2. Recognition of research gaps and determining research objectives

1. Extensive literature review on the concept of sustainability in MtSCs

3. Determining research questions

4. Designing questionnaire

5. Sample size selection

6. Pilot testing of a questionnaire

7. Final questionnaire modification

8. Online and offline data collection

9. Data screening and reaching usable data

10. Empirical analysis such as data reliability, validity, and factors categorization

11. Designing of the Fuzzy Expert System for assessing constructs

12. Validation of Fuzzy Expert System

13. Discussion of finding, theoretical and practical implications

14. Conclusion and future directions

**Figure 2.** Research methodology framework

**3.1. Designing a questionnaire**

Following the extensive literature review shown in Table 1, the most effective factors for the assessment of three main pillars of sustainability in MtSCs are extracted. For assessing the effectiveness of factors and categorizing them into limited constructs, a questionnaire is designed to collect respondents’ judgments about the importance of factors on the sustainability of MtSCs. The questionnaire is designed in simple and clear language to better convey the researcher’s message to respondents aimed at exercising sound judgments. The questionnaire is made of two sections. The first section seeks respondents’ demographic information such as name, gender, education, occupation. The second section is asked for the effectiveness of the factors on the sustainability of MtSCs on a set of five-point Likert scale from 1 (not Strongly important) to 5 (Strongly important).

**3.2. Validation of the questionnaire**

After designing the questionnaire, a pilot testing was conducted between eight experts active in the textile industry to leave their comments regarding the questionnaire’s quality such as the relevancy of factors, language and transparency of questions. Their comments are collected and further modification and revision were carried out to make the sentences more transparent and understandable as well as adding new factors. Based on the extensive literature review and the experts’ inputs, Table 2 shows the final list of factors for assessing sustainability in MtSCs with a brief description.

**Table 2.** The final list of factors

|  |  |  |
| --- | --- | --- |
| Factor | Description | Reference |
| Materials consumption | Since manufacturing companies use virgin raw material in the production chain from suppliers and sub-suppliers, thus, lead companies are supposed to minimize raw material consumption by modifying the production chain. | Lopez and Ruiz-Benitez (2020); Tuni et al. (2020) |
| Land occupation | It is referred to decreasing allocated land for providing raw materials and infrastructure settlement by lead company, suppliers, and sub-suppliers in MtSCs.  | Lopez and Ruiz-Benitez (2020); Tuni et al. (2020) |
| Water consumption | Manufacturing companies have a significant impact on the environment and water consumption is the main part of such an effect which is supposed to be minimized by actors in MtSCs. | Lopez and Ruiz-Benitez (2020); Tuni et al. (2020) |
| Energy consumption | Manufacturing equipment consumes a high amount of energy for production. Higher energy consumption has a direct effect on air and water pollution. Thus, lead firms and suppliers should minimize energy consumption for creating a sustainable environment. | Lopez and Ruiz-Benitez (2020); Tuni et al. (2020) |
| Solid waste | Manufacturing companies and their suppliers make a high amount of refuse and garbage, which devastate the environment. They are supposed to reduce or recycle solid waste as much as possible. | Lopez and Ruiz-Benitez (2020); Tuni et al. (2020) |
| Governance structure | Establishing rules, structure, and institutions that guide and control lead firm, suppliers, and sub-suppliers behaviour within MtSCs, have a direct impact on sustainability. | Jia et al. (2019); Sauer and Seuring (2019) |
| Cooperation | Enhancing cooperation and collaboration between lead firm, suppliers, and low-tier suppliers can reduce fragmentation and increase the integration within MtSCs. Cooperation can enhance the MtSCs sustainability. | Jia et al. (2019); Sauer and Seuring (2019) |
| Strategic partnership | A strategic partnership is defined as setting up one or more contracts to assure commitment and long-term association between lead firms, suppliers, and sub-suppliers. | Venkatesh et al. (2020); Sancha et al. (2019) |
| Ethical standards | Lead firms are supposed to make a set of principles to push suppliers and sub-suppliers to behave and communicate underlying moral values in MtSCs. | Adesanya et al. (2020); Hannibal and Kauppi (2019) |
| Top-level management support | Top-level management support and commitment are defined as management tendency and inclination to comply with sustainability practices within MtSCs. | Adesanya et al. (2020); Agyemang et al. (2018) |
| Traceability System | The system enables lead firms to easily monitor and investigate working conditions, employees’ rights, environmental and economic practices conducted by suppliers and low-tier suppliers in MtSCs. | Fraser et al. (2020); Agyemang et al. (2018) |
| Incentives and penalties  | Setting up incentives for sticking to sustainable practices such as free training, free technical advice, and support for suppliers and sub-suppliers. | Agyemang et al. (2018); Grimm et al. (2016) |
| Training | Holding regular workshops for suppliers and sub-suppliers to train and equip them with practical sustainable practices and having direct communication with them. | Govindan et al. (2021); Adesanya et al. (2020) |
| Code of conduct | It is referred to setting up criteria for assessing suppliers and sub-suppliers behavior within MtSCs. | Adesanya et al. (2020); Venkatesh et al. (2020) |
| Trust and commitment | It is referred to existing trust between lead firms and customers. Moreover, it is also considered as the trust and commitment between lead firms and suppliers and sub-supplies. | Mejias et al. (2019); Grimm et al. (2018) |
| Knowledge sharing and transparency | It is defined as sharing organizational knowledge between suppliers and sub-suppliers to increase transparency. It is referred as having common access to product-related information by lead firms, suppliers, and sub-suppliers. | Fraser et al. (2020); Tachizawa and Wong (2014) |
| Cost of material purchasing | It is referred to as decreasing the total cost of purchasing material, which is seen as an important factor for enhancing sustainability. | Lopez and Ruiz-Benitez (2020); Darvish et al. (2019) |
| Cost of energy consumption | The factor is made of two main dimensions of power consumption and usage time. Decreasing both dimensions by suppliers and sub-suppliers has a positive effect on higher sustainability in MtSCs. | Lopez and Ruiz-Benitez (2020); Darvish et al. (2019) |
| Fee for waste management | It is referred to as reducing cost for implementing required actions to conduct waste management by suppliers and sub-suppliers. | Lopez and Ruiz-Benitez (2020); Darvish et al. (2019) |
| Transportation cost | It is referred to as reducing transportation cost in MtSCs for facilitating product mobility from low-tier suppliers to suppliers and lead firms within MtSCs chain. | Lopez and Ruiz-Benitez (2020); Darvish et al. (2019) |
| Recycled materials | Increasing the use of recycled materials by sub-suppliers and suppliers within the production process. | Lopez and Ruiz-Benitez (2020) |
| Worker’s motivation | It is referred to worker’s passion and interest in abiding by sustainable standards and principles.  | Hannibal and Kauppi (2019); Lopez and Ruiz-Benitez (2020) |
| Health and safe working | It is referred to as providing safe working conditions for workers to work without being exposed to potential danger within MtSCs based on safety standards. | Lopez and Ruiz-Benitez (2020); Hannibal and Kauppi (2019) |
| Worker’s skill | It is defined as employing highly competent workers to fulfil sub-suppliers and supplier’s sustainability practices efficiently. | Lopez and Ruiz-Benitez (2020); Hannibal and Kauppi (2019) |
| Leadership | It is referred to the significant role of supply chain leaders in influencing suppliers and sub-suppliers to pursue sustainability practices by their investment and using the arms-length mechanism. | Jia et al. (2019); Govindan et al. (2021) |
| Learning | It is defined as the collaboration of organizational members jointly to create collective knowledge and learn to collaborate, share, and create knowledge.  | Jia et al. (2019); Gong et al. (2018) |
| Human rights | It is referred to as observing the fundamental human rights of workers in sub-suppliers, suppliers, and lead firms. | Lopez and Ruiz-Benitez (2020); Hannibal and Kauppi (2019) |
| Diversity | It is defined as purchasing virgin raw materials from minor or female-owned sub-suppliers and suppliers. | Hanni ball and Kauppi (2019) |
| Customer awareness | Customer’s awareness regarding the concept of sustainability motivates lead firms to practice sustainable practices within MtSCs. | Gong et al. (2019); Agyemang et al. (2018) |
| Geographical distance | It is referred to the physical distance between lead firms, suppliers, and sub-suppliers which is supposed to be as little as possible. Little geographical distance has a direct impact on sustainability. | Tachizawa and Wong (2014) |
| Cultural distance | It is referred to the difference in the culture of suppliers, sub-suppliers, and lead firm in MtSCs, which is supposed to be as little as possible. Less cultural difference has a direct effect on MtSCs sustainability. | Grimm et al. (2018) |
| Supply-know-how | It is referred to the comprehensive knowledge of lead firms about supply chain including process, characteristics of sourcing marketing, and procured product. | Grimm et al. (2018) |
| Participation of direct suppliers | The involvement of direct suppliers as a mediator for coordinating and managing sub-supplier play a crucial role in enhancing sustainability. The coordination of sub-suppliers is not the responsibility of the lead firm. Direct suppliers should be involved as well. | Hannibal and Kauppi (2019); Grimm et al. (2018) |
| Flexibility | It is referred to as sub-suppliers and supplier’s flexibility in adopting sustainable initiatives in their operations. | Venkatesh et al. (2020); Agyemang et al. (2018) |
| Dependability | It is referred to the extent of dependency between sub-suppliers, suppliers, and lead firm. Higher dependency helps more collaboration between actors and reaching higher sustainability in MtSCs. | Tachizawa and Wong (2014) |
| Speed of delivery | It is referred to as the required time for delivering raw materials to suppliers and lead firms. The factor also assesses the delivery time of giving final products to customers. | Govindan et al. (2021); Venkatesh et al. (2020) |
| National regulation and policy | It is referred to as relevant regulation and policy to compel sub-suppliers and suppliers to comply with sustainability practices within MtSCs. | Govindan et al. (2020); Agyemang et al. (2018) |
| Stakeholder pressure | It is referred to as the lead firm’s visibility by media and the public. Being the center of attention urges lead firms to take proactive behavior to follow up sustainability behavior in MtSCs.  | Gong et al. (2019);Tachizawa and Wong (2014) |
| Innovation | It is referred to as applying new and modified processes, techniques, technology and system to enhance the main pillars of sustainability within MtSCs. | Adesanya et al. (2020); Orji et al. (2020) |
| Emission to air | It is referred to as the number of gases and particles are emitted by manufacturing equipment of sub-suppliers, suppliers and lead firms. Emission to air should be as little as possible to have a less destructive effect on the environment. | Lopez and Ruiz-Benitez (2020); Tuni et al. (2020)  |

**3.3. Data collection**

Several industries have initiated to adjust their performances and business with a sustainable perspective. The textile industry has gained remarkable attention recently to enhance sustainability in its complicated supply chain (Li et al., 2020). Sustainability is so crucial for the textile industry because its production creates a lot of pollution into the environment (Shen et al., 2020). Several academics and practitioners have investigated the sustainability of the textile industry in developed countries. However, because the vast majority of textile production and processing are located in developing countries, these concepts are in relevant infancy in emerging economies and developing countries (Li et al., 2020). Thus, the population selected for data collection was from the Iranian textile Industry. The respondents were selected from seven textile manufacturing companies located in three industrial megacities of the Islamic Republic of Iran. The companies are active in texturizing, high pile and circular knitting. 152 respondents’ data was collected. According to Yap et al. (2020), a sample size exceeding 100 responses is normally adequate and suitable to conduct reliable statistical analysis. Due to keeping the company’s privacy and confidentiality, the companies’ names were omitted and represented with a letter of the English Alphabet. The data collection and analysis took almost seven months. The study was initiated on the 20th of July in 2020 and finalized on the 18th of February in 2021. Table 3 displays the demographic information of respondents.

**Table 3.** The demographic information of respondents

|  |  |  |  |
| --- | --- | --- | --- |
| **Characteristics** | **Categorization** | **Number** | **Percentage** |
| Company | A | 27 | 18% |
| B | 32 | 21% |
| C | 12 | 7% |
| D | 19 | 12% |
| E | 9 | 5% |
| F | 23 | 15% |
| G | 30 | 22% |
| Gender | Female | 31 | 21% |
| Male | 121 | 79% |
| Education | Bachelor | 101 | 66% |
| Master | 47 | 27% |
| PhD | 4 | 5% |
| Career | Operative staff | 112 | 73% |
| Project manager  | 32 | 21% |
| Senior manager  | 8 | 6% |
| Work experience | Less than 5 years | 54 | 35% |
| Between 5 and 10 years  | 61 | 40% |
| More than 10 years | 37 | 25% |

**3.4. Data analysis**

Providing strong theoretical support for the current study, an empirical study is suggested to ensure that the selected factors have a strong impact on sustainable MtSCs. In this study, the collected data reliability conducted by computing Cronbach Alpha. The result can determine the validity and reliability of the collected data whether can be trusted for further statistical investigation then EFA is conducted to check the effectiveness of factors on sustainability of MtSCs as well as reducing the number of factors into limited constructs (Znaidi and Gherib, 2020). EFA can easily unveil potential correlations between different unrelated factors (Makkar and Singh, 2018). IBM SPSS Statistics 25 software is selected to conduct the empirical study. After data collection, the entire data reliability is conducted by checking the Cronbach Alpha.

Checking data consistency by Kaiser– Meyer–Olkin (KMO) method (More than 0.5)

Checking data reliability by Cronbach Alpha (More than 0.7)

Data reliability

Sample size adequacy

Checking data correlation by Bartlett’s test of sphericity method (p < 0.05)

Categorizing variables by Principal Component Analysis (PCA) with VARIMAX rotations technique

Variables’ loading factor > 0.4

Omitted from the list

Exploratory Factor Analysis (EFA)

Yes

Checking the unidimensionality of the loading factor

No

Yes

Face validation for choosing a suitable name for each construct

**Figure 3.** Main empirical study phase

The result should exceed 0.7 to make sure that the collected data are reliable and can be used for further statistical investigation (Yap et al., 2020). The Cronbach alpha for the current research was calculated as 0.899 for all factors in the questionnaire, which denotes high data reliability. Prior to applying EFA method, there are two requirements for checking the sample size adequacy, which is assessed by Kaiser-Meyer-Olkin (KMO) and Bartlett’s test of sphericity methods. They are both conducted to check the sample size adequacy for conducting EFA method. KMO value should be greater than 0.5 (Aggarwal and Singh, 2020). For Bartlett’s test, the value should be significant (p < 0.05) (Aggarwal and Singh, 2020). The KMO test was calculated as 0.735 and Barlet’s test was significant as p-value was 0.000 which is lower than 0.05. Figure 3 shows the main empirical study procedures. The EFA is used by Principal Component Analysis (PCA) with VARIMAX rotations. Applying the PCA and VARIMAX rotations and Eigenvalue greater than one creates seven constructs with a total of 76.14 percent variance (Which should be greater than the minimum value variance of 60% for satisfactory factor analysis) (Yap et al., 2020). Factor rotation is also applied to a better understanding of all factors loading which is supposed to be greater than 0.4 to denote reasonable communalities (Asghar et al., 2020). Table 4 shows the loading factor and the variance value:

**Table 4.** Factor loading and variance value

|  |  |  |  |
| --- | --- | --- | --- |
| **Group** | **Factors** | **Loading factor** | **Variance (%)** |
| Environmental issues (α = 0.756) | -Recycled materials-Emission to air-Materials consumption-Water consumption-Energy consumption-Solid waste-Land occupation | 0.9210.9110.8900.8210.8110.7240.753 | 15.21 |
| Economic issues (α = 0.823) | -Cost of material purchasing-Cost of energy consumption-Transportation cost-Fee for waste management | 0.9110.8410.8310.723 | 13.19 |
| Policy and governance(α = 0.714) | -Governance structure-National regulation and policy-Ethical standards-Code of conduct**-Speed of delivery**-Incentives and penalties  | 0.8840.8240.8130.756**0.714**0.635 | 12.63 |
| Participation(α = 0.863) | -Trust and commitment-Cooperation-Strategic partnership-Participation of direct suppliers-Flexibility**-Speed of delivery**-**Dependability** | 0.9650.9350.8250.7250.702**0.689****0.326** | 10.19 |
| Social issues(α = 0.801) | -Health and safe working-Worker’s motivation-Worker’s skill-Human rights-Cultural distance-Geographical distance-Diversity | 0.8630.8230.8110.7760.7240.6210.603 | 9.25 |
| Transparency(α = 0.725) | -Knowledge sharing and transparency-Customer awareness-Learning-Supply-know-how-Traceability system-Training-Innovation | 0.8560.8450.8320.8120.7210.7030.683 | 8.11 |
| Leadership and support(α = 0.845) | -Top-level management support-Leadership-Stakeholder pressure | 0.8560.7560.721 | 7.56 |
| Cumulative variance |  |  | 76.14 |

As shown in Table 4, The vast majority of factors managed to reach the loading factor more than the threshold (more than 0.4) to be accepted other than “Dependability” whose loading factor is 0.326 lower than the accepted value. Thus, the factor was omitted from group 4. The next step was checking the cross-loading factor to check the unidimensionality of factors. The most optimal structure is created when each loading factor appears on a single construct. If the cross-loading factor exists on multiple constructs, the factor is going to be omitted from the list. In this research, the factor “Speed of delivery” appeared on both “Group 3” and “Group 4”. Thus, the factors are omitted from the effective factor. Moreover, the Cronbach Alpha for each construct was calculated to check the internal consistency. The Cronbach alpha value ranges from 0.714 to 0.863 (should be more than 0.7 to be accepted) to check internal consistency within each relevant construct. After conducting PCA and rotation technique to categorize the factors into the limited number of groups and checking internal construct’s reliability, face validation is required to interpret the categorized factors with an appropriate name, which conveys the relevant factors concept. After evaluation of all relevant factors in each construct, a meaningful name is assigned to each construct. Table 4 shows the assigning name for each construct with Cronbach Alpha (α) value.

**3.5. Fuzzy sets theory**

Zadeh proposed fuzzy sets theory in 1965 in order to deal with existed uncertainty in real-world phenomena by using mathematical formulation and modelling (Xu et al., 2019). The theory is able to model inherent ambiguity within subjective concepts and human judgments in problems (Xu et al., 2019; Khan et al., 2018).

Each member of fuzzy set theory is presented by a membership function denoted by (Asees Awan and Ali, 2019). It can take a value between zero and one. The higher value determines the higher dependency on the set. Fuzzy numbers are recognized by a membership function. There are different types of fuzzy numbers including triangular, trapezoidal and Gaussian (Majumdar et al., 2020; Ghorbani et al., 2013).

The triangular fuzzy number is the most common use fuzzy number due to straightforward computation and high precision. The number is made of three boundaries such lower boundary, median boundary and upper boundary .The membership function of fuzzy triangular number is determined by (Majumdar et al., 2020; Ghorbani et al., 2013):

 (1)

Table 5 denotes the mathematical operations on two fuzzy triangular numbers and (Majumdar et al., 2020; Ghorbani et al., 2013):

**Table 5.** Mathematical operations

|  |  |  |
| --- | --- | --- |
| **Outcome** | **Operations**  | **No.** |
|  | Sum | 1 |
|  | Subtraction | 2 |
|  | Multiply | 3 |
|  | Multiplication of positive crisp number (k) into fuzzy number | 4 |
|  | Multiplication of negative crisp number (k) into fuzzy number | 5 |

**3.6. Fuzzy Expert System**

An expert system is a computing system being able to represent and reason the accumulated knowledge. Applications of the expert system have been increasing drastically over the past years. Knowledge-oriented processing of the expert system is the main outstanding and distinguishing feature comparing to other methods operating following collected data (Hamedan et al., 2020). An expert system can quantify information by applying if-then rules base (Khan et al., 2018). The expert system is able to provide useful advice for policymakers and managers to make a better decision and provide many useful pieces of advice for policymakers for enhancing sustainability in MtSCs comparing to statistical and mathematical modelling. The outcome denotes a crisp number and linguistic variables for each construct to provide a clear picture of the sustainability in MtSCs. The information can be so beneficial for managers and policymakers to make the right strategic decisions for reaching higher sustainability in all pillars and competitive advantages. Using fuzzy triangular numbers as expert system input can model the existed uncertainty in expert’s judgments in setting rules, which leads to increased accuracy and precision of outcome (Hamedan et al., 2020; Fasanghari and Montazer, 2010).

A fuzzy expert system was designed for making decision following IF-THEN rules. The input is based on the collected expert’s knowledge, which has been categorized based IF-THEN rules in the knowledge base. Fuzzy expert system is comprised of knowledge-based rules, inference engine, fuzzifier and defuzzifier (Mahanta et al., 2020; Fasanghari and Montazer, 2010). Figure 4 shows the main expert system components (Mahanta et al., 2020):

Crisp Output

Defuzzifier

Inference engine

Crisp Input

Fuzzifier

Knowledge base (IF-Then rules)

**Figure 4.** Fuzzy expert system components

Since there are seven constructs following factors categorization, seven fuzzy expert systems are designed for each construct. Each fuzzy system can illustrate the readiness status of case studies in each construct.

**3.6.1. Fuzzification**

Fuzzification is the process of transforming the crisp value of the input into fuzzy numbers. The input can be set by measuring sensor and hardware or by users. If the input consists of uncertainty, the input’s form is most probably is fuzzy. If the input stems from hardware or sensor, the input is a crisp number, which can be deffuzified into fuzzy number. Singleton fuzzification method was proposed to accelerate the fuzzy expert system calculation (Shokouhyar et al., 2019). Since no studies have addressed the sustainability of MtSCs within Textile Industry, there was a dire need to determine triangular fuzzy numbers for each factor. Therefore, five textile industry experts, who were comprised of three academicians and two industrialists, were invited to allocate specific fuzzy triangular numbers for each factor. After the all-out agreement between experts, the final numbers were determined. The demographic information of the experts are presented in Appendix 1. Table 6 denotes the fuzzy triangular numbers for fuzzification of environment linguistic factors:

**Table 6.** Fuzzy linguistic factors for environmental issues

|  |  |  |
| --- | --- | --- |
| **Factor** | **Linguistic Factors** | **Fuzzy triangular number** |
| Materials consumption | LowMediumHigh | (0,1,2)(1,2,3)(2,3,4) |
| Land occupation | LowMediumHigh | (0,2,4)(1,3,5)(3,5,7) |
| Water consumption | LowMediumHigh | (0,1,2)(1,2,3)(2,3,4) |
| Energy consumption | LowMediumHigh | (0,1,2)(1,2,3)(2,3,4) |
| Solid waste | LowMediumHigh | (0,1.5,3)(1,2.5,4)(2,3.5,5) |
| Emission to air | LowMediumHigh | (0,1,2)(1,2,3)(2,3,4) |
| Recycled materials | LowMediumHigh | (0,1,2)(1,2,3)(2,3,4) |

The details of the fuzzification of other factors into fuzzy triangular numbers are mentioned in Appendix 1. Figure 5 shows the simulation of the linguistic triangular fuzzification of environmental factors in Matlab 2018b:

**Figure 5.** Fuzzy triangular numbers

**3.6.2. Fuzzy inference engine and knowledge base**

The inference engine is driven by IF-THEN rules in the knowledge base extracted from experts’ judgments. and inference algorithm was applied in the fuzzy inference process. Such a method is the most common use in the fuzzy expert systems in different applications. The method was used for two associations and delineated on Cartesian products and which results in new association defined on the product space . The new association delineated by (Fasanghari and Montazer, 2010):

 (2)

Where and determine the and operators respectively. In the method, the operator is applied for AND conjunction and is applied for OR disjunction. For calculation of membership in the clause, there are three common types of inference engines including Sugeno, Mamdani and Tsukamoto (Khan et al., 2018). Since Mamadani is the most common inference engine in the literature review, it was selected for the fuzzy experts (Fasanghari and Montazer, 2010):

 (3)

Figure 6 denotes the IF-THEN rules in Matlab2018b for environmental factors:



**Figure 6.** Fuzzy expert system rules in Matlab software

**3.6.3. Deffuzification**

Since the fuzzy expert system result is in fuzzy format, it is required to convert them into crisp numbers to be understandable for users. There are different methods, which can be applied to deffuzify the final results such as maximum, center of gravity and average height. In this research, center of gravity (COG) was applied to reach to crisp result of the fuzzy expert system. The method is so common for converting the fuzzy results into a crisp number. The deffuzification calculation is computed by (Shokouhyar et al., 2019; Fasanghari and Montazer, 2010):

 (4)

The fuzzification value is compared with the predefined fuzzy triangular numbers. The highest coverage with the predefined fuzzy triangular number indicates the right linguistic variables (Low, Medium and High) (Shokouhyar et al., 2019). Table 7 shows the triangular deffuzification linguistic variables:

**Table 7.** Fuzzy linguistic factors for output deffuzification

|  |  |
| --- | --- |
| **Linguistic variable** | **Fuzzy triangular number** |
| Low | (0,1,2) |
| Medium | (1,2,3) |
| High | (2,3,4) |

**4. Readiness status (Case Study: Iranian textile-manufacturing company)**

Making the framework applicable and measurable for different case studies requires the use of a quantitative method. Fuzzy expert system is one of the strongest quantitative methods to assess the readiness status of case studies. The output is a useful dashboard to enable policymakers to monitor the direct and low-tier suppliers’ behaviour as well as recognizing the strength and weakness of sustainability in MtSCs. The designed fuzzy expert system applied for an Iranian textile manufacturing company as the proxy of developing countries to assess the readiness status of each construct. The company has 94 staff, which produce fabric and tissue for Iranian megacities such as Tehran, Isfahan, Mashhad and Shiraz. The input data was collected from 13 experts working for the company. The experts have more than 15-year experience in manufacturing textile products such as cotton and silks. They are working as technical and commercial managers in the company. The experts were invited for face-to-face meetings and different questions were asked directly following the factors in each construct. Their judgments regarding each factor changed into the predefined linguistic variables and consider as an input of fuzzy expert system.

The data was fuzzified into triangular fuzzy numbers to be analysed by an inference engine. The fuzzy expert system output was deffuzified into a crisp number to be understandable for policymakers and managers. Table 8 shows the readiness status of the textile-manufacturing company:

**Table 8.** Readiness status of the Iranian textile company

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No.** | **Construct** | **Readiness Score (fuzzy number)** | **Deffuzification** | **Linguistic factors** | **Ranking** |
| 1 | Environmental issues | (0.1,0.13,0.23) | 0.17 | Low | 7 |
| 2 | Economic issues | (1.2,1.8,2.4) | 1.47 | Medium | 5 |
| 3 | Policy and governance | (0.4,0.8,1.6) | 0.93 | Low | 6 |
| 4 | Participation | (1.4,2.3,2.9) | 2.28 | Medium | 3 |
| 5 | Social issues | (1.4,1.9,2.5) | 1.84 | Medium | 4 |
| 6 | Transparency | (1.9,2.6,3.1) | 2.65 | High | 1 |
| 7 | Leadership and support | (1.3,2.4,3.4) | 2.57 | High | 2 |

As shown in Table 8, “Transparency” construct has received the highest readiness with a total readiness score of 2.65. The company conducted efficient knowledge sharing practices between staff and suppliers by providing common access to information for all actors in MtSCs. The lead firm’s customers are not well aware of the main pillars of sustainability and do not care about the sustainability of MtSCs actors. The lead firm applied a strong traceability system to expand its vision regarding the behaviour of low-tier suppliers about the main pillars of sustainability. The lead company has also modified its process, production activities and the type of communication with sub-suppliers and suppliers to mitigate the potential damages to sustainability.

“Leadership and support” construct is in high readiness with a total readiness score of 2.57. The lead firms as a leader company in the textile industry exert a strong impact on suppliers and sub-suppliers to comply with sustainability practices. Moreover, the top-level management is supportive of sustainable activities in MtSCs, thus there is strong support and commitment to apply sustainable standards within operations.

“Participation” construct is at medium level with a total readiness score of 2.28. There is reasonable cooperation between the lead firm, suppliers and sub-suppliers to deliver the appropriate products to customers. However, there is no strategic partnership between actors in the form of an official contract to strengthen long-term collaboration. The suppliers show dynamic gestures to push low-tier suppliers to abide by sustainable protocols while sub-suppliers are unlikely to show flexibility in adopting sustainable initiatives accordingly.

“Social issues” are also in the medium level with a total readiness score of 1.84. There are high ambitions among workers to apply sustainable behaviours in MtSCs. The working condition is well- observed by all actors to create a safe and healthy environment for workers. Human rights such as equal pay based on worker’s skills are also well-considered. Due to the congregation of workers from different cities and various cultural background, there are high cultural differences between workers, which might have a serious effect on the development of sustainability. Diversity is not observed when it comes to employment. Managers tend to hire men rather than women for vacant positions.

“Economic issues” is at the medium level with a total readiness score of 1.47. The lead firm pays a high cost for purchasing virgin material from low-tier suppliers. However, the lead firm tries to optimize the energy consumption by optimizing the two dimensions of the factor including usage time and power cost. Due to the high cost of waste management infrastructure, the lead firm avoids applying a waste management system to reduce garbage production. Transportation cost is relatively high, which impedes product mobility within MtSCs.

“Policy and governance” construct is at a low level with a total readiness score of 0.93. There are no concrete rules and structure for guiding MtSCs actors to comply with sustainability practices. Moreover, the lead firm has not set up any principles for suppliers and sub-suppliers to behave and communicate based on moral values. The lead firm has not established any incentive or penalties policy regarding the sustainability behaviour of MtSCs actors. The government did not legislate regulation and strategic policy for increasing sustainability for the textile-manufacturing industry in MtSCs.

“Environmental issues” is at a low level with a total readiness score of 0.17. Due to the low cost of water, energy and raw materials, the lead firm tends to consume a huge amount of virgin raw materials, water and energy. Moreover, the lead firm and suppliers emit a high amount of gasses into the air and cause high pollution. The MtSCs actors avoid using recycled materials to reuse them in the production line.

Figure 7 shows the readiness score of the constructs:

**Figure 7.** Readiness score of constructs

**4.1. Fuzzy Expert System Validity**

The fuzzy expert system was validated based on the expert’s judgments. The result from the applied fuzzy expert system for the textile manufacturing company in Iran was presented to the same textile manufacturing experts to judge and make their comments on the results. Table 9 shows the level of expert’s satisfaction with the outcome:

**Table 9** Expert’s satisfaction with the result

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  ConstructRespondents | Environmental | Social issues | Procedure management | Economy | Leadership support | Trust and loyalty |
| Top-level management | 92.2% | 89.32% | 93.21% | 87.85% | 86.32% | 96.12% |
| Staff | 82.78% | 86.96% | 89.29% | 91.55% | 89.31% | 92.47% |
| Suppliers | 85.29% | 93.45% | 91.87% | 84.21% | 82.36% | 82.67% |
| Customers | 91.22% | 93.73% | 85.23% | 93.37% | 86.24% | 87.12% |
| Total average | 87.87% | 90.86% | 89.9% | 89.24% | 86.05% | 89.59% |

The final assessment shows that the vast majority of respondents are highly satisfied with the outcome, which shows high system reliability and validity to be extended for other potential case studies. Thus, the fuzzy expert system can be extended for other textile-manufacturing companies in emerging economies.

**5. Discussion**

In this study, a novel data-driven framework was proposed to assess sustainability in MtSCs. The framework can evaluate wider aspects of sustainability’s pillars by considering seven constructs and relevant factors. The most significant constructs are “Environmental issues”, “Economic issues”, “Policy and governance”, “Participation”, “Social issues”, “Transparency”, “Leadership and support”.

The constructs and relevant factors can be used as critical factors for assessing the three main pillars of sustainability in MtSCs. The previous studies have introduced limited factors for the sustainability of the supply chain while considering the direct supplier (avoid recognition of downstream suppliers). Venkatesh et al. (2020) proposed a framework for assessing the sustainability of MtSCs for the Apparel industry. The study only considered the social aspect of sustainability. On the other hand, Sancha et al. (2019) considered the behaviour of nexus suppliers for improving sustainability in the electronic industry. The study considered the environmental aspect of sustainability within MtSCs. The previous studies contribute to recognizing more factors in the single-tier SC. While the current study has contributed to introducing a comprehensive set of factors to assess wider aspects of sustainability pillars in MtSCs. In line with RBV theory, the assessment of the three main pillars of sustainability through the extracted factors, which are comprised of behavioural and relational aspects of both internal and external actors, in MtSCs is seen as a strategic resource and capability. Being equipped with such information enables lead firms to have better performance and reach to sustainable competitive advantage.

The first construct with the total variance value of 15.21% is environmental issues, which is responsible for minimizing energy, land and water consumption as well as increasing recycling practices for reaching more sustainability in MtSCs. Since there is a high shortage of raw materials for textile-manufacturing products, it is highly important to modify the production chain and setting up initiatives for suppliers and sub-suppliers to minimize the usage of raw materials in the production line. Land occupation focuses on the amount of area seized by MtSCs actors to manufacture a product. Thus, lead firms should have an appropriate strategy to decrease land occupation as much as possible to avoid further destruction of the environment. Tuni et al. (2020) applied the same strategy for minimizing steel usage as raw material and land occupation for the machinery industry, focal firm pushed second-tier supplier to decrease the raw material (steel) and land occupation as much as possible by creating an all-out agreement framework. The outcome denoted that such two operations contributed to the higher sustainability of MtSCs within the machinery industry. Textile equipment requires a high amount of energy and water to manufacture final products. Thus, the shortage of water and energy requires initiatives and practical actions to minimize them within MtSCs. Textile production lines make a lot of garbage and toxic gas into the environment, which is likely to ruin the nature and environment. Thus, using recycled materials by suppliers and sub-suppliers is so helpful for decreasing the destructive impact of refuse and gas emission in the environment. Drawing upon the RBV theory, considering environmental issues within supply chain operations is critical for lead firms to turn out to be an eco-friendly company in their operations and conducting better performance. This leads to reaching a more sustainable competitive advantage (Li et al., 2020). The high importance of environmental issues for improving sustainability in MtSCs was highlighted by Tuni et al. (2020).

The second important construct is economic issues with a total variance value of 13.19%. The construct mostly concentrates on decreasing the total cost of the production process from low-tier suppliers to lead firms. Textile-manufacturing infrastructure uses a huge amount of virgin raw materials, which are procured by sub-suppliers. Thus, lead firms should apply strategic initiatives to decrease such costs. Energy consumption is relatively high in textile manufacturing comparing to other industries. The cost of energy consumption should be minimized to reach higher sustainability. Lopez and Ruiz-Benitez (2020) reached the same outcome for the aerospace industry. They proved that decreasing the cost of raw materials and energy consumption has a direct effect on increasing the sustainability of MtSCs within the aerospace industry. They also proved that decreasing the cost of transportation causes higher mobility in supply chain circles and leads to higher sustainability. Textile actors such as sub-suppliers and suppliers allocate a significant budget for goods transportation. The high cost of transportation impedes the mobility of raw materials and production in MtSCs network, which is supposed to be minimized for higher sustainability. In line with the RBV theory, minimizing the cost of transportation, energy consumption and material purchasing is a significant capability for lead firms to decrease the total cost of manufactured products compared to other rivals for reaching sustainable competitive advantages. The significant importance of the economic construct in increasing sustainability in MtSCs was highly supported by López and Ruiz-Benítez (2020) and Sauer and Seuring (2020).

“Policy and governance” is the third construct with a total variance of 12.63%. The presence of governance structure including rules and institutions contributes to creating coherency between low-tier suppliers and direct suppliers to behave and cooperate more efficiently following sustainable practices. Venkatesh et al. (2020) applied governance structure within the apparel industry to see the level of sustainability within MtSCs. The findings show that governance structure makes the sub-suppliers bide by compliance and operates more coherently together as well as bridging the gap between the sub-suppliers and direct suppliers. The outcome shows that governance structure enhances the level of sustainability within MtSCs. Additionally, setting up predominated moral values mostly by lead firms urge MtSCs actors to behave under ethical principles. There is a dire need to use strong leverage for encouraging or discouraging MtSCs actors, which can take place by incentive and penalties policy including free technical advice and exerting financial fine for law-breakers. National regulation is also seen as effective leverage to compel MtSCs actors to abide by standards and regulations. From the RBV perspective, forming sustainable governance and policy in MtSCs makes actors work coherently to develop their capability and give lead firm synergistic benefits as a competitive advantage (Whitelock, 2015). The significant importance of governance and policy in increasing sustainability within MtSCs was strongly highlighted by Sauer and Seuring (2020) and Venkatesh et al. (2020).

“Participation” is the fourth construct with a total variance of 10.19%. The construct concentrates on paving the way for constructive collaboration and cooperation between sub-suppliers, suppliers and lead firm. Cooperation tends to reduce the existing fragmentation between MtSCs actors and increase more integration. Strategic partnership in the form of an official contract between actors is so helpful for more participation. Venkatesh et al. (2020) considered a strategic partnership for the apparel industry as a great tool for pushing sub-suppliers to stick to sustainable principles and compliance. The findings also proved that sustainability is directly affected by having a strategic partnership between focal company and sub-suppliers. Trust and commitment is a game-changing factor, which assures participation, and cooperation in MtSCs. Grimm et al. (2018) have investigated the effect of trust and commitment on the sustainability of MtSCs in the food industry. The findings suggested that trust and commitment cause suppliers and sub-suppliers to participate more actively to fulfil their requirements which leads to higher sustainability of the entire supply chain. Direct suppliers always play a dual role with lead firm and sub-suppliers. Thus, its involvement is so critical for facilitating sub-suppliers and lead firm for reaching sustainability. The importance of the participation construct in increasing sustainability within MtSCs was supported by Hannibal and Kauppi (2019) and Grimm et al. (2018).

“Social issues” is the fifth construct with a total variance of 9.25%. The construct focuses on the MtSCs actor’s responsibilities to observe social practices aimed at enhancing sustainability. The main prerequisite of applying social practices is assessing the worker’s interest and motivation about following up sustainable practices. Providing a safe working environment and observing worker’s health is all actors’ social responsibility in MtSCs. Lopez and Ruiz-Benitez (2020) assessed the impact of safety and health working conditions on sustainability within MtSCs in the aerospace industry. Their findings proved that the factors should be considered for distant upstream suppliers where workers are under pressure. Findings show that observing the healthy working condition of workers contributes to leveraging sustainability within MtSCs. Since MtSCs is comprised of sub-suppliers, suppliers and lead firm, thus the worker’s cultural background and geographical distance are different, which causes to increase in fragmentation between actors. There is a dire need to employ workers from similar cultural backgrounds and close geographical distances to reach higher sustainability. Grimm et al. (2018) considered cultural and geographical distance in the food industry within MtSCs. The findings showed that higher cultural distance between sub-suppliers and suppliers avoids long-term collaboration between actors and causes prolonging tensions between staff with various background. Moreover, high geographical distance relegates the commitment between long-distance sub-suppliers and suppliers.

Drawing upon RBV theory, considering social issues by all actors in MtSCs has a constructive impact on a lead firm’s performance, which is seen as a strategic resource for creating and developing intangible organizational resources to reach sustainable competitive advantage (Nardo and Veltri, 2013). The high importance of social issues is supported by López and Ruiz-Benítez (2020) and Sauer and Seuring (2020).

“Transparency” is the sixth construct with a total variance of 8.11%. The construct focuses on facilitating knowledge sharing between actors and increasing learning through MtSCs network. The first prerequisite for sharing knowledge is providing free and easy access to relevant information in MtSCs for sub-suppliers, suppliers and lead firm then learning to take place by a collaboration of all actors to share and create new knowledge. A traceability system is a potent tool for providing more transparency. It enables lead firms to exceed their dyadic and narrow vision to low-tier suppliers and monitor them easily. Finally, innovation should take place to apply novel idea and practices to modify MtSCs process and operations. Fraser et al. (2020) assessed the role of transparency in increasing sustainability for the automatic industry. Their finding denotes that creating transparency is the main prerequisite for increasing the sustainability within MtSCs and it helps increase the level of trust and commitment between supply chain actors within MtSCs.

In line with RBV theory, having new knowledge about MtSCs is an intangible strategic resource, which brings a competitive advantage for a lead firm (Vivas-López et al., 2013). The significant importance of transparency was supported by Fraser et al. (2020) and Venkatesh et l. (2020).

“Leadership and support” is the last construct with a total variance of 7.56%. The construct concentrates on the significant role of leaders and management in encouraging low-tier suppliers and suppliers to follow up sustainable standards. Leadership is defined as the most influential company in MtSCs whose actions can influence actors to pursue sustainability. The leaders are supposed to conduct investment and use their power and authority to convince actors to behave based on sustainable protocols. Another influential action is using social media to make the MtSCs behaviour centre of attention. Such issues urge all sub-suppliers, suppliers and lead the firm to take proactive actions and stick to sustainable standards. Top-level management is one of the main perquisites for developing sustainability in MtSCs, otherwise, all managers’ efforts will go vain and yield no efficient result. Jia et al. (2019) focused on the significant role of leadership on the sustainability of MtSCs in the furniture industry. The results show that the focal company should play a leadership role within MtSCs to lead the entire supply chain actors following up sustainable framework and principles.

Drawing upon RBV theory, leadership is considered a valuable resource within MtSCs. Thus, it helps create a platform to integrate actors in a sustainable manner, which leads to better performance of lead firms to reach a competitive advantage (Al Mamun et al., 2018). The high importance of leadership and support was highlighted by Adesanya et al. (2020) and Jia et al. (2019).

To summarize the most effective lessons within each construct, Table 10 shows the summary of recommended actions for improving sustainability within MtSCs:

**Table 10**. Summary of recommended actions

|  |  |
| --- | --- |
| Construct | Recommended Actions |
| Environmental issues | It is highly important to apply strategic initiatives for modifying the usage of water, raw materials and land occupation.It is also suggested to use recycled materials and setting up a recycled process for mitigating the destruction of the environment. |
| Economic issues | Setting up an efficient strategy to minimize the transportation cost to leverage raw materials mobility within MtSCs. Higher mobility has a positive effect on increasing sustainability.Decreasing raw materials and energy consumption cost avoid exerting pressure on supply chain actors, therefore, it is highly required to apply compelling strategy to keep the cost low which leads to higher sustainability.  |
| policy and governance | Governance structure creates sustainable coherency and integration between supply chain actors and avoids deviation of the sustainable framework. It is highly needed to enforce ethical and moral principles by a focal company to disseminate sustainable behaviour among suppliers and sub-suppliers without any legal obligations. Applying incentive-oriented policy encourages supply chain actors to pay more attention to sustainability and keep it as one of their main priorities. National bodies are expected to enforce stringent actions against lawbreakers by legislating relevant regulation in all aspects of sustainability including economic, social and environmental issues. |
| participation | Increasing trust and commitment creates a dependency on suppliers and sub-suppliers. Such dependency enables supply chain actors to practice more collaboration. Such a concept is the main requirement for increasing sustainability.It is highly required to make the strategic partnership between supply chain actors to strengthen binding and collaboration. Top-level management should encourage actors to sign a strategic partnership for direct and upstream suppliers.  |
| Social issues | It is highly suggested to practice regular assessment of workers’ working condition, safety and human rights, particularly in upstream suppliers. Before selecting suppliers and sub-suppliers, a focal company should consider cultural similarity and geographical distance. Less cultural difference and geographical distance are highly recommended for keeping the actors more integrated. |
| Transparency | It is highly recommended to apply a robust traceability system to keep the track of supply chain actors and make sure about compliance with sustainability within MtSCs. Supply chain learning should be practised seriously for all supply chain actors to keep the actors informed and tuned with sustainable behaviour through holding workshops and training sessions. It is highly recommended to increase customers’ awareness by advertising on social media and social network. Such activities exert indirect pressure on suppliers and sub-suppliers to abide by sustainable practices.  |
| Leadership and support  | Top-level management support is so essential and mandatory for increasing sustainability. It is highly recommended to select senior managers whose attitude is in favour of sustainability otherwise any further actions are not practical.It is highly suggested for the most influential companies within MtSCs to play a role as a leader to convince all other actors to follow them up aiming at observing sustainable practices.  |

After categorizing the effective drivers of sustainability in MtSCs into seven constructs, fuzzy expert systems were designed to make the framework applicable and measurable for potential case studies. Fuzzy expert system is a quantitative method, which turns the first phase result (Empirical study) into practical application. The fuzzy expert system enables the framework to be applied for different real case studies for measuring the readiness status and score of sustainability pillars using inference engine and IF-THEN rules. The fuzzy expert system allocates readiness score and linguistic variables for each construct, which denotes the level of readiness in the targeted case study. Thus, fuzzy expert system was created for each construct. The fuzzy expert system outcome indicates the strength and weakness of sustainability in case studies and enables policymakers to expand their vision regarding the potential challenges and difficulties in sustainability. Such results are so helpful for managers and policymakers to make a right decision aimed at reaching higher sustainability and competitive advantages.

**5.1. Implications to theory and practice**

The study proposes both theoretical and practical implications. The main theoretical implications are:

* Conducting extensive literature review and collecting a comprehensive set of factors from the most relevant studies for assessing the three main pillars of sustainability within MtSCs.
* The second theoretical implication is regrouping a comprehensive set of the factors into seven groups based on the most associated factors and assigning an appropriate name for each construct. The constructs and factors can see wider aspects of sustainability in MtSCs comparing to previous studies.
* Designing an expert system is another theoretical implication, which enables the framework, to be applicable for assessing the readiness status and score of sustainability in MtSCs.
* Due to high uncertainty and ambiguity in subjective factors proposed in the framework, fuzzy sets theory is applied to capture the inherent ambiguity and reaching to a more reliable outcome.
* The study has extended RBV theories for the sustainability of MtSCs by proposing a complete set of factors and recognizing strategic resources to reach competitive advantages respectively.

The study suggests understanding the main drivers of sustainability in MtSCs including:

* The framework helps managers to expand their vision from just considering direct suppliers to low-tier suppliers for reaching higher sustainability in supply chain network. The study has proposed seven constructs including “environmental issues”, economic issues”, policy and governance”, “participation”, “social issues”, transparency” and “leadership and support” for policymakers and managers to take into account while doing decision-making.
* The finding shows that policymakers should put a high priority on environmental issues as the most important construct for reaching sustainability in MtSCs. Managers should urge MtSCs actors to decrease energy, materials, water consumption and emission to air as much as possible to have a less destructive impact on the environment. The high importance of the construct for enhancing sustainability in MtSCs was proven in the Machinery industry by Tuni et al. (2020).
* Economic issues are the second most important sustainability pillar, which encourages policymakers and managers to consider the economic aspect in their decision-making. It is highly recommended to decrease purchasing and energy consumption costs as well as the fee for waste management. The significant role of the economic construct in enhancing sustainability in MtSCs was proved in the aerospace industry by Lopez and Ruiz-Benitez 2020).
* Since one of the main responsibilities of managers is facilitating compliance with the sustainable protocol, therefore, policy and governance construct enables MtSCs actors to communicate and behave in standard principle, which can drive sustainability in the entire SC. The importance of such construct was proved in the mineral industry by Sauer and Seuring (2019).
* Cooperation and participation of sub-suppliers and suppliers with lead firm is the prerequisite of conducting sustainable practices within MtSCs. Policymakers and managers should pay high attention to any required actions to bridge the gap between actors for further participation including strategic partnership and increasing trust and commitment. The significant role of such construct in leveraging sustainability was highly mentioned in the technology industry by Grimm et al. (2018).
* There is a high number of workers involved in the textile industry with different cultural and social backgrounds. Observing their rights and providing a safe and healthy environment to work is managers’ responsibility to increase sustainability in MtSCs. Managers are supposed to take care of all workers and make sure that their rights and working environment are properly well-observed. The high importance of social construct was proved in the food industry by Hannibal and Kauppi (2019).
* Analysing a high volume of information in MtSCs can enable policymakers and managers to make accurate decisions and increase their visibility over the entire SC. Reaching and exploiting the supply chain information increases the manager’s understanding to set up the right policy to reach sustainability. The significant effect of transparency for increasing sustainability in MtSCs was proved in the automatic industry by Fraser et al. (2020).
* Leadership and support encourage stakeholders and policymakers to have a proactive stance on sustainable practices. Their support can accelerate the development of sustainability in MtSCs. The high importance of the construct was proved in the food and furniture industry by Jia et al. (2019).

**6. Conclusions**

High pressure from multiple stakeholders has urged many well-reputed companies to change their approach from first-tier to multi-tier suppliers. Due to the sophistication of sustainability in MtSCs, leading firms have significant challenges in practising sustainability in MtSCs. The vast majority of previous studies have concentrated on first-tier suppliers and neglected the significant role of lower-tier suppliers in higher sustainability. Moreover, only a few studies have considered sustainability in lower-tier suppliers by considering the limited factors and sustainability pillars. In this study, a data-driven framework was proposed to assess the wider aspects of sustainability pillars including social, economic and environmental issues in MtSCs using an empirical study. The validated factors were categorized to limit the number of groups through the EFA method. The factors were categorized, based on their importance, into the following constructs, namely: “Environmental issues”, “Economic issues”, “Policy and governance”, “Participation”, “Social issues”, “Transparency” and “Leadership and support”.

Since the majority of the previous studies have recognized the potential association between different factors and disregarded the application of the framework for assessing case studies, in this research an expert system was designed to assess the readiness status of case studies following the categorized constructs as well as providing practical and helpful pieces of advice. Due to the existing uncertainty in factors such as ‘trust and commitment’, fuzzy sets theory was applied to capture their vagueness. Such results can provide practical implications for policymakers and managers to evaluate the readiness status of sustainability in MtSCs and achieve higher sustainability and competitive advantages.

The framework was applied in a textile Industry company in the Islamic Republic of Iran. The framework denoted the readiness status of the considered constructs. The findings suggested that “Transparency” and “Leadership” had the highest level of readiness, with a total readiness score of 2.65 and 2.7 respectively. The “Participation”, “Social issues” and “Economic issues” factors’ readiness value were 2.28, 1.84 and 1.47 respectively, which linguistic variable was Medium. The rest of the constructs, including “Environmental issues” and “Policy”, were assessed as the least ready constructs, which readiness scores were 0.17 and 0.93 respectively. The framework provides some practical advice for decision-makers to address environmental issues such as decreasing gas emissions and using more recycled materials. Moreover, it is highly suggested to enhance top-level management willingness to support sustainable operations within MtSCs.

**6.1. Limitation and Future Scope of the Research**

The current research study has considered the most credible papers from the Web of Science and SCOPUS to extract relevant studies aimed recognizing the most impactful factors for assessing sustainability in MtSCs within the textile industry. It is highly recommended to use the expert’s knowledge and judgments to expand the number of factors for broader aspects of sustainability in MtSCs. Due to the subjective concept of factors and the inherent uncertainty in expert judgments, fuzzy sets theory was applied to capture the vagueness. It is highly recommended to use Interval-valued Intuitionistic Fuzzy Sets (IVIFS) to model the expert’s judgment more precisely in an interval [0,1]. The IVIFS can better model the expert’s judgments and opinions for subjective construct and factors. Following the extensive literature review, each study has been conducted for a specific industry such as the fashion industry, fleet management and cashew industry (Mejías et al., 2019). In this study, the textile industry as one of the most pivotal industries was considered. It is highly suggested considering other critical industries for creating the most appropriate framework aimed at assessing the sustainability in MtSCs within the context. In this study, Empirical analysis and fuzzy expert system were applied to categorize factors and assessing the readiness status of the construct in different case studies. The current study avoided determining the potential association between factors and constructs. It is highly recommended to apply Structural Equitation Modelling (SEM) method to recognize the factors’ association. Such results can help policymakers and managers to make a better decision following the extracted relationship.

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