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Sustainable Supplier Selection Criteria for HVAC Manufacturing Firms: A Multi-Dimensional Perspective Using the Delphi–Fuzzy AHP Method

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Abstract: *Background*: The supplier selection process (SSP) has grown as a crucial mechanism in organizations' supply chain management (SCM) strategies and as a foundation for continuously gaining a competitive advantage. The concept of the circular economy has garnered significant interest due to its ability to address both environmental and social criteria. It is highly important to carefully choose suppliers across all industries that take into account circular and sustainability issues, as well as traditional criteria. There is very limited research involving the supplier selection process in the Indian HVAC manufacturing sector. *Design/Methodology/Approach*: Thus, this study aimed to determine the critical factors for sustainable supplier selection for HVAC manufacturing firms using a mixed research method with three stages: a secondary study, the Delphi method, and the fuzzy analytical hierarchy process (FAHP). Thirty-two critical sub-factors were identified and grouped into eight major factors: delivery, economic, environmental, social, management and organization, quality, services, and supplier relationship. *Results/Conclusions*: For HVAC manufacturing firms, the major factors of delivery, quality, and economics were found to be top-ranked among the factors, followed by environmental factors. Studies in developing countries using sustainable factors are still nascent, especially in India. *Originality/Value*: This study's novelty lies with the proposed eight major factors, comprising all facets of organizations, including sustainability factors. Supplier selection in HVAC manufacturing firms is exhaustively dealt with in this study, filling a gap in the existing literature. This is important because HVAC products are high-energy-consuming, high-energy-releasing, and costly.

Keywords: sustainable supplier selection; innovation; sustainable supply chain management; supplier selection; fuzzy AHP; Delphi

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1. Introduction

The SSP has grown as a crucial mechanism in organizations' supply chain management (SCM) strategies and as a foundation for continuously gaining a competitive advantage [1]. However, supplier selection challenges can still be found across multiple aspects of a company's operations, for example, delivery, quality, costs, flexibility, and innovation [2]. Companies must rely on their suppliers to enhance product quality, reduce costs, and improve operations [3].

Rapid industrial globalization has impacted competition among businesses by changing the model from 'firms vs. firms' to a 'supply chain vs. supply chain' model [4]. Firms' dependency on suppliers has been increasing, which makes the supplier selection process a critical concern in their overall purchasing strategy [1]. With the rapid growth in manufacturing sectors globally, and especially in developing countries, future resource management has become a major concern and task for humankind [5]. Thus, Firms should use socio-economic and environmental factors for sustainable supplier selection in supply chains.

The challenges and ramifications of the SSP can be observed across a firm's entire operations [2]. Companies must consider strategies and external sustainability capabilities, especially in upstream supply chains [6]. Recently, several firms have adopted sustainable practices and thus moved towards sustainability-oriented innovation [5,7].

The awareness of sustainability has grown exponentially in the last few decades, especially after the Paris Climate Conference (COP 21) https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement, which was held in 2015. The circular economy concept has also garnered significant interest due to its ability to address environmental and social criteria [8]. Choosing suppliers across all industries that consider circular and sustainability issues is imperative. Environmental sustainability has become the focal point of countries' strategic goals. Thus, it has impacted the modes of production and delivery of goods and services to customers and clients. As a result, the concept of SSS (sustainable supplier selection) has emerged, attracting corporate interest, both in public and private organizations [9]. With the current competition in the world, most enterprises seek to reduce costs and upgrade the quality of their products simultaneously. In a few organizations, about 70 percent of costs pertain to details linked with purchases [10].

Researchers and practitioners have been building a consensus that supply chains need to broaden their attention from focusing only on traditional criteria (such as cost and quality) and social, economic, and financial dimensions [11–18] to also include a focus on the social and environmental dimensions of sustainability [19].

Firms must innovate, modify their existing organizational structures, and incorporate advanced strategies to address these challenges and focus on sustainability [5]. Many researchers have examined the literature and found that knowledge creation in firms generally focuses on sustainability and social responsibility in supply chains [20,21]. While adopting the TBL theory, various researchers have considered all three factors, i.e., social, economic, and environmental, in order to construct a sustainability-focused supplier selection framework [15,22–26]. Several researchers have studied sustainable processes and product innovation in supplier evaluation and finalization and have confirmed that empirical analyses in developing nations are still lacking [5,27].

With globalization, green supply chain management (GSCM) has been adopted as a strategic approach in SCM. MNCs have formed an SC leadership collaboration to reduce carbon footprints. With an emphasis on environmental and social issues, firms must include green-related factors in the GSC decision-making process [28]. The objective of green consumption is to reduce environmental damage from the SC and to lower the environmental impact of the manufacturing industry. Researchers have started to account for green innovation and waste generation as major environmental add-in factors in the existing theory of the green supplier selection process. Several researchers are more focused on green-based supplier selection for various automotive, machine manufacturing, electronics, and R&D industries [18,29–32]. In this context, [33] also added that the sustainability approach is an important criterion in terms of human rights, equity, and ethics in the framework of the integrated sustainable supply network.

However, the research accounting for integrated sustainability, traditional management, and organization, technology, innovation, services, buyer–supplier relationships, etc., factoring in a holistic approach to the framework of the sustainable supplier circular selection theory, still requires more investigation. Thus, this study proposes the following objectives:

OBJ-1: Identify the factors used in the literature for supplier selection;

OBJ-2: Identify the critical factors for sustainable supplier selection for the HVAC company;

OBJ-3: Estimate the relative preference (relative) weight of the critical factors for SSS for an HVAC manufacturing company;

OBJ-4: Evaluate the robustness of the outcome through sensitivity analyses.

Why focus on HVAC (heating, ventilation, and air conditioning) firms? HVAC products are high-energy-consuming, high-energy-releasing, and costly. The manufacturer continuously changes its product characteristics to be competitive. The changes mainly involve reducing energy consumption (star rating), reducing greenhouse gases released into the environment, and improving quality, flexibility, and price. Still, the products with high star ratings are costly.

This study uses a mixed research method approach involving three stages—a secondary study, the Delphi method, and the fuzzy AHP technique—to study the sustainable supplier selection criteria for HVAC manufacturing firms.

The structure of the paper includes a literature review section, a section describing the methodology, a section discussing the results, and, finally, a conclusion outlining the study's limitations and future research opportunities.

2. Literature Study

2.1. Literature Search Protocol

A literature search was conducted using the following keywords: "sustainable supplier"; "Green suppliers"; "Sustainable", Suppliers"; and "Supplier selection", etc., in the title, abstract, and keywords section of the related articles. The Scopus database was used for the search. The inclusion criteria included English language articles published in business and management, decision science, and engineering journals within the last 10–14 years (2010–2024). Around 60 journals were reviewed thoroughly based on the sector of study, geography, SSSP factors, and methodology. Around 73 unique factors were identified (Appendix A: Table A1).

2.2. Literature Review

The SSP is one of the most important and critical processes acknowledged within the SCM function [1]. Continued emphasis on outsourcing has increased the complexity of the SSP, and, thus, it has become essential and critical to firms' competitiveness [1]. Numerous experimental studies have found evidence supporting its impact on business performance [34,35].

Sustainable SCM is the management of materials (RM and FG), information, and capital flows between corporate SCs, considering the socio-economic and environmental dimensions of sustainable development [5,11]. Many corporations have already considered sustainability metrics, including environmental and social practices, to assess production sustainability and achieve sustainability objectives [6].

Existing studies on SSP structures are centered around two perspectives: one focused on identifying the criteria and the other using the criteria to provide an efficient framework for supplier selection. The sustainability factors for supplier selection are based on the TBL, i.e., environmental, social, and economic factors. Research on estimating the relative importance of these sustainable factors and their sub-factors exists in the literature [12,22,36–38]. A review of SSS from 1997 to 2014 observed that most of the research (around 60%) targeted economic and environmental sustainability factors, followed by TBL sustainability factors (about 30%). Environmental or social factors or social and environmental factors were used least (around 10%) [36]. Research on social sustainability factors and social and environmental sustainability factors is limited [39–42]. Sustainable or green supplier selection uses environmental factors related to product characteristics, green technology, environmental performance measures, green purchasing, supplier orientation, etc. [29,43,44]. Research on triple bottom line factors (social–economic–environmental factors) has shown different relative preferences depending upon the sector of study but has been mainly inclined towards economic factors followed by environmental factors. A survey of SSSPs for Chinese solar air conditioner manufacturers reflected more emphasis on economic factors, followed by social factors [37], which is similar to results found for the healthcare industry [45] and Chinese truck manufacturers [23]. Studies have also observed that environmental factors were rated high, followed by economic factors (Indian automotive) [46] and social factors [24].

The literature on the sustainable supplier selection process (SSSP) is summarized in Table 1. Most of the studies using the SSSP used the already identified sustainability factors related to social, economic, and environmental factors and the proposed framework for the SSSP using classic MCDM or hybrid MCDM techniques [23,24,45–47], while other studies used environment performance criteria including/excluding traditional factors (i.e., cost quality, delivery, etc.) [40,48]. Recent research used sustainable factors and risk and inflation factors for SSSP analysis [49]. In [50], the authors used sustainable technological capability, financial capability, management capability, and technology solution as sustainable factors for the SSSP. Similarly, a study estimated and established the interdependence of sustainable factors for the SSSP using ISM [51]. There are also reviews in the literature of techniques and methods used from 1990 to 2019 for the supplier selection process [9].

Table 1. Literature review summary (methods and techniques).

Reference	Country	Sector	Area of Application	Technique
[11]	Indonesia	Manufacturing	Racket	Fuzzy AHP and CoCoSo
[13]	Brazil	Services	FM services	Fuzzy AHP
[33]	India	Manufacturing	Electronics	Grey stratified decision-making (GSDM) model
[14]	-	Manufacturing	-	BWM-MARCOS
[52]	China	Manufacturing	Automobile	FAHP-FTOPSIS
[23]	China	Manufacturing	Forklift truck manufacturer	Fuzzy MULTIMOORA
[53]	China	Manufacturing	SMEs	PLTS-PROMETHEE II
[12]	Turkey	Manufacturing	Textile	Stratification theory
[24]	China	manufacturing	Sustainable supply chain management	PF-EDAS
[47]	China	Chemical industry	Petrochemical companies	FGRA, FMEA, EWM, and DEMATEL
[50]	China	Water environment treatment	PPP projects	Shapley-AHP-TOPSIS-IVIFS
[54]	Iran	Manufacturing	Garment Industry	Fuzzy BWM
[10]	Iran	Petroleum	Petrochemical Industry	TOPSIS and MCDM
[45]	Bosnia and Herzegovina	Healthcare	Polyclinic	MARCOS
[55]	Iran	Manufacturing	Steel industry	BWM, Fuzzy TOPSIS
[56]	Turkey	Production	-	Fuzzy BWM and Fuzzy CoCoSo
[57]	India	Manufacturing	Steel industry	FIS and Fuzzy Kano
[1]	USA	Race	Race	Descriptive analysis
[28]	Taiwan	Environment	Global climate change	Fuzzy goal programming
[58]	Japan	Environment	CO_2 emissions	Mathematical modeling
[3]	China	Manufacturing	Electronic manufacturing	Mathematical modeling
[59]	Iran	Logistics	Warehouse	FANP and DEMATEL and Fuzzy TOPSIS
[60]	Taiwan	Manufacturing	Personal computers	Statistical analysis, Monte Carlo simulation, MCB, Bonferroni
[61]	Iran	Manufacturing	Distribution chain of automotive parts	FANP and FDEMATEL
[62]	Japan	Manufacturing	Semiconductor	Fuzzy MADM TOPSIS
[4]	Poland	-	-	Mathematical modeling
[63]	USA	Manufacturing	Production	Mathematical modeling
[64]	Malaysia	-	-	MCDM
[65]	China	Electric Vehicle	New energy vehicle	Fuzzy MCDM
[66]	Taiwan	Airlines	catering	AHP-ARAS-MCGP
[67]	India	Manufacturing	Home appliance	Fuzzy TOPSIS
[68]	China	Manufacturing	Photovoltaic module	Fuzzy AHP
[69]	Turkey	Manufacturing	Automobile	MCDM
[19]	Iran	Supermarket	Supermarket	Fuzzy
[70]	China	Home Appliance	Decision-making process	Fuzzy TOPSIS

Table 1. *Cont.*

Reference	Country	Sector	Area of Application	Technique
[71]	USA	Natural Disasters	Supply structure post-natural disaster	Stochastic programming model
[72]	Germany	Manufacturing	Automobile	Mathematical modeling
[73]	China	Power plant	Straw biomass industry	MCDM Fuzzy AHP
[21]	Brazil	Manufacturing	Textile	AHP
[74]	Europe	Manufacturing	Automobile	-
[46]	India	Manufacturing	Automobile	AHP-VIKOR
[48]	Iran	Dairy Company	Dairy product	QFD-DEMATEL-COPRAS
[40]	China	Manufacturing	Electronics machinery	AHP-Entropy/TOPSIS
[75]	Malaysia	Manufacturing	Manufacturing industry	Survey

Classic MCDM and hybrid MCDM techniques are used mainly to identify and select the best suppliers. In [55], the authors applied the best–worst method and fuzzy TOPSIS to study the GSCM for the steel industry in Iran, and they also presented a case study of the Khuzestan steel company. One major limitation of their research was that the decision-makers' psychological behaviors, which are essential factors, were not considered. In [54], the authors applied the fuzzy BWM method to study the sustainable closed-loop supply chain for the garment industry in Iran. In [56], the authors used fuzzy BWM and fuzzy CoCoSo to study sustainable supplier selection in Turkey. One major limitation of their research was that some important SSCM practices and dimensions were not considered, such as political factors. In [10], the authors applied TOPSIS and MCDM to study the sustainable development goals in the petrochemical industry in Iran. Their approach was to integrate the MCDM and FIS to evaluate and rank the suppliers toward the transition in the circular supply chain. In [63], the authors analyzed the SSP criteria and methods using the MCDM technique in Malaysia. The outcome reflected the importance and criticality of structured decision-making in a complex environment.

Apart from MCDM techniques, studies have also used mathematical and statistical methods to propose the best outcome, [1] used descriptive analysis to study the impact of race on the SSP and evaluation processes. The major limitation of such studies was that a scenario-based experiment was used to study the role of race in the SSP. In [28], the authors used the fuzzy goal programming technique to study supplier portfolio selection under green market segmentation in Taiwan. In [58], the authors proposed integrated supplier and disassembly part selections using mathematical modeling techniques to reduce and recover the design problem in Japan. In [57], the authors applied FIS and fuzzy Kano methods to study the sustainable supplier selection process in the Indian steel industry.

From Figure 1 below, it is evident that most of the recent studies regarding the supplier selection process have been conducted in Iran and China. In India, three studies have been completed involving the home appliance, automobile, and steel industries. Many more sectors in India are unexplored and require future studies, such as HVAC.

2.3. Research Gap and Novelty

The research on estimating relative preferences for the economic, social, and environmental factors is inconsistent and broadly depends on the sector of study. Research using sustainable factors in developing countries, especially India, is still nascent [46,76]. This is mainly attributed to a slow appreciation of sustainable factors or knowledge [46] or a low willingness to pay extra for green products [77–79]. Though SSSP studies on Indian automotive manufacturers [46] and steel manufacturers [57] exist, studies on the SSSP for HVAC (heating, ventilation, and air conditioning) manufacturers are still lacking. HVAC products are high-energy-consuming, high-energy-releasing, and costly, and manufacturers continuously change their product characteristics to be competitive. These changes mainly involve reducing energy consumption (star rating), reducing the amount of greenhouse gases released into the environment, and improving quality, flexibility, and price, but the products with high star ratings are costly.

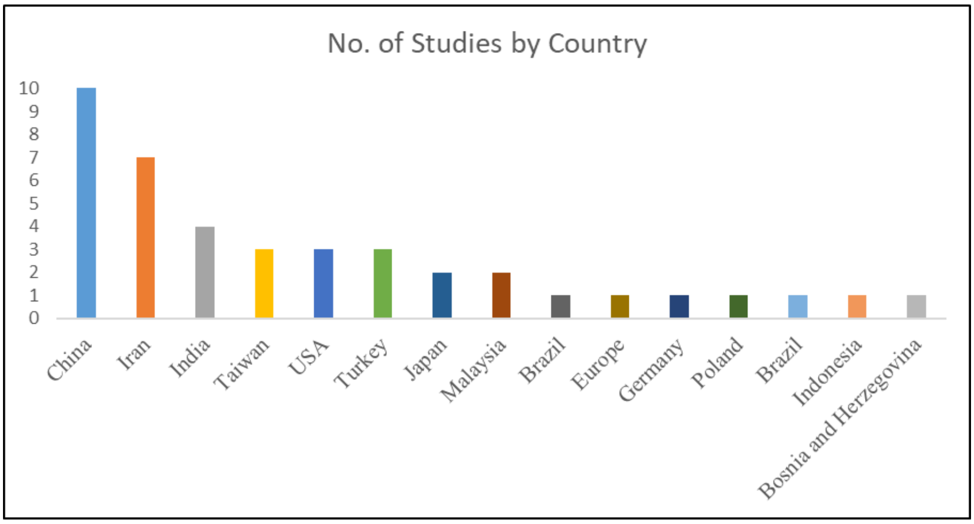

Figure 1. Background study.

Existing studies on the SSSP only considered sustainable factors, while there is sufficient literature on the importance of traditional factors such as flexibility, quality, delivery, management-related factors, and technological factors. Researchers have used different or extra factors/criteria for three sustainable factors for SSS. Though studies based on integrated traditional and sustainable factors are complex [46,80], they can provide a holistic approach to SSS.

Thus, this study identifies all the factors used for SSS and traditional supplier selection through a study of the literature. Then, an integrated Delphi–fuzzy AHP is employed to determine the prominent factors (criteria) and sub-factors (sub-criteria) and estimate their relative preference weights.

3. Materials and Methods

This study aims to aid decision-making in the sustainable supplier selection process (SSSP) for the HVAC (heating, ventilation, and air conditioning) manufacturing industry based in India. Thus, this study aims to identify all the relevant factors existing in the literature and estimate the relative preference weights of the critical factors of SSS for HVAC firms. A three-stage methodology is proposed, using mixed research methods. The stages include the following:

1. Identifying the factors studied for SSS: secondary study (literature review);
2. Determination of critical factors for SSS for HVAC firms: Delphi technique study;
3. Estimating relative preference weights of the critical factors for SSS: fuzzy AHP technique.

3.1. Secondary Study: Identifying the Factors Studied for the SSSP

Around 73 unique factors were identified through a literature study of 60 journals, based on the sector of study, geography, SSSP factors, and methodology.

3.2. Delphi Technique: Determination of Critical Factors for SSS for HVAC Firms

The well-structured Delphi technique uses the collective opinion of experts. A questionnaire is evaluated by experts in two or more specified steps [81]. To determine the critical factors among the 73 identified sub-factors from the research review, a survey was prepared using the scale of importance with 5 response points and sent to experts in 20 different companies. However, only 23 individuals responded from 14 different companies. The survey was sent to HVAC industries in India. The expert profile is summarized in Table 2.

Table 2. Respondent profile.

Designation	Numbers	Experience	Numbers
AM/M/SM	10	(Exp <10 yrs.)	7
CM/DGM/AGM/GM	9	(Exp: 10–15 yrs.)	10
Director/MD/	4	(Exp >15 yrs.)	6

An index was prepared to determine the critical factors based on mean response and coefficient of variance (COV) values. A mean value of at least 3.5 (scale of importance with 5 response points) and a COV value of <0.2 were set as cutoff values. A COV of less than 0.2 signified a consistent response from the experts [23]. Any higher value reflected confusion or inconsistency and was thus not included. Actors were filtered out. A focus group of 10 experts in the field of HVAC was created to filter critical factors further if required. A similar survey was distributed, followed by an interview to determine their preferences. Finally, 32 factors were obtained after deliberation. These factors were grouped using the literature and the discussion with the experts. Finally, 8 major factors and 32 sub-factors for the SSSP for HVAC firms were determined (Table 3).

Table 3. Delphi results summary.

Major Factor	Sub-Factor	Citations
Delivery (Del)	On-time delivery (Del1)	[24,40,45,47,53]
	No error in product type and quantity (Del2)	[23,75]
	The product received in good condition (Del3)	[47,75]
	Order lead time (Del4)	[10,46,53]
Economic (Eco)	Reliability (Eco1)	[45,63]
	Service and after-sales service (Eco2)	[53,54]
	Performance history (Eco3)	[75]
	Cost (Eco4)	[12,23,24,40,45–47,53,63]
Environmental (Env)	Enhanced value to customers (Env1)	[55]
	Customer-friendly and environmental adaptability (Env2)	[23,53,64]
	Pollution control (Env3)	[24,45,47,56]
	Environmental certifications (Env4)	[40,45,54]
Management and organization (Mo)	Skilled and potential staff (MO1)	[75]
	The financial status of the company (MO2)	[24]
	Strategic organization structure (MO3)	[50]
	Good reputation among the industry (MO4)	[23,45,50]
Quality (Qa)	Long durability (life) (Qa1)	[75]
	Low rejection/return rate (Qa2)	[40,75]
	Meeting minimum standards and requirements (Qa3)	[53]
	ISO certified (Qa4)	[75]

Table 3. *Cont.*

Major Factor	Sub-Factor	Citations
Services (Sv)	Fast reaction/responsiveness (Sv1)	[75]
	Technical support (Sv2)	[75]
	Warranty/Insurance (Sv3)	[75]
	Ability to collocate to buyer's manufacturing side (Sv4)	[75]
Social (So)	Ethical issues and legal compliance (So1)	[64]
	Mutual trust and easy communication (So2)	[63]
	Information disclosure (So3)	[12,45,46,56]
	Staff training (So4)	[24,45,56]
Supplier relationship (Sr)	Long-term cooperation (Sr1)	[23,75]
	Attitude (Sr2)	[63]
	Flexibility (Sr3)	[23,24,46,70]
	Customer trade record (Sr4)	[75]

3.3. Fuzzy Analytical Hierarchy Process (AHP)

The AHP method is a numerical approach propounded by [82] for multi-criteria decision-making (MCDM). AHP and fuzzy AHP are the best and most widely used techniques to build/develop criteria and estimate their weights, as opposed to other MCDM techniques used for evaluating alternatives [83]. The limitation of this method is its limited applicability with certain economic and environmental parameters and individual situations. Fuzzy AHP is used to relieve such limitations. The FAHP quantifies the linguistic response or judgment of experts. The FAHP technique used in this paper is depicted in Figure 2.

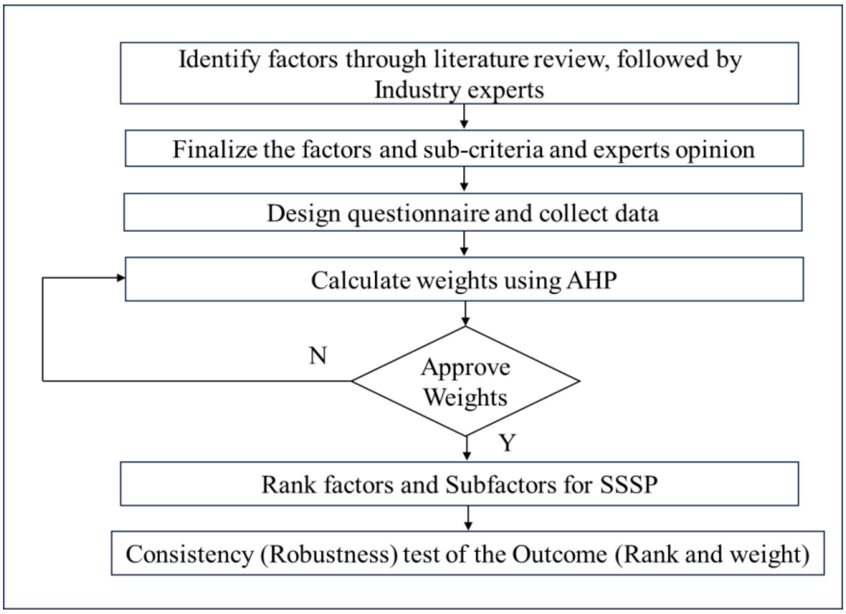

Figure 2. Proposed fuzzy AHP methodology.

Fuzzy AHP process: Following this methodology, detailed analyses are conducted for each criterion, and each criterion is examined and subjected to experimentation. The following notation is employed to determine the values for each criterion:

$T^1{}_{gi}$, $T^2{}_{gi}$, $T^3{}_{gi}$, . . ., $T^j{}_{gi}$, where i = 1, 2, 3, . . ., n and j = 1, 2, 3, . . ., m denote triangulated fuzzy numbers. The steps involved in fuzzy AHP are followed as recommended by [84]:

Step 1: The fuzzy synthetic extent value (Fs_i) concerning the ith criterion is determined by Equation (1):

$$Fs_i = \sum_{j=1}^{m} T_{gi}^{j} * \left[\sum_{i}^{n}\sum_{j}^{m} T_{gi}^{j}\right]^{-1}$$
$$\sum_{j=1}^{m} T_{gi}^{j} = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij}\right) \quad (1)$$
$$\left[\sum_{i}^{n}\sum_{j}^{m} T_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} u_{ij}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} m_{ij}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} l_{ij}}\right)$$

where the set (l, m, u) denotes the lower, most promising, and upper limit values.

Step 2: The degree of possibility of $Fs_2 = (l_2, m_2, u_2) \geq Fs_1 = (l_1, m_1, u_1)$ is explained as follows:

$$V(Fs_2 \geq Fs_1) = \sup_{b \geq a}\left[min\left(\mu_{Fs_1}(a), \mu_{Fs_2}(b)\right)\right] \quad (2)$$

where 'a' and 'b' are the points on the association function axis for each measure. This equivalent phrase is given by Equation (3):

$$v(Fs_2 \geq Fs_1 = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} = \mu d, & otherwise \end{cases} \quad (3)$$

where μd denotes the highest intersection point: μ_{Fs1} and μ_{Fs2}. To compare Fs_1 with Fs_2, both $V(Fs_1 \geq Fs_2)$ and $V(Fs_2 \geq Fs_1)$ are required (Figure 3).

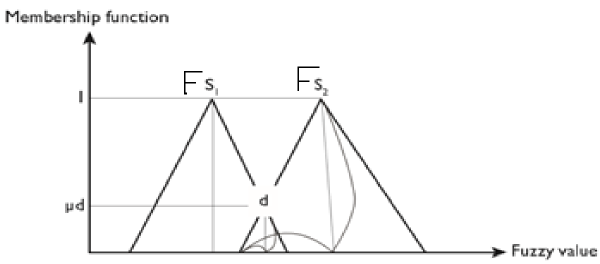

Figure 3. The common area of the fuzzy numbers.

Step 3: The weights are normalized using Equation (4), given below:

$$W = (d(A_1), d(A_2), \ldots, d(A_m))^T \quad (4)$$

The experts were requested to evaluate each criterion pairwise on a scale of importance from 1 to 9 [85]. The single response values were converted into the triangular fuzzy numbers used for the fuzzification process, as shown in Table 4 [84].

Table 4. Triangulated fuzzy numbers used for comparison.

1	1,1,1		
3	2,3,4	**0.33**	0.25,0.33,0.5
5	4,5,6	**0.2**	0.167,0.2,0.25
7	6,7,8	**0.14**	0.125,0.143,0.167
9	9,9,9	**0.11**	0.11,0.11,0.11
2	1,2,3	**0.5**	0.33,0.5,1
4	3,4,5	**0.25**	0.2,0.25,0.33
6	5,6,7	**0.17**	0.143,0.167,0.2
8	7,8,9	**0.13**	0.11,0.125,0.143

The weights for criteria and sub-criteria were estimated separately. The experts were asked to give their pairwise responses on Saaty's importance scale. Seven experts were requested for the focus group. The demographic details of the experts are summarized in Table 5.

Table 5. Demographic details of the experts.

Company	Respondent Expertise	Mgt Position	Year of Experience
AC manufacturing—A	Supply Chain Commodity	GM, SCM Commodity Manager	15 8
AC manufacturing—B	Materials Handling Sourcing	AGM Materials Manager Sourcing	13 10
HVAC OEM—C	Strategic Sourcing Marketing Sourcing	Head Strategic Sourcing Head Marketing Senior Manager Sourcing	14 15 12

The geometrical mean method (GMM), arithmetical mean method (AMM), and median are the most common methods used for response aggregation [86–88]. Outliers often affect the AMM, thus GMM and Median are the most appropriate methods [88]. The single response matrix was created by taking the median of the responses received by all seven experts. The initial single response matrix values were fuzzified using the respective triangulated fuzzy numbers. Final weights were estimated using the abovementioned steps [84]. The calculations were carried out in MS Excel. The calculations performed to evaluate the weights (preferences) of the major criteria are shown in Table 6.

Table 6. Pairwise comparison between major factors (criteria) using fuzzy AHP.

	Del	Eco	Env	MO	Qa	Sv	So	Sr
Del	1,1,1	0.33,0.5,1	0.2,0.25,0.33	0.25,0.33,0.5	1,2,3	0.33,0.5,1	0.25,0.33,0.5	0.25,0.33,0.5
Eco	1,2,3	1,1,1	0.25,0.33,0.5	0.25,0.33,0.5	1,1,1	0.33,0.5,1	0.2,0.25,0.33	0.33,0.5,1
Env	3,4,5	2,3,4	1,1,1	0.33,0.5,1	1,1,1	0.25,0.33,0.5	0.2,0.25,0.33	0.33,0.5,1
MO	2,3,4	2,3,4	1,2,3	1,1,1	1,1,1	0.33,0.5,1	0.33,0.5,1	1,1,1
Qa	0.33,0.5,1	1,1,1	1,1,1	1,1,1	1,1,1	0.25,0.33,0.5	0.167,0.2,0.25	0.2,0.25,0.33
Sv	1,2,3	1,2,3	2,3,4	1,2,3	2,3,4	1,1,1	0.2,0.25,0.33	0.33,0.5,1
So	2,3,4	3,4,5	3,4,5	1,2,3	4,5,6	3,4,5	1,1,1	1,1,1
Sr	2,3,4	1,2,3	1,2,3	1,1,1	3,4,5	1,2,3	1,1,1	1,1,1
GM Lower	1.30	1.19	0.86	0.62	1.49	0.54	0.32	0.45
GM Middle	1.96	1.71	1.19	0.83	1.82	0.76	0.39	0.56
GM Upper	2.71	2.28	1.53	1.11	2.09	1.18	0.51	0.80
Fuzzy Wt Lower	0.11	0.10	0.07	0.05	0.12	0.04	0.03	0.04
Fuzzy Wt Middle	0.21	0.19	0.13	0.09	0.20	0.08	0.04	0.06
Fuzzy Wt Upper	0.40	0.34	0.23	0.16	0.31	0.17	0.08	0.12
Overall Wt	0.24	0.21	0.14	0.10	0.21	0.10	0.05	0.07
Normalized Wt	**0.214**	**0.184**	**0.127**	**0.091**	**0.187**	**0.090**	**0.043**	**0.065**
Rank	1	3	4	5	2	6	8	7

As given in Table 6, there were a total of 8 constructs: delivery, quality, economic, environmental, management and organization, services, social, and supplier relationship. Out of the 8 factors, delivery, quality, and economic were the top-ranked, followed by environmental, management and organization, services, supplier relationship, and social. The social factor was least preferred. The top 3 factors, delivery, quality, and economic, contributed 58.5% of the overall satisfaction of the model.

Similarly, estimation of the weights of the sub-factors was carried out, and the outcome is summarized in Table 7.

Table 7. Estimated weights and preferences of the sub-factors (sub-criteria) using fuzzy AHP.

Economic Factors				**Management and Organization Factors**				**Delivery Factors**				**Environment Factors**			
Eco1	Eco2	Eco3	Eco4	MO1	MO2	MO3	MO4	Del1	Del2	Del3	Del4	Env1	Env2	Env3	Env4
0.506	0.231	0.123	0.14	0.417	0.201	0.21	0.171	0.376	0.287	0.108	0.228	0.323	0.323	0.198	0.156
1	2	4	3	1	3	2	4	1	2	4	3	1	2	3	4
Quality factors				Social factors				Service factors				Supplier relationship factors			
Qa1	Qa2	Qa3	Qa4	So1	So2	So3	So4	Sv1	Sv2	Sv3	Sv4	Sr1	Sr2	Sr3	Sr4
0.451	0.285	0.173	0.092	0.579	0.122	0.22	0.079	0.403	0.288	0.177	0.132	0.433	0.232	0.233	0.103
1	2	3	4	1	3	2	4	1	2	3	4	1	3	2	4

As given in Table 7, Eco1 and Eco2 were the top-ranked among the factors. Eco1 was the most dominant economic factor, satisfying 50% of the total. MO1 was the most dominating factor among management and organization (41%), followed by MO3 and MO2. Del1 and Del2 were the top-ranked delivery factors, contributing 66%. Similarly, Env1 and Env2 contributed 65% of the environmental factor, and Qa1 and Qa2 were the top-ranked quality factors and contributed 73%. Social sub-factors So1 and So3 and service sub-factors Sv1 and Sv2 contributed 80% and 69% of the total, respectively. Sr1 and Sr3 were the top-ranked supplier relationship factors and contributed 66%.

3.3.1. Calculation of Consistency Index

We needed to check whether the respondent data qualified for a consistency check to determine if we needed to go back to industry experts and repeat the pairwise comparisons from scratch (fuzzy AHP). Using the largest eigenvalue, we were able to capture the inconsistency of judgments through the matrix.

λmax-n measures the deviation of the judgments from the consistent approximation in a given (n × n) square matrix. The closer λmax is to n, the more consistent the result. CI represents the deviation of consistency, and CR represents the consistency ratio. First, the consistency index is calculated, and then CR can be calculated.

Table 8 represents the random index (RI), which can be determined from the size of n [1]. A CR value less than or equal to 0.1 indicates consistency.

Table 8. Random index.

N	**3**	**4**	**5**	**6**	**7**	**8**
RI	0.52	0.89	1.11	1.25	1.35	1.4

From the respondents' data, the following λ max value was found:

$$\lambda\ max = 8.766581;\ n = 8$$

$$CI = (\lambda max\text{-}n)/(n - 1) = 0.109512$$

$$RI = 1.40$$

$$CR = CI/RI = 0.077668$$

Thus, the respondents' data were reliable and consistent, since CR < 0.1.

Similarly, consistency tests were performed for all the sub-criteria. The CR values for the response matrix of the sub-factors are summarized in Table 9.

Table 9. CR values for the sub-factors.

Sub-Factors	Eco	MO	Del	Env	Qa	So	Sv	Sr
CR value	0.074	0.095	0.097	0.092	0.096	0.02	0.092	0.085

CR values for all the sub-factors were less than 0.1; thus, the pairwise comparison responses from all the experts were consistent and reliable.

3.3.2. Global Weight and Ranks of the Sub-Factors

The normalized weights and ranks of major factors and local weights and ranks of sub-factors were estimated using the FAHP technique. The global weights and corresponding ranks of the sub-factors were calculated by multiplying the weights of major weights with their corresponding local weights of the sub-factors (Equation (5)):

$$Gij = Lij \times Mj \quad (5)$$

where Gij represents the global weight of the ith sub-factor of the jth major factor; Lij represents the normalized local weight of the ith sub-factor of the jth major factor; and Mj represents the normalized weight of the jth major factor.

The global weight of reliability (sub-factor (Ec1) of major factor "Economic" (Ec)) was calculated as follows (the results are given in Table 10):

$$Gij \text{ (Reliability (Ec1)} = Lij\ (0.506) \times Mj\ (0.184) = 0.0934$$

The ranking of the sub-factors, based on the global weights, was obtained using the "RANK()" function in Excel.

Table 10 shows the overall weights and overall ranks of all the sub-factors when multiplying the local normalized weights of the sub-factors with the respective major factors. Reliability (Eco1), long durability (life) (Qa1), on-time delivery (Del 1), no error in product type and quantity (Del2), and low rejection/return rate (Qa2) were the top 5 ranked sub-factors among a total 32 sub-factors.

Table 10. Global weights and ranks of the sub-factors using fuzzy AHP.

Major Factors	Sub-factors	Local Wts	Global Wts	Overall Rank
Economic (0.184)	Reliability	0.5064	0.0934	1
	Service and after-sales service	0.2314	0.0427	7
	Performance history	0.1225	0.0226	19
	cost	0.1397	0.0258	15
Management and organization (0.091)	Skilled and potential staff	0.4174	0.0378	10
	Financial stability	0.2010	0.0182	22
	Production capacity	0.2104	0.0190	21
	Company background	0.1712	0.0155	25
Delivery (0.214)	On-time delivery	0.3764	0.0806	3
	No error in product type and quantity	0.2873	0.0615	4
	Order lead time	0.1078	0.0231	18
	Delivery reliability	0.2285	0.0489	6
Environment (0.127)	Enhanced value to customers	0.3230	0.0409	8
	Customer-friendly and environmental adaptability	0.3226	0.0409	9
	Process integration	0.1983	0.0251	16
	Pollution control	0.1561	0.0198	20

Table 10. *Cont.*

Major Factors	Sub-factors	Local Wts	Global Wts	Overall Rank
Quality (0.187)	Long durability (life)	0.4512	0.0844	2
	Low rejection/return rate	0.2846	0.0533	5
	Meeting minimum standards and requirements	0.1726	0.0323	12
	ISO certified	0.0916	0.0171	23
Social (0.043)	Ethical issues and legal compliance	0.5786	0.0248	17
	Mutual trust and easy communication	0.1219	0.0052	31
	Information disclosure	0.2202	0.0094	29
	Staff training	0.0793	0.0034	32
Services (0.09)	Fast reaction/responsiveness	0.4034	0.0361	11
	Technical support	0.2880	0.0258	14
	Warranty/Insurance	0.1768	0.0158	24
	Ability to collocate to buyer's manufacturing side	0.1317	0.0118	28
Supplier relationship (0.065)	Long-term cooperation	0.4329	0.0279	13
	Attitude	0.2317	0.0149	27
	Good communication system	0.2329	0.0150	26
	Good supplier relationship management (SRM)	0.1025	0.0066	30

3.3.3. Sensitivity Analysis

Any slight change in the relative weights can produce major changes in the final ranking [89]. These weights were based on individual judgments; thus, the stability of the ranking of major factors and sub-factors must be tested. The robustness of the techniques was tested by changing the weights of the most-preferred major factors. Stepwise small changes in weights were made in the highest-ranked major factors, and changes in the other major factors and all sub-factors were adjusted accordingly.

Sensitivity analysis of the major factors:

The top-ranked major construct (Del) was selected, and its value was changed from 0.1 to 0.9, in gradual increments of 0.1 (Table 11). The weights of other major factors were adjusted accordingly using Equation (6) [90].

$$mj = (1 - w) \times Mj/Sum(Mj) \quad (6)$$

where mj is the new weight of the jth major factor; w is the weight assigned to the top-ranked major factor (Del) (0.1, 0.9); Mj is the normalized weight of the jth major factor; and Sum(Mj) is the sum of the weights of the major factors other than the top-ranked major factor (Del).

For example, (w = 0.1)

$$Mj(Eco) = (1 - 0.1) \times 0.184/(0.184 + 0.127 + 0.091 + 0.187 + 0.09 + 0.043 + 0.065) = 0.211$$

Similarly, the adjusted weights of all other major factors were estimated for values of w ranging from 0.1 to 0.9, as shown in Table 11.

The ranks of all the major factors were recalculated at different values of w (0.1, 0.9), and a spider chart was drawn, as shown in Figure 4. It can be observed that the rank of the major factors remained consistent at all the values of "w" except at w = 0.1, where the rank of Del was reduced to 6, while the rank of the other major factors remained the same.

Table 11. Sensitivity analysis of major factors.

Major Factor	N. Wt (0.214)	W-0.1	W-0.2	W-0.3	W-0.4	W-0.5	W-0.6	W-0.7	W-0.8	W-0.9
Del	0.214	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000
Eco	0.184	0.2113	0.1878	0.1644	0.1409	0.1174	0.0939	0.0704	0.0470	0.0235
Env	0.127	0.1452	0.1290	0.1129	0.0968	0.0807	0.0645	0.0484	0.0323	0.0161
MO	0.091	0.1037	0.0922	0.0806	0.0691	0.0576	0.0461	0.0346	0.0230	0.0115
Qa	0.187	0.2143	0.1905	0.1667	0.1429	0.1191	0.0953	0.0714	0.0476	0.0238
Sv	0.090	0.1026	0.0912	0.0798	0.0684	0.0570	0.0456	0.0342	0.0228	0.0114
So	0.043	0.0490	0.0436	0.0381	0.0327	0.0272	0.0218	0.0163	0.0109	0.0054
Sr	0.065	0.0739	0.0657	0.0575	0.0493	0.0411	0.0328	0.0246	0.0164	0.0082
	1	1	1	1	1	1	1	1	1	1

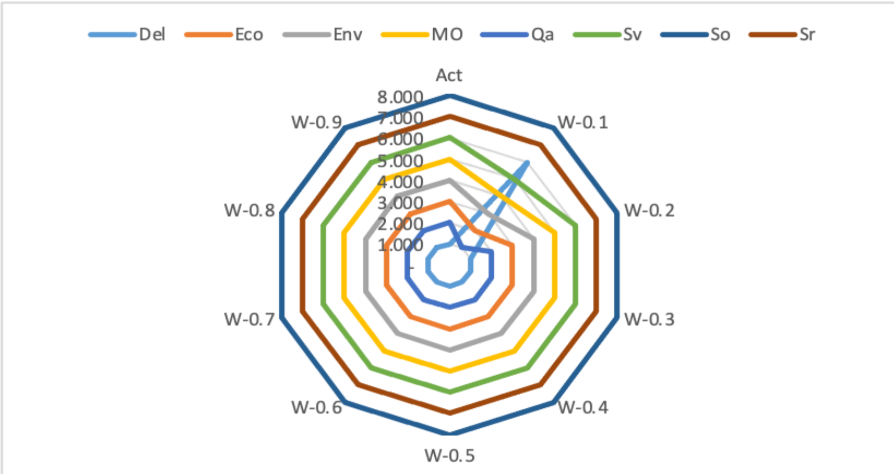

Figure 4. Ranking of major factors by increasing weights in a sensitivity analysis.

Spearman bivariate correlation was estimated using SPSS for the final rank and rank at each value of "w". The average value of the Spearman correlation obtained was 0.97, reflecting better consistency and thus the technique's robustness.

Sensitivity analysis of the sub-factors:

The values of the sub-factors were estimated based on the changed value of the respective major factors using Equation (7):

$$gij = Gij \times mj/Mj \quad (7)$$

where gij is the new global weight of the ith sub-factor of the jth major factor; mj is the new weight of the jth major factor; and Mj is the normalized weight of the jth major factor estimated using FAHP. The estimated global weights of gij are given in Table 12.

As per Table 12, from 0.1 to 0.2, the Eco1 factor held the highest weight, and Qa1 held the second-highest weight, but from 0.3 to 0.9, weight reversal happened, and Del1 held the highest weight, followed by Del2, Del4, and Del3. From the sensitivity analysis, it was evident that the delivery factor was the most important.

Figure 5 represents the rank variation according to the change in weights of sub-factors. Most of the sub-factors showed consistency in the weights and rank, except the sub-factors of delivery (Del) and Qa1. Five sub-factors, i.e., four of delivery (Del) and Qa1, showed a rank reversal. The delivery sub-factors retained new, higher ranks from 1 to 4. At the same time, Qa1 dropped from 2nd to 6th in rank.

Table 12. Sensitivity analysis of sub-factors.

Factors	G Wts	W-0.1	W-0.2	W-0.3	W-0.4	W-0.5	W-0.6	W-0.7	W-0.8	W-0.9
Del1	0.0806	0.0376	0.0753	0.1129	0.1506	0.1882	0.2258	0.2635	0.3011	0.3388
Del2	0.0615	0.0287	0.0575	0.0862	0.1149	0.1436	0.1724	0.2011	0.2298	0.2585
Del3	0.0231	0.0108	0.0216	0.0324	0.0431	0.0539	0.0647	0.0755	0.0863	0.0971
Del4	0.0489	0.0228	0.0457	0.0685	0.0914	0.1142	0.1371	0.1599	0.1828	0.2056
Eco1	0.0934	0.1070	0.0951	0.0832	0.0713	0.0594	0.0476	0.0357	0.0238	0.0119
Eco2	0.0427	0.0489	0.0435	0.0380	0.0326	0.0272	0.0217	0.0163	0.0109	0.0054
Eco3	0.0226	0.0259	0.0230	0.0201	0.0173	0.0144	0.0115	0.0086	0.0058	0.0029
Eco4	0.0258	0.0295	0.0262	0.0230	0.0197	0.0164	0.0131	0.0098	0.0066	0.0033
Env1	0.0409	0.0469	0.0417	0.0365	0.0313	0.0260	0.0208	0.0156	0.0104	0.0052
Env2	0.0409	0.0468	0.0416	0.0364	0.0312	0.0260	0.0208	0.0156	0.0104	0.0052
Env3	0.0251	0.0288	0.0256	0.0224	0.0192	0.0160	0.0128	0.0096	0.0064	0.0032
Env4	0.0198	0.0227	0.0201	0.0176	0.0151	0.0126	0.0101	0.0076	0.0050	0.0025
MO1	0.0378	0.0433	0.0385	0.0337	0.0289	0.0240	0.0192	0.0144	0.0096	0.0048
MO2	0.0182	0.0208	0.0185	0.0162	0.0139	0.0116	0.0093	0.0069	0.0046	0.0023
MO3	0.0190	0.0218	0.0194	0.0170	0.0145	0.0121	0.0097	0.0073	0.0048	0.0024
MO4	0.0155	0.0178	0.0158	0.0138	0.0118	0.0099	0.0079	0.0059	0.0039	0.0020
Qa1	0.0844	0.0967	0.0860	0.0752	0.0645	0.0537	0.0430	0.0322	0.0215	0.0107
Qa2	0.0533	0.0610	0.0542	0.0474	0.0407	0.0339	0.0271	0.0203	0.0136	0.0068
Qa3	0.0323	0.0370	0.0329	0.0288	0.0247	0.0206	0.0164	0.0123	0.0082	0.0041
Qa4	0.0171	0.0196	0.0175	0.0153	0.0131	0.0109	0.0087	0.0065	0.0044	0.0022
Sv1	0.0361	0.0414	0.0368	0.0322	0.0276	0.0230	0.0184	0.0138	0.0092	0.0046
Sv2	0.0258	0.0295	0.0263	0.0230	0.0197	0.0164	0.0131	0.0098	0.0066	0.0033
Sv3	0.0158	0.0181	0.0161	0.0141	0.0121	0.0101	0.0081	0.0060	0.0040	0.0020
Sv4	0.0118	0.0135	0.0120	0.0105	0.0090	0.0075	0.0060	0.0045	0.0030	0.0015
So1	0.0248	0.0284	0.0252	0.0221	0.0189	0.0158	0.0126	0.0095	0.0063	0.0032
So2	0.0052	0.0060	0.0053	0.0046	0.0040	0.0033	0.0027	0.0020	0.0013	0.0007
So3	0.0094	0.0108	0.0096	0.0084	0.0072	0.0060	0.0048	0.0036	0.0024	0.0012
So4	0.0034	0.0039	0.0035	0.0030	0.0026	0.0022	0.0017	0.0013	0.0009	0.0004
Sr1	0.0279	0.0320	0.0284	0.0249	0.0213	0.0178	0.0142	0.0107	0.0071	0.0036
Sr2	0.0149	0.0171	0.0152	0.0133	0.0114	0.0095	0.0076	0.0057	0.0038	0.0019
Sr3	0.0150	0.0172	0.0153	0.0134	0.0115	0.0096	0.0076	0.0057	0.0038	0.0019
Sr4	0.0066	0.0076	0.0067	0.0059	0.0051	0.0042	0.0034	0.0025	0.0017	0.0008

The consistency of the ranks for different values of "w" was tested using two methods. First, the Spearman correlation of the ranks of sub-factors obtained using FAHP (Table 13) and the ranks obtained due to change in "w" was estimated. The average of all these correlation values was 0.958. This shows good consistency and robustness of the technique and result.

Table 13. Spearman correlation values.

	W-0.1	W-0.2	W-0.3	W-0.4	W-0.5	W-0.6	W-0.7	W-0.8	W-0.9	Average
G-wts	0.907	1	0.986	0.964	0.959	0.952	0.952	0.952	0.952	0.9582222

Secondly, we estimated the "MODE" of the ranks of the sub-factors from w-(0.1, 0.9), and Spearman bivariate correlation was calculated with the actual global rank. The correlation value estimated was 0.952.

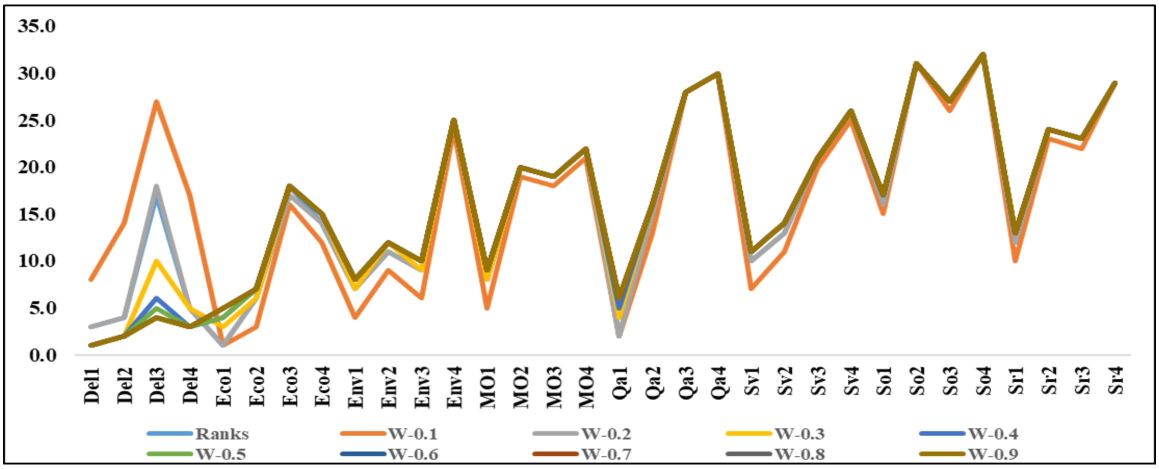

Figure 5. Ranking of sub-factors by increasing weights in a sensitivity analysis.

4. Results and Discussion

This study designed a model for the sustainable supplier selection process in the Indian HVAC manufacturing context after carefully collecting and analyzing the consensus of industry experts and calculating relative stability.

The model comprises eight constructs: delivery, economic, quality, social, service, environmental, supplier relationship, and management and organization. The eight major factors are further classified into 32 sub-factors, which are reliability, service and after-sales service, performance history, cost, skilled and potential staff, strategic organizational structure, financial status of the company, good reputation among industry, on-time delivery, no error in product type and quantity, order lead time, product received in good condition, enhanced value to customers, customer-friendly and environmental adaptability, pollution control, environmental certifications, long durability (life), low rejection/return rate, meeting minimum standards and requirements, ISO certified, ethical issues and legal compliance, mutual trust and easy communication, information disclosure, staff training, fast reaction/responsiveness, technical support, warranty/insurance, ability to collocate to buyer's manufacturing side, long-term cooperation, attitude, flexibility, and customer trade record.

The major factors delivery (0.214), quality (0.187), and economic (0.184) were the top-ranked, followed by environmental (0.127), management and organization (0.091), services (0.09), supplier relationship (0.065), and social (0.043). These results confirm those in the literature [11] indicating that the Indian HVAC manufacturing industry least considers social factors. This study also revealed that Indian HVAC manufacturing industries still prioritize economic, quality, and delivery factors over environmental and social factors, confirming the existing literature [36]. Indian industries also have low awareness or knowledge of environmental factors and little eagerness to update environmental technologies.

Multi-dimensional delivery and quality factors were taken for this study, meeting its basic definition in the context of the manufacturing industry. The existing literature on the SSSP included delivery and quality as a single-dimension sub-factor within economic sustainability factors, focusing on significant quality and correct delivery [23,36,46]. The dimensions (sub-factors) of delivery included the following: "On time delivery (0.3764, 0.081)", "error-free product type and quantity (0.287, 0.0615)", "Condition of product received (reliability) (0.2285, 0.0489)", and "Order lead time (0.1078, 0.0231)". Similarly, the quality dimensions (sub-factors) taken were "Durability (0.4512, 0.0844)", "Rejection/return rate (0.2846, 0.0533)", "meeting standard (0.1726, 0.0323)", and "ISO certified (0.0916, 0.0171)". The delivery sub-factors "On-time delivery (Global rank-2)" and "error-free product type and quantity (Rank-3)" and the quality sub-factors "Durability (rank-4)" and "Rejection/return rate (rank-5)" were the top five most preferred sub-factors/criteria for supplier selection. This outcome was similar to that found by [22].

Economic sustainability factors were the third most preferred major factors for supplier selection in the HVAC manufacturing industry. The sub-factors of economic sustainability factors taken for the study comprised "reliability (0.5064, 0.0934)", "Service and after-sales service (0.2314, 0.0427)", "performance history (0.1225, 0.0226)", and "Cost (price) (0.1397, 0.0258)". The reliability (rank-1) sub-factor was preferred for the HVAC industry supplier selection, while cost (price) (rank-15), though important, was given lesser preference.

Environment sustainability (rank-4) factors were also among the preferred factors due to the basic nature/characteristics of the HVAC products, though they ranked after economic sustainability factors. The sub-factors considered for environmental sustainability were "enhanced value to customers (0.323, 0.0409)", "customer-friendly and environmental adaptability (0.3226, 0.0408)", "Process integration (0.1983, 0.0251)", and "pollution control (0.1561, 0.0198)". Enhanced value to customers (rank-8) and customer-friendly and environmental adaptability (rank-9) were the preferred sub-factors of environmental sustainability for HVAC supplier selection.

The market competition, product characteristics, and environmental relationship of the HVAC products confirm the outcome related to the top factors and sub-factors for supplier selection. HVAC products are generally composed of air conditioners, freezers, heating pumps, etc. With globalization and infrastructure growth, the accessibility of towns, cities, and countries to HVAC products has become easy, faster, and closer. Similarly, the living standards and styles of the residents have improved. The growth in logistics and supply chain technologies has helped move products across all boundaries and make them available to all, regardless of demography and geography. Thus, in order to increase the ability to supply more perishable products, all supply chain stakeholders have demanded and started using HVAC products.

Similarly, for employee retention, well-being, performance, and satisfaction, firms have started using air conditioners and ventilation systems to maintain a healthy work environment [91–94]. The demand for HVAC products is high, and so is the innovation of the product characteristics, owing to their energy consumption and GHG release into the environment. Thus, delivery, quality, and economic factors play a vital role. Since the products, mainly air conditioners and freezers, release GHG gases, seeking alternatives and innovation from suppliers becomes imperative. Owing to the product size and usability of these HVAC products, environmental sustainability factors are not the top priority but are definitely among the preferred in refrigerant use.

5. Managerial and Practical Implications and Limitations

This study's research findings were shared and discussed with the HVAC industry experts. They agreed with most of the results, especially with the top factors/criteria for sustainable supplier selection. The findings were also discussed with the executives and fellow students for the sake of real problem solving. The feedback received was very encouraging.

This study identifies the multi-dimensional critical factors of the SSSP that may enable better procurement and supplier selection decisions. The framework will help consider the environmental aspects and the technological and traditional factors, thus leading to sustainable systems and outcomes. This study stresses the importance of sustainability factors, i.e., economic, environmental, and social, for the SSSP. It provides guidelines to the industry's decision-makers for using specific factors for supplier selection. Apart from sustainability factors, this study reflects the importance of traditional factors, supplier relationship factors, service-related, and management and organizational-related factors/criteria for SSS.

Since multi-dimensional factors are important, group decision-making becomes a prominent aspect of supplier selection that provides more comprehensive information and knowledge [95]. The sensitivity analyses performed on different parameters of the model validate the model's ability to adapt allocations based on fluctuations in key elements of the problem.

This study identifies delivery and quality as the top two critical factors. The literature shows that suppliers with a strong track record in manufacturing capacity, delivery reliability, and quality assurance are probably better equipped to handle risk [95]. Similarly, to mitigate the disruption, firms may proactively allow suppliers to reserve capacity [96]. The supplier having better production capability, quality assurance, and delivery reliability can ensure the availability of materials [11].

This study will also help managers use Delphi techniques and interpret the outcomes to achieve the best results. The index was defined to select the preferred factors from a group of many factors. The index was formed with the combination of COV and the experts' mean response. Any value of COV > 0.2 was considered an inconsistent response by the expert for the specific factors. Similarly, fuzzy AHP was used to better anticipate a qualitative response from the experts and to estimate the most critical or preferred factors. This study will also help managers understand the outcome's consistency through consistency tests by varying values for top factors.

However, the research has a few limitations. The Delphi survey and fuzzy AHP survey were conducted in northern India; however, all major HVAC manufacturing companies have their corporate office or manufacturing units in the northern part of the country. Future research should include respondents from all over India. A case study for the selection of suppliers can be conducted using these criteria.

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Appendix A

Table A1. Factors accumulated from the literature on the SSP.

Factors	Mean	Count	COV	Factors	Mean	Count	COV
(Quality)	4.48	22	0.19	[Good reputation among industry]	3.83	22	0.19
[Ethical issues and legal compliance]	4.48	22	0.16	[Flexibility]	3.78	22	0.19
[On-time delivery]	4.43	22	0.18	[Pollution control]	3.78	22	0.19
[Long-term cooperation]	4.39	22	0.18	[Design of products to reuse]	3.78	22	0.17
[Reliability]	4.35	22	0.19	[Hazardous waste management]	3.78	22	0.19
[Mutual trust and easy communication]	4.26	22	0.18	[Staff training]	3.78	22	0.18
[Skilled and potential staff]	4.26	22	0.18	[Employee right and welfare]	3.78	22	0.18
[Attitude]	4.26	22	0.18	[Customer trade record]	3.74	22	0.24

Table A1. *Cont.*

Factors	Mean	Count	COV	Factors	Mean	Count	COV
[No error in product type and quantity]	4.22	22	0.19	[Environmental certifications]	3.74	22	0.24
[Fast reaction / responsiveness]	4.22	22	0.19	[Recyclable package]	3.74	22	0.27
[Financial stability]	4.22	22	0.16	[Designing energy efficient products]	3.74	22	0.26
[Technical support]	4.17	22	0.17	[Transportation cost]	3.70	22	0.21
[Production capacity]	4.09	22	0.19	[Development of culture and technology]	3.70	22	0.21
[Service and after-sales service]	4.09	22	0.18	[Utilizing eco-friendly and recyclable raw materials]	3.70	22	0.24
[Information disclosure]	4.04	22	0.19	[Green R&D and innovation]	3.70	22	0.24
[Performance history]	4.04	22	0.19	[Internal R&D and scientific expertise]	3.65	22	0.21
[Cost]	4.00	22	0.16	[Automation]	3.57	22	0.25
[Company background]	4.00	22	0.19	[Integration and partnership]	3.57	22	0.20
[Long durability (life)]	4.00	22	0.16	[Trained human resources]	3.57	22	0.28
[Low rejection / return rate]	4.00	22	0.17	[Designing products so that they are easily reusable and recyclable]	3.57	22	0.30
[Product development]	4.00	22	0.19	[Geographical location]	3.52	22	0.22
[Warranty/Insurance]	3.96	22	0.19	[Environmental and social responsibility]	3.52	22	0.22
[Developing supplier's capabilities]	3.96	22	0.19	[Ability to collocate to buyers manufacturing side]	3.52	22	0.24
[Enhanced value to customers]	3.96	22	0.19	[Green operational efficiencies]	3.52	22	0.22
[Financial status of the company]	3.91	22	0.17	[Environmental management systems]	3.43	22	0.30
[Meeting minimum standards and requirements]	3.91	22	0.19	[Creating job opportunities]	3.43	22	0.31
[ISO certified]	3.91	22	0.18	[Carbon reduction initiatives]	3.43	22	0.30
[Provide sample before first ordering]	3.91	22	0.18	[Production cost]	3.39	22	0.25
[Confidence in a durable product]	3.91	22	0.17	[Reverse logistics]	3.39	22	0.30
[Reduced consumption of materials and energy through better design of products]	3.91	22	0.16	[CSR]	3.39	22	0.29
[Good communication system]	3.87	22	0.18	[Environmental cost]	3.35	22	0.25
[Good supplier relationship management (SRM)]	3.87	22	0.18	[N2 environmental commitment of the firm]	3.30	22	0.32
[Customer-friendly and environmental adoptability]	3.87	22	0.17	[Green operational practices]	3.30	22	0.28
[Product shelf life]	3.87	22	0.16	[Selecting supplier based on environmental criteria]	3.30	22	0.31
[Process integration]	3.83	22	0.15	[Green transportation]	3.26	22	0.23
[Strategic organization structure]	3.83	22	0.19	[Pressuring suppliers for green initiatives at their end]	3.22	22	0.31
				[R&D investments]	3.17	22	0.35

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