

## Review Article

# Green Supplier Evaluation and Selections: A State-of-the-Art Literature Review of Models, Methods, and Applications

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The role of green supplier evaluation and selection (GSES) in supply chain management is increasingly appreciated due to the intensification of competition, raising public consciousness, and environmental issues. To improve GSES, a large number of approaches have been proposed in the past decades. However, few attempts have been made to systematically review and classify the literature in this field. The objective of this study is to afford a comprehensive review of the studies which aim to develop models and methods in helping enterprises to assess and select the right green suppliers. To achieve this goal, a total of 193 journal articles extracted from the Scopus database over the period of 2009 to 2020 were chosen and reviewed. These publications were classified into ten categories based on their adopted GSES models and analyzed concerning the evaluation criteria, criteria weighting methods, and performance evaluation methods. Moreover, a bibliometric analysis was conducted according to the frequency of supplier selection methods, citation number, publication year, journal, country, and application area. This study supports practitioners, managers, and researchers in effectively recognizing and applying the GSES models to enhance organizational competitiveness and provides an insight into its state of the art.

## 1. Introduction

Nowadays, the intensification of competition, stringent government laws, and increasing environmental issues have forced enterprises to improve sustainable outcomes in their operation and supply chain practices. Achieving sustainability needs the integration of environmental, social, and economic attributes into their manufacturing processes and supply chains [1]. Supply chains are sophisticated, composed of different organizations dispersed across multiple tiers and different geographies [2]. Green supply chain management (GSCM) is an enterprise strategy which integrates environmental thinking into the supply chain management [3, 4]. In GSCM, complicated mechanisms were employed to the integration and factory level to appraise or enhance environmental outcomes [5]. Via the association among suppliers and consumers, manufacturers could build and practice a compelling arrangement programme while

confronting environmental challenges. The implementation of green supply chain can reduce the generation of pollutants from the source, and the greening degree of suppliers will directly affect the environmental performance of firms [6, 7]. In addition, implementing the green supply chain can bring economic benefits and competitive advantages to a firm, which is paramount important to the development of the firm [8].

Since GSCM includes different phases from raw material purchase to the final product delivery, a focal company should not only green the intraorganizational supply chain operations but also focus on the interorganizational aspects. Suppliers, as upstream supply chain partners, play a significant role in the achievement of sustainability objectives of a firm. Thus, selecting the most qualified green supplier in a supply chain is a vital strategic decision to maintain the competitive position of an organization internationally [5, 6]. For the purpose of high quality and environmental

standards, various aspects and criteria are needed to be considered in the green supplier selection. So, green supplier selection can be seen as a challenging decision-making problem with the goal of ensuring better performance from an enterprise's suppliers.

In the past few years, the development of practical green supplier evaluation and selection (GSES) methods is rapidly evolving [7, 8]. Some literature reviews on GSCM or green supplier selection have been conducted in prior studies from different aspects. For instance, Koeborg and Longoni [2] proposed a systematic literature review of the papers focused on GSCM in global supply chains. Badi and Murtagh [9] performed a systematic review of the literature on GSCM in the construction industry. Bastas and Liyanage [1] undertook a literature review on the integration of quality management, supply chain management, and sustainability management. Maditati et al. [3] investigated the relationships among GSCM drivers, practice indicators, and performance measures via a bibliometric analysis of GSCM articles. Fang and Zhang [10] explored the overall relationship between GSCM practice and company performance by a meta-analysis of the GSCM literature. Fahimnia et al. [4] analyzed the published studies related to GSCM with the aid of bibliometric and network analysis tools. Mardani et al. [11] presented a systematic review of the application of structural equation modelling in the assessment of sustainable and green supply chain management. Igarashi et al. [12] provided a literature review on supplier selection and proposed a conceptual model to integrate the different dimensions of green supplier selection. Konys [13] conducted a meta-analysis of the literature on green-oriented supplier selection and introduced an ontology-based method to synthesize the analyzed selection and evaluation criteria of suppliers. In addition, the quantitative and qualitative decision methodologies in sustainable supplier management were reviewed and analyzed in [7], the multicriteria decision-making (MCDM) methods for designing green supply chains were reviewed in [14], and the MCDM approaches for evaluating green supplier performance were analyzed in [15].

Although the existing literature on GSCM is extensive, no or few research studies have been conducted to review the mathematical models used for supporting GSES comprehensively. The reviews [14, 15] only focused on the MCDM models for green supplier selection, and a previous study by Zimmer et al. [7] does not report criteria weighting methods and performance evaluation methods. Moreover, these literature surveys need an update since more than half of all related papers have been published after their analysis. Therefore, in this study, we systematically review the scientific literature related to GSES models by using the academic database of Scopus. Following a methodological review process, a total of 193 journal articles published between 2009 and 2020 were identified. The main aim of this study is to solve the following research questions: (1) What GSES methodologies have been developed in the literature? (2) What are the criteria considered for GSES problems? (3) What are the weighting methods used for deriving criteria weights? (4) What are the uncertainty methods adopted for

managing experts' evaluation information? Moreover, the statistical analyses on year, journal, country, and application area have been analyzed in order to provide a roadmap to researchers studied in this field.

The rest of this study is organized as follows. After Section 1, Section 2 describes the research methodology followed for the literature review. Section 3 conducts a detailed review of the selected articles classified into ten categories. The bibliometric analysis results and future research suggestions are presented in Sections 4 and 5, respectively. Finally, we conclude this paper in Section 6.

## 2. Research Methodology

To perform a systematic review on the literature of green supplier evaluation and selection, we here followed the PRISMA method [16]. The PRISMA method mainly includes three stages: literature search, eligible article selection, and data extraction. First, the electronic database of Scopus was used for literature search since it is the largest abstract and citation database of the peer-reviewed literature, allowing in-depth exploration of the literature. Only articles written in English and published in academic peer-reviewed journals are considered in this review study. The literature search was conducted by searching the keywords "green supplier selection" and "sustainable supplier selection" in the title, abstract, or keywords for identifying pertinent papers comprehensively. In addition, the time span of this literature review is limited to 2009–2020, and the search was completed in May 2020. As a consequence, a total of 501 papers were retrieved in line with the search strategy as described above. In the second stage, we choose the scientific literature which is in line with the scope of this review. This study only centers on the research studies which had proposed a method or model to address green supplier evaluation and selection problems. Conversely, those papers that research the actual practices of green purchasing and green procurement or only include the environmental performance in supplier selection without quantitative analysis were omitted in the review. Eventually, 193 relevant papers were selected after title ( $n = 318$ ), abstract ( $n = 281$ ), and full-text screening ( $n = 193$ ) based on our inclusion criteria. In the third stage, necessary data were collected from the 193 papers, and the included scholarly researches were summarized (Section 3) and analyzed based on, e.g., supplier selection model, publication year, and published journal (Section 4). Figure 1 illustrates the entire review procedure of this literature survey. It may be mentioned that this literature review was performed very carefully and presents a comprehensive basis regarding the models, methods, and applications of green supplier evaluation and selection.

## 3. Green Supplier Evaluation and Selection Methods

From the collected literature, we can find that multifarious models and methods have been proposed and used to handle the GSES problems. Based on the methods employed in determining the ranking of candidate green suppliers, we

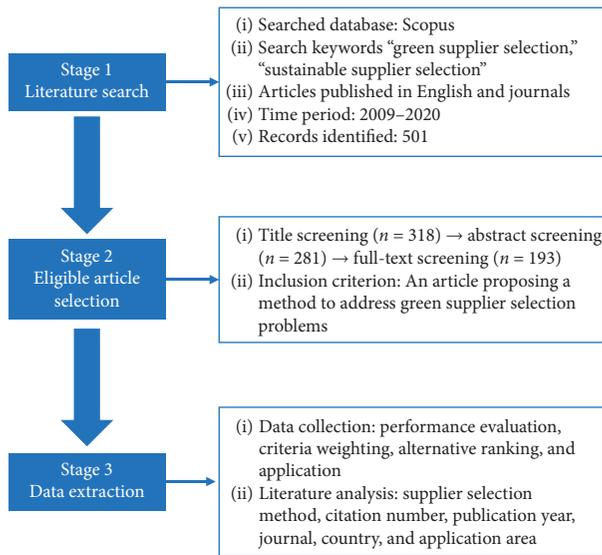


FIGURE 1: Article review process based on the PRISMA method.

construct a classification framework to segregate the literature of the topic to be studied. According to the classification framework, the identified 193 articles are classified into ten categories, including distance-based methods, compromise methods, outranking methods, pairwise comparison methods, mathematical programming methods, aggregation operator-based methods, value and utility methods, combined methods, other green supplier selection methods, and supplier selection and order allocation (SSOA) methods. The categories with their related GSES approaches and papers are summarized in Table 1. Note that the value in the parenthesis denotes the number of articles included in the category.

In the following sections, each of the ten categories is focused and the relevant literature is reviewed in detail with focus on the approaches adopted for green supplier evaluation and selection.

**3.1. Distance-Based Methods.** First, 31 articles were identified to employ the distance-based methods for GSES. Gupta and Barua [17] proposed a hybrid methodology comprising the best worst method (BWM) and the fuzzy technique for the order of preference by similarity to an ideal solution (TOPSIS) for selecting suppliers among small and medium enterprises based on their green innovation ability. Tian et al. [18] applied an intuitionistic fuzzy TOPSIS method integrated with BWM for green supplier selection, and Yucusan et al. [19] combined the BWM with an interval type-2 fuzzy TOPSIS method to solve green supplier selection problems. Wang Chen et al. [20] developed an integrated fuzzy analytic hierarchy process (AHP)-TOPSIS approach for green supplier selection. Abdel-Basset et al. [21] presented an integrated interval-valued neutrosophic analytical network process (ANP)-TOPSIS framework to deal with sustainable supplier selection problems. Some researches selected the most suitable supplier regarding the environmental competencies by using the fuzzy TOPSIS [25, 26], the

intuitionistic fuzzy TOPSIS [23, 24], and the interval type-2 fuzzy TOPSIS [22] methods.

dos Santos et al. [28] integrated fuzzy TOPSIS with the entropy method for the evaluation and selection of green suppliers; Yu et al. [27] utilized an entropy-based TOPSIS method for sustainable supplier selection in the interval-valued Pythagorean fuzzy context. In [35], a hesitant fuzzy TOPSIS model is constructed for supplier evaluation in the green supply chain, in which the evaluation criteria were determined by the decision-making trial and evaluation laboratory model (DEMATEL), and the criteria weights were obtained using the maximizing deviation method. In [36], a hybrid MCDM approach based on the DEMATEL, ANP, and fuzzy TOPSIS was introduced to evaluate green suppliers in fuzzy environment. In [37], a hybrid rough-fuzzy DEMATEL-TOPSIS method was proposed for sustainable supplier selection for a smart supply chain. Fallahpour et al. [30] utilized a hybrid model based on fuzzy preference programming and fuzzy TOPSIS for sustainable supplier selection in a textile company, and Van et al. [29] adopted an integrated approach based on quality function deployment (QFD) and interval neutrosophic TOPSIS for green supplier evaluation in a transportation parts company. Besides, different combination weighting methods (i.e., AHP+entropy method, expert judgement+entropy method, expert judgement+maximizing distance method, and expert judgement+statistical variance method) have been combined with the TOPSIS [32], the fuzzy TOPSIS [34], the intuitionistic fuzzy TOPSIS [33], and the rough cloud TOPSIS [31], respectively, for selecting the best green supplier.

In [41], an integrated green supplier selection approach was proposed with ANP and an improved grey relational analysis (GRA). In [39], an enhanced hybrid GRA model was presented for green resilient supply chain network assessment. A GRA-based green supplier selection method was suggested in [38] that incorporates BWM and fuzzy grey cognitive map to assign criteria weights. Tseng and Chiu [42] applied the fuzzy GRA approach for evaluating firm’s green supply chain management in linguistic preferences, and Tseng [43] utilized fuzzy set theory with grey degree for green supplier selection with linguistic preferences and incomplete information. A weighted grey incidence decision approach was developed by Quan et al. [40] to evaluate and choose the best green supplier in the process industry.

Based on the EDAS method, Yazdani et al. [44] developed a hybrid decision-making model to deal with the GSES problem of a construction company under legislation and risk factors. In this study, the DEMATEL method was employed to calculate the weight of each evaluation criterion, and the failure mode and effect analysis (FMEA) technique was used to determine the risk rating of each alternative supplier. Xu et al. [45] established an extended EDAS model with single-valued complex neutrosophic sets and applied it for green supplier selection. Xu et al. [46] developed a GSES model through the combination of heterogeneous criteria information and an extended multi-attributive border approximation area comparison (MABAC) method. A soft computing approach based on

TABLE 1: GSES methods used in the reviewed literature.

Classification	GSES method	Reference	Frequency
<i>Distance-based methods (31)</i>	TOPSIS	[17–37]	21
	GRA	[38–43]	6
	EDAS	[44, 45]	2
	MABAC	[46]	1
	Relative-closeness coefficient	[47]	1
Compromise methods (19)	VIKOR	[48–61]	14
	MULTIMOORA	[62–66]	5
Outranking methods (14)	ELECTRE	[67–72]	6
	PROMETHEE	[73–76]	4
	QUALIFLEX	[77–80]	4
Pairwise comparison methods (11)	AHP	[81–85]	5
	ANP	[86–90]	5
	AQM	[91]	1
Mathematical programming methods (22)	DEA	[92–109]	18
	MOLP	[110–113]	4
<i>Value and utility methods (30)</i>	TODIM	[114–119]	6
	Prospect theory	[120–122]	3
	Axiomatic design method	[123–125]	3
	Possibilistic statistical method	[126–128]	3
	Digraph and matrix method	[128, 129]	2
	WASPAS	[130–132]	3
	COPRAS	[133, 134]	2
	MAUT	[135]	1
	MARCOS	[136]	1
	Range of value	[137]	1
	Possibility degree	[138]	1
	Fuzzy comprehensive evaluation	[139]	1
	Fuzzy performance index	[140]	1
	Fuzzy preference relationship	[141]	1
	Piecewise linear value function	[142]	1
Aggregation operator-based methods (12)	Choquet integral	[143–146]	4
	Hybrid aggregation operator	[147]	1
	Prioritized average operator	[148]	1
	PBM operator	[149]	1
	HFHPWA operator	[150]	1
	IVIFGWHM operator	[151]	1
	FWA operator	[152]	1
	TOWA operator	[153]	1
	SVTNDPNBM operator	[154]	1
Combined supplier selection methods (14)	GRA-TOPSIS	[155, 156]	2
	TOPSIS, MOORA, GRA	[157]	1
	TOPSIS, VIKOR, GRA	[158]	1
	MOORA, COPRAS	[159]	1
	MOORA, WASPAS	[160]	1
	MLMCDM, TOPSIS	[161]	1
	AHP, TOPSIS, IRP	[162]	1
	VIKOR, ELECTRE	[163]	1
	ARAS, MOLP	[164]	1
	TOPSIS, ELECTRE	[165]	1
	TOPSIS, TODIM	[166]	1
	TOPSIS, ANFIS	[167]	1
	TOPSIS, FIS	[168]	1

TABLE 1: Continued.

Classification	GSES method	Reference	Frequency
Other supplier selection methods (9)	Bayesian network, genetic algorithm	[169]	1
	Bayesian framework, Monte Carlo Markov chain	[170]	1
	Systems dynamics	[171]	1
	FIS	[172, 173]	2
	Satisfaction degree framework, regret theory	[174]	1
	Consensus decision-making method	[175]	1
	Decision-theoretic rough set	[176]	1
Supplier selection and order allocation methods (31)	Six sigma quality indices	[177]	1
	<i>TOPSIS, MOLP</i>	[178–188]	11
	AHP, MOLP	[189–192]	4
	GRA, MOLP	[193]	1
	BWM, MOLP	[194]	1
	QFD, MOLP	[195]	1
	MOORA, FMEA, MOLP	[196]	1
	Decision field theory, MOLP	[197]	1
	AQM, MOLP	[198]	1
	DEMATEL, Taguchi loss function, MOLP	[199]	1
	MOLP model	[200–208]	9

interval type-2 trapezoidal fuzzy sets and relative-closeness coefficients was presented in [47] for the green supplier selection problem.

**3.2. Compromise Methods.** Nineteen articles in our reviewed literature apply the compromise methods to handle GSES problems. First, the interval-valued fuzzy VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) [49], the picture fuzzy VIKOR [56, 61], and the interval-valued intuitionistic fuzzy VIKOR [57] were proposed to evaluate and select the best supplier in sustainable supplier management. In [48], a green supplier selection method based on BWM and VIKOR was introduced to address the GSES problem in interval type-2 fuzzy environment; in [58], a hybrid approach combining fuzzy BWM and interval VIKOR was provided for sustainable circular supplier selection. The AHP was coupled with the VIKOR [44] and the fuzzy VIKOR [43] for green suppliers’ performance evaluation and selection. The ANP was integrated with the VIKOR [51] and the neutrosophic VIKOR [52] for sustainable supplier selection and evaluation in supply chains. The fuzzy preference programming, a modification of AHP, was integrated with fuzzy VIKOR by Fallahpour et al. [59] to assess suppliers’ performance with respect to carbon management criteria. In addition, Zhou and Xu [54] developed an integrated DEMATEL-ANP-VIKOR model for sustainable supplier selection with heterogeneous information, Phochanikorn and Tanand [60] suggested an integrated DEMATEL-ANP-VIKOR approach for sustainable supplier selection under intuitionistic fuzzy environment, and Kuo et al. [55] proposed a green supplier selection method using the DEMATEL-based ANP and the VIKOR to evaluate green suppliers in an electronics company.

Quan et al. [62] proposed a hybrid MCDM approach for the evaluation of suppliers’ environmental performances within the large group environment. Specifically, interval-valued intuitionistic uncertain linguistic sets were used for

assessing candidate green suppliers, an extended linear programming technique for multidimensional analysis of preference (LINMAP) method was adopted to calculate the objective weights of criteria, and an improved multiobjective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA) technique was applied to rank green suppliers. Liu et al. [63] developed a two-stage integrated model for the supplier selection of the green fresh product. In the first stage, the relationships of customer requirements, company strategies, and selection criteria were analyzed by QFD, and subjective criteria weights were computed by fuzzy BWM. In the second stage, the objective criteria weights were determined by the entropy method, and the most suitable suppliers were obtained using the fuzzy MULTIMOORA method. Mohammadi et al. [64] presented a group decision-making method for evaluating and ranking green suppliers, in which the relative preference relation was employed to weight selection criteria and the interval type-2 fuzzy MULTIMOORA method was applied for selecting the best green supplier. Liu et al. [65] developed a large-scale green supplier selection approach based on q-rung interval-valued orthopair fuzzy sets and the MULTIMOORA method, and Liou et al. [66] reported a data-driven green supplier evaluation model using the random forest algorithm, the DEMATEL-based ANP, and the multiobjective optimization on the basis of ratio analysis to the aspiration level (MOORA-AS) method.

**3.3. Outranking Methods.** Fourteen articles in the data set proposed the outranking methods for achieving sustainable supplier selection. Kumar et al. [69] evaluated the suppliers’ performances based on green practices using the fuzzy ELECTRE (elimination and choice translating reality) approach. Lu et al. [68] evaluated and selected the right suppliers by the use of an integrated method based on rough set theory and the ELECTRE approach. Shojaie et al. [67] examined the suppliers of a pharmaceutical company by

using the fuzzy ELECTRE and the entropy method in order to achieve a green health supply chain. Gitinavard et al. [70] investigated the green supplier evaluation problem in manufacturing systems by using the interval-valued hesitant fuzzy ELECTRE and the maximizing deviation method. Tsui and Wen [71] analyzed and prioritized green polarizer suppliers via a hybrid MCDM model, in which the AHP and the entropy method were used to measure the compromised weights of criteria and the ELECTRE III method was adopted to provide the ranking results for executive managers. Guarnieri and Trojan [72] proposed a model which combines AHP with the ELECTRE-TRI to support supplier selection based on social, ethical, and environmental criteria.

Abdullah et al. [74] selected the right suppliers by using the preference ranking organization method for enrichment evaluation (PROMETHEE) under the usual criterion preference functions, and Govindan et al. [75] addressed the green supplier selection problem in the food supply chain by combining revised Simos procedure and PROMETHEE method. Based on the fuzzy AHP and the PROMETHEE methods, Roy et al. [73] established a framework for sustainable supplier selection with heterogeneous information. Wan et al. [76] presented a hesitant fuzzy PROMETHEE method for green supplier selection, in which an entropy-based nonlinear programming model was built to determine criteria weights. The hesitant fuzzy QUALIFLEX method was proposed by Liang and Chong [77] for green supplier selection in the Hong Kong-Zhuhai-Macau bridge project. The probability hesitant fuzzy QUALIFLEX model was suggested by Li and Wang [78] for selecting green suppliers in an automobile manufacturing company. In [79], an integrated decision support framework using cloud model theory and the QUALIFLEX method was developed for the evaluation of qualified green suppliers, and a TOPSIS-based optimization model was constructed to derive the criteria weights with unknown or incompletely known weight information. In [80], a green supplier selection approach for heterogeneous information and dependent criteria based on the QUALIFLEX method and the Choquet integral was proposed.

**3.4. Pairwise Comparison Methods.** Eleven of the reviewed research studies suggested pairwise comparison methods for the selection of optimal green suppliers. The fuzzy AHP [81], the interval type-2 fuzzy AHP [85], the voting AHP [82], and the multiplicative AHP [83] were used for evaluating the performance and selecting the best green supplier in different areas. Xu et al. [84] proposed the use of the sorting method, AHP Sort II, to assess green suppliers in interval type-2 fuzzy environment. The ANP approach was employed in choosing the most suitable sustainable supplier in a white goods manufacturer [86], a bicycle manufacturer [87], an electronics company [88], and multiple manufacturing companies [90]. Büyüközkan and Çifçi [89] developed an approach based on fuzzy ANP within the multiperson decision-making scheme under incomplete preference relations for sustainable supplier selection. Liu et al. [91] reported a model by integrating BWM and alternative queuing method (AQM) within the interval-valued

intuitionistic uncertain linguistic setting to evaluate and select sustainable suppliers under interval-valued intuitionistic uncertain linguistic environment.

**3.5. Mathematical Programming Methods.** The mathematical programming methods have been used by 22 studies for suppliers' green performance evaluation. Dobos and Vörösmarty [93] evaluated and improved the green performance of suppliers using data envelopment analysis (DEA) with incomplete data, and Jafarzadeh Ghoushchi et al. [94] selected sustainable suppliers in the supply chain with a goal programming-DEA model in the presence of imprecise data. Dobos and Vörösmarty [92] developed a DEA-type green supplier selection method, in which the effect of inventory ordering and holding costs on the selected supplier is considered. Wang et al. [97] integrated fuzzy AHP and DEA to identify the optimal suppliers for edible oil production. Kuo and Lin [98] provided an approach using ANP and DEA for evaluating green suppliers, and Kuo et al. [99] built a green supplier selection system by combining the artificial neural network and the ANP into DEA. Kumar et al. [105] proposed a green DEA (GDEA) approach to model the supplier selection problem considering both cost cutting and environmental efficiency. Later, two advanced GDEA modes, the carbon market sensitive-GDEA [103] and the genetic/immune strategy-GDEA [104], were presented for performance evaluation and selection of sustainable suppliers. A systematic DEA approach was introduced in [107] to select suppliers for a sustainable supply chain, and a genetic programming-based DEA method was applied in [106] for green supplier selection under fuzzy environment. In addition, the two-stage DEA [95], the differential evolution-based DEA [96, 101], the fuzzy DEA [100], the interval-valued Pythagorean fuzzy DEA [108], the context-dependent DEA [109], and the ecoefficiency DEA [102] have been established for sustainable supplier evaluation and selection.

Pandey et al. [112] reported a two-phase fuzzy goal programming approach integrating hyperbolic membership function to determine suppliers under the sustainable supply chain environment. Bakeshlou et al. [110] constructed a multiobjective fuzzy linear programming model to solve the green supplier selection problem. In this study, the fuzzy DEMATEL method was used to analyze the interrelations among criteria, and the fuzzy ANP method was utilized to compute the criteria weights with respect to their dependencies. Yeh and Chuang [113] suggested an optimum mathematical planning model for selecting suppliers in green supply chain problems and employed two multiobjective genetic algorithms to find the set of Pareto-optimal solutions. A multiobjective mixed-integer programming model was introduced in [111] to identify optimal suppliers for a green supply chain network considering green factors and stochastic parameters.

**3.6. Value and Utility Methods.** From the review, it has been found that 30 articles used various value and utility methods for solving the green supplier selection problems. The TODIM (an acronym in Portuguese of interactive and multicriteria decision-making) method has been extended by

Qin et al. [115] and Sang and Liu [116] for green supplier selection in the context of interval type-2 fuzzy sets. Bai et al. [114] put forward a grey-based group decision support approach composed of the BWM and the TODIM for social green supplier evaluation and selection, and Arshadi Khamseh and Mahmoodi [117] presented the fuzzy TOPSIS-TODIM hybrid model to choose the best sustainable supplier using fuzzy time function. In [119], the TODIM method was combined with continuous interval-valued linguistic term sets to solve green supplier selection problems. In [118], a green supplier selection approach was suggested based on q-rung orthopair fuzzy sets and the TODIM method, and the weights of criteria were computed by a subjective weighting method and a deviation maximization model.

Phochanikorn and Tan [120] designed an integrated decision-making model based on prospect theory for green supplier selection. It used the fuzzy DEMATEL method to consider the cause and effect relationships of relevant criteria and the fuzzy ANP to assign their weights; the prospect theory was applied to synthesize procurement's psychological and behavioral factors in selecting green suppliers. Wu et al. [121] provided a sustainable photovoltaic module supplier selection model based on triangular intuitionistic fuzzy numbers and cumulative prospect theory. Further, a method combining AHP and entropy theory is proposed to measure the importance of evaluation criteria. An integrated decision framework based on the third-generation prospect theory was given in [122] for sustainable supplier selection under heterogeneous information environment.

The fuzzy axiomatic design approach was used by Guo et al. [123] to address the green supplier selection problem in apparel manufacturing, by Kannan et al. [124] to select the best green supplier for an engineering plastic material manufacturer, and combined with the fuzzy AHP by Büyüközkan [125] to evaluate green supplier alternatives for a Turkish automotive company. Rabbani et al. [126] provided a method for sustainable supplier selection by using interval-valued fuzzy sets and possibilistic statistical reference point systems, and Foroozesh et al. [127] presented a method for green supplier performance evaluation with the interval-valued fuzzy possibilistic statistical model and FMEA. Foroozesh et al. [128] reported interval-valued fuzzy sets and possibilistic statistical approach to select the sustainable supplier for manufacturing services with the lowest risk.

Sinha and Anand [129] presented a framework based on the digraph and matrix method for supplier selection in new product development from sustainability perspective, and KhanMohammadi et al. [209] employed the fuzzy group graph theory and matrix approach for supplier evaluation in sustainable supply chain management. Yazdani et al. [130] considered customer attitudes in the green supplier selection process and applied step-wise weight assessment ratio analysis (SWARA), QFD, and weighted aggregated sum-product assessment (WASPAS) for selecting the optimum green supplier. Zavadskas et al. [131] proposed the use of an interval type-2 fuzzy WASPAS method for multicriteria evaluation of green suppliers, and Mishra et al. [132] suggested a hesitant fuzzy WASPAS method for the assessment of green suppliers based on exponential information measures. A rough complex

proportional assessment (COPRAS) model was developed in [133] for sustainable supplier selection in a construction company. An intuitionistic fuzzy COPRAS method based on parametric measures was proposed in [134] to solve the green supplier selection problem. In addition, the researchers have proposed other green supplier selection methods based on the multiple attribute utility theory [135], the range of value [137], the possibility degree [138], the fuzzy comprehensive evaluation [139], the fuzzy performance index [140], the fuzzy preference relationship [141], the piecewise linear value function [142], and the measurement of alternatives and ranking according to compromise solution (MARCOS) method [136].

*3.7. Aggregation Operator-Based Methods.* Twelve studies have proposed a variety of aggregation operator-based methods for evaluating and selecting suppliers in the sustainable supply chain. Wu et al. [143] selected the optimal green supplier of electric vehicle charging facility based on the Choquet integral operator and interval type-2 fuzzy uncertainty. Shahryari Nia et al. [146] determined the best green supplier for a manufacturing company using interval-valued intuitionistic fuzzy sets and the Choquet integral operator. Zhu and Li [145] established an integrated framework combining the consensus reaching process, the prioritized operator, and the Choquet integral for green supplier selection under hesitant fuzzy linguistic environment. Wang and Li [118] proposed a Choquet integral-based model for sustainable supplier selection which considers the interaction among criteria with heterogeneous decision information.

Xu et al. [147] dealt with the GSES problem by using the interval 2-tuple hybrid averaging (ITHA) operator, the interval 2-tuple ordered weighted averaging-weighted averaging (ITOWAWA) operator, and the interval 2-tuple hybrid geometric operator. Liu et al. [148] addressed the GSES problem with the prioritized average operator under ordered weighted hesitant fuzzy environment. Liu et al. [149] investigated the green supplier selection problem by combining QFD with partitioned Bonferroni mean operator in the context of interval type-2 fuzzy environment. In addition, the fuzzy weighted average operator [152], the 2-tuple ordered weighted averaging (TOWA) operator [153], the hesitant fuzzy Hamacher power weighted average (HFHPWA) operator [150], the interval-valued intuitionistic fuzzy geometric weighted Heronian means (IVIFGWHM) operator [151], and the single-valued triangular neutrosophic Dombi prioritized normalized Bonferroni mean (SVTNDPNBM) operator [154] have been employed for evaluation and selection of the best supplier in green supply chain management.

*3.8. Combined Supplier Selection Methods.* It can also be found from the literature review that 14 studies have combined multiple methods to generate green supplier rankings in solving GSES problems. Chen [155] developed a multicriteria assessment model based on the GRA-TOPSIS for sustainable building material supplier selection in intuitionistic fuzzy setting, and Shi et al. [156] put forward an integrated approach using the GRA-TOPSIS for green

agrifood supplier selection with interval-valued intuitionistic uncertain linguistic information. Yu et al. [165] proposed a hybrid sustainable supplier selection approach integrating the TOPSIS and the ELECTRE methods, and Mao et al. [166] presented an integrated interval-valued intuitionistic fuzzy sustainable supplier selection approach based on the TOPSIS and the TODIM methods. Sen et al. [157] applied the methods of TOPSIS, MOORA, and GRA for evaluating sustainability performance of suppliers under intuitionistic fuzzy context, and Banaeian et al. [158] used the methods of TOPSIS, VIKOR, and GRA for green supplier evaluation and selection in fuzzy environment. In [167], a hybrid model based on the adaptive neurofuzzy inference system (ANFIS) and the TOPSIS was implemented for sustainable supplier selection. In [168], an integrated method based on the fuzzy inference system (FIS) and the fuzzy TOPSIS was used to evaluate the supplier's sustainability performance.

Yazdani et al. [159] developed an integrated approach consisting of DEMATEL, QFD, COPRAS, and MOORA for selecting the best green supplier, and Tavana et al. [160] provided an integrated method combining ANP, QFD, MOORA, and WASPAS for solving sustainable supplier selection problems. Sahu et al. [161] explored the application feasibility of the fuzzy multilevel MCDM (FMLMCDM) approach in evaluating green suppliers by comparing with the fuzzy TOPSIS method. Kaur et al. [162] proposed an integer linear programming model toward the appraisal and selection of green suppliers by integrating the ranking results obtained from AHP, TOPSIS, and interpretive ranking process (IRP). Girubha et al. [163] first used the combination of interpretative structural modelling and ANP for computing the weights of criteria considering their interactions and then applied both VIKOR and ELECTRE algorithms to determine the ranking of available sustainable suppliers. An integrated model was developed in [164] to facilitate supplier selection in the sustainable supply chain by combining fuzzy AHP, fuzzy additive ratio assessment (ARAS), and multisegment goal programming (MSGP) techniques.

*3.9. Other Supplier Selection Methods.* There are nine studies addressing the GSES problems with other methods. Zhang and Cui [169] designed a model combining the Bayesian network with an improved genetic algorithm for selecting suppliers of agricultural means of production. Sarkis and Dhavale [170] put forward a triple bottom line approach using Bayesian framework and Monte Carlo Markov chain simulation toward the evaluation and selection of suppliers for sustainable operations. Orji and Wei [171] developed a modelling approach of integrating the fuzzy logic and the system dynamics to rank and select a sustainable supplier in the manufacturing industry. Amindoust et al. [173] introduced a ranking model based on FIS for the selection of suppliers considering sustainable perspectives, and Amin-doust and Saghafinia [172] applied a modular model on the basis of FIS for textile supplier selection in the sustainable supply chain. In [174], a stochastic dual hesitant fuzzy

linguistic method was proposed based on the group satisfaction degree framework and the regret theory to rank and select green chain suppliers. In [175], a group consensus decision-making model was developed to help choosing the best green supplier for electronics manufacturing. Ma et al. [176] proposed a three-way group decision-making approach to address the selection of the green supplier by extending the decision-theoretic rough sets into hesitant fuzzy linguistic environment. Chen et al. [177] applied the six sigma quality indices to the evaluation of suppliers based on their process yields and quality levels.

### *3.10. Supplier Selection and Order Allocation Methods.*

There are still 31 articles in the reviewed literature which not only support the selection of the green supplier but also determine order allocation among the potential suppliers. Yadavalli et al. [182] adopted a modified TOPSIS using Z-numbers for selecting green suppliers based on customers' expectations, and developed a biobjective mathematical model for allocating optimal amounts to the best performing suppliers. Duan et al. [198] used an extended AQM with linguistic Z-numbers for green supplier selection and established a multiobjective linear programming (MOLP) mode to determine the optimal order quantity for the qualified green suppliers. Govindan and Sivakumar [183] adopted fuzzy TOPSIS for the rating and selection of green suppliers and used an MOLP model for order allocation among the selected suppliers. Tirkolaei et al. [186] implemented a hybrid approach based on fuzzy ANP, fuzzy DEMATEL, and fuzzy TOPSIS to determine the priority of suppliers considering sustainability aspects and developed a multiobjective mixed-integer linear programming model to determine the lot size and program the order allocation.

Kannan et al. [180] presented an integrated approach of fuzzy AHP, fuzzy TOPSIS, and MOLP for rating and selecting the best green suppliers according to economic and environmental criteria, and then allocated the optimum order quantities among them. Similar integrated methods based on the fuzzy AHP, the fuzzy TOPSIS, and the MOLP are also discussed in [178, 179, 181, 187, 188] for green supplier selection and order allocation. Lo et al. [184] established a model that integrates the BWM, the fuzzy TOPSIS, and the fuzzy MOLP for solving problems in green supplier selection and order allocation, and Nourmohamadi Shalke et al. [185] proposed a model by using entropy method, TOPSIS, and multichoice goal programming to evaluate the problem of green supplier selection and order allocation considering quantity discounts.

Banaeian et al. [193] introduced a compound green supplier evaluation and order allocation approach, in which the AHP was used to weight green criteria, the fuzzy GRA was utilized to determine the best suppliers, and the MOLP was constructed to allocate the orders among them optimally. Almasi et al. [189] proposed an AHP-based multiobjective and multiperiod mathematical model for sustainable supplier selection and order allocation under risk and inflation condition, Khoshfetrat et al. [191] suggested an AHP-based fuzzy, multiobjective, multiproduct, and

multiperiod mathematical model for sustainable supplier selection and order allocation in the automotive industry, and Cheraghalipour and Farsad [194] gave a BWM-based biobjective and multiperiod mathematical model for green supplier selection and quota allocation considering quantity discounts under disruption risks. Shaw et al. [190] developed a sustainable supplier selection and order allocation model using the fuzzy AHP and the fuzzy MOLP for developing a low carbon supply chain. Laosirihongthong et al. [192] obtained the ranking of green suppliers using fuzzy AHP and determined purchasing order allocation among the ranked suppliers using cost minimization subject to multiple criteria of economic, environmental, and social conditions.

Babbar and Amin [195] solved the sustainable supplier selection and order allocation problem by fuzzy QFD and stochastic multiobjective mathematical model. Arabsheybani et al. [196] considered supplier's sustainability and order allocation simultaneously on the basis of the fuzzy MOORA, the FMEA, and the multiobjective mathematical model. Gören [199] investigated the sustainable supplier selection and order allocation problem with lost sales by using a decision framework consisting of fuzzy DEMATEL, Taguchi loss function, and biobjective optimization model. You et al. [197] developed a model for selecting the most suitable sustainable suppliers and determined the optimal order sizes among them by combining double hierarchy hesitant linguistic term sets, decision field theory, and MOLP model.

In [201], the authors developed an inclusive multiobjective mixed-integer linear programming model, which accounts for multiple periods, multiple products, and multimodal transportation, to evaluate suppliers and allocate order quantities. In [202], the authors proposed a multiobjective mixed-integer linear program model for selecting critical suppliers in a global supply chain setting and allocated orders incorporating general business and environmental performance objectives. In [204], a biobjective two-stage mixed possibilistic-stochastic programming model was put forward for the sustainable supplier selection and order allocation problem under operational and disruption risks. In [200], a multiobjective integer linear programming model for multiple sourcing and multiple product designs was used to address the green supplier selection and order allocation problem based on regional information. Moheb-Alizadeh and Handfield [201] considered a multiobjective mixed-integer nonlinear programming model for efficient sustainable supplier selection and order allocation with stochastic demand. In addition, Kim et al. [205] established a mixed-integer programming model for large-scale sustainable supplier selection and order allocation, Tsai and Hung [206] constructed a fuzzy goal programming model for optimal green supplier selection and flow allocation, Yu et al. [165] presented a multiobjective mathematical integer programming to select green suppliers and determine their order allocation, and Jia et al. [207] developed a distributionally robust goal programming model including expected constraints and chance constraints for sustainable supplier selection and order allocation problems.

## 4. Findings and Discussions

In this section, the analyses of the selected reviewed articles regarding green supplier evaluation criteria, criteria weighting methods, and green supplier evaluation methods are described. Also, we conducted a bibliometric analysis on the frequency of the green supplier selection method, citation time, year of publication, journal of publication, country of origin, and application field.

*4.1. Green Evaluation Criteria.* In traditional supplier selection, only the economic criteria (such as price, quality, and delivery) are taken into account to arrive at a prioritization or final selection of green suppliers. Over the past decade, the topic of green supplier selection has received increasing attention as organizations started to focus on issues of environmental performance in purchasing due to stricter regulations and pressure from various stakeholders. and social criteria have been included by companies to choose a comprehensive sustainable supplier for improving their sustainable supply chain performance. Thus, it is necessary to analyze the green supplier evaluation criteria employed in the reviewed articles. Taken together, a lot of criteria have been mentioned in the selected research studies, but the classification into different groups varies among them. In this study, we divided the identified criteria into economic, environmental, and social dimensions according to the triple bottom line sustainability framework [7, 12]. The most popular evaluation criteria proposed and used in the literature are shown in Table 2.

In summary, 2270 criteria have been identified from the reviewed articles. Grouping the criteria having the same or similar labels, 4930 unique criteria were derived. Among them, 47.45% economic, 38.41% environmental, and 14.14% social criteria are included. From Table 2, we can observe that the most frequently used criteria are quality, resource consumption, price, green design, environmental management system, and greenhouse gas emission. In the economic dimension, quality, price, and cost are the most important criteria in the selected studies. In the environmental dimension, environmental management system, resource consumption, and green design are the most frequently used criteria. Besides, health and safety, interests and rights, and information disclosure are ranked as the top three social criteria in the literature sample. Figure 2 shows the whole intellectual landscapes of co-occurrence green evaluation criteria in the considered field. It can be seen that environmental, green, management, quality, cost, capability, and delivery are the significant green evaluation criteria taking over notable positions.

*4.2. Criteria Weighting Methods.* An important step of the GSES process is to determine the weight of each green supplier evaluation criterion. In the reviewed literature, multifarious weighting approaches have been proposed for obtaining appropriate criteria weights. Table 3 demonstrates the different types of weighting approaches utilized in the included GSES studies. In general, the currently used

TABLE 2: Green evaluation criteria frequently used in the literature.

Dimension	Criteria	Subcriteria	Literature	Frequency
Economic	Cost	Cost	[22, 27, 39, 41, 47, 50, 58, 61, 62, 64, 69, 70, 72, 74, 83, 85, 91, 100, 106, 108, 110, 112, 115, 116, 128, 132, 143, 146, 148, 151, 154, 162, 164, 165, 167, 170, 172, 173, 178-181, 185-188, 190, 194, 196, 201-203, 207, 210]	54
		Price	[17, 18, 21, 35, 38, 40, 45, 46, 51, 52, 56, 65, 71, 73, 76, 83, 84, 92, 93, 96, 98, 99, 103-105, 107, 109, 122, 124-126, 130, 136, 139, 140, 142, 145, 149, 150, 153, 155, 157-159, 163, 169, 173, 175, 182, 183, 189, 191-193, 195, 198, 199, 205]	58
	Transportation cost		[30, 51, 52, 73, 84, 94, 99, 112, 123-126, 138, 139, 143, 146, 169, 175, 183, 189, 191, 193, 198, 203-205, 211]	27
		Quality	[17, 18, 22, 23, 27, 29, 31, 35, 37-39, 41-43, 45, 46, 47, 48, 54, 56-58, 60-62, 64, 65, 68-70, 72-76, 82-84, 86, 91-93, 96, 98, 100, 112-116, 121, 130, 132, 133, 136, 138, 139, 141-143, 145, 148, 150, 151, 153, 154, 156-160, 163, 165, 170-179, 184, 185, 187, 188, 190, 192-194, 196-199, 202, 207, 208, 211]	97
	Rejection rate	Delivery	[19, 30, 32, 75, 99, 101, 110, 122-124, 137, 143, 146, 163, 169, 175, 180, 183, 198, 204]	20
			[22, 23, 27, 37-40, 45, 51, 54, 58, 60, 62, 63, 65, 70-75, 82, 91, 98, 106, 112, 122, 125, 133, 142, 150, 162-165, 172, 173, 182, 185, 192, 194, 196, 202, 208, 211]	45
	Delivery	Lead time	[20, 30, 51, 57, 73, 86, 92, 93, 96, 103-105, 112, 123-125, 143, 146, 162, 169, 180, 190, 199, 204]	24
		On-time delivery	[17, 30, 32, 35, 61, 64, 67, 72, 86, 94, 108, 109, 116, 121, 124, 126, 136, 138, 140, 153, 167, 169, 170, 186, 198, 209]	26
	Service	Service quality	[24, 27, 32, 35, 36, 42, 43, 72, 76, 79, 83, 89, 96, 122, 124, 145, 156, 158, 164, 170, 200]	21
		Technology capability	[17, 18, 22, 23, 36, 38, 39, 51, 54, 58, 61, 62, 64, 67, 70-72, 74, 75, 79, 83, 87, 89, 112, 114, 116, 124, 129, 132, 137, 141, 142, 144, 162, 165, 167, 170, 173, 182, 185-188, 193-195, 207, 211]	48
Technology	Technology level	[23, 27, 46, 74, 81, 98, 99, 110, 120, 123, 124, 135, 143, 148, 149, 152, 169, 175, 180, 189, 191, 199, 204, 208]	24	
	R&D capability	[17, 30, 35, 71, 75, 77, 81, 110, 121, 123-126, 135, 139, 143, 151, 152, 157, 180, 206]	20	
Flexibility	Flexibility	[27, 30, 39, 46, 51, 58, 59, 64, 69, 71-73, 86, 128, 132, 133, 135, 140, 157, 162, 165, 173, 181, 182, 186]	25	
	Green image	[22-24, 26, 28, 32, 35, 38, 47, 49, 60, 72, 78, 87, 94, 113, 115, 119, 120, 135, 139, 146, 151, 154, 161, 163, 179, 197]	28	
Green image	Environmental management system	[19, 26-29, 43, 47, 51, 57, 61, 72-78, 85, 88, 94, 98, 108, 110, 119, 120, 123, 125-127, 131-134, 136, 142, 145, 156-158, 160, 161, 165, 172, 173, 178, 180, 181, 185, 187, 188, 192, 193, 195, 196, 199, 207-209, 211]	59	
	Pollution control	[29, 38, 49, 54, 57, 69, 71, 84, 106, 124, 126, 127, 133, 136, 137, 141, 157, 160, 167, 173, 175, 192]	22	
Pollution control	Pollution prevention	[17, 19, 51, 52, 55, 77, 81, 86, 112, 120, 124, 135, 152, 161, 189, 191, 195, 207]	18	
	Reduce, reuse, and recycle	[25, 27, 30, 32, 33, 35, 38, 63, 67, 77, 79, 81, 83, 85-87, 92, 93, 101, 107, 111, 113, 122, 124, 126, 127, 130, 136, 149, 151-153, 157, 159, 161, 165, 173, 183, 195, 198, 206]	41	
Pollution control	Pollution production	[26, 28, 38, 41, 47, 48, 54, 58, 61, 78, 110, 115, 122, 123, 131, 134, 143, 147, 163, 178, 180, 185-188, 194, 204, 207]	28	
	Hazardous waste	[25, 29, 30, 33, 35, 42, 43, 55, 72, 87, 88, 90, 95, 99, 113, 118, 124, 135, 140, 146, 175, 204]	22	
Greenhouse gas emission	Greenhouse gas emission	[30, 35, 40, 44, 50, 55, 56, 58, 59, 72, 75, 77, 81-83, 90, 92, 93, 95, 96, 99, 100, 102-105, 107, 111, 113, 123, 124, 135, 138, 152, 153, 157, 168, 173, 183, 185, 190, 194, 198, 201, 203, 211]	46	
	Green manufacturing	[17, 19, 23, 31, 37, 43, 49, 51, 52, 66, 77, 79, 85, 95, 117, 124, 125, 132, 133, 141, 143, 151, 157, 173, 175, 176, 184, 189, 191, 197]	30	
Environmental	Green packaging and labeling	[19, 21, 27, 30, 32, 51, 52, 58, 72-74, 77, 79, 85, 112, 124, 135, 146, 152, 168, 181, 195]	22	
	Green certifications	[20, 25, 30, 32, 33, 42, 43, 55, 77, 81, 85, 99, 113, 118, 124, 136, 138, 139, 146, 151, 152, 161-163, 174, 175, 189, 191, 195, 204]	30	
Green competencies	Green logistics	[17, 30, 31, 33, 37, 57, 72, 77, 79, 86, 113, 114, 118, 119, 125, 137, 146, 151, 160, 168, 184, 197]	22	
	Green design	[17, 26-29, 31, 33, 37, 43, 51, 54, 61, 63, 66-68, 78, 79, 85, 88, 94, 95, 99, 108, 113, 122, 124-127, 130-135, 143, 149, 151, 157, 159, 165, 171, 173, 179, 180, 189, 191, 195, 199, 208, 209]	52	
Environmental	Resource consumption	[21, 26, 28, 33, 35, 38, 41, 48, 50, 54, 57, 59, 63, 75, 77, 78, 81-85, 90, 102, 106, 110, 113, 115, 118, 123, 130-135, 139, 140, 143, 144, 152, 153, 157, 159, 160, 163, 165, 169, 170, 173, 180, 192, 199, 202, 204]	53	
	Use of environmentally friendly technology	[18, 26, 30, 48, 61, 77, 78, 81, 91, 112, 115, 124, 126, 127, 131, 134, 146, 147, 152, 164, 170, 181, 193, 211]	24	
Environmental	Use of environmentally friendly materials	[18, 26, 28, 30, 32, 50, 58, 60, 61, 66, 67, 77, 78, 81, 112, 124, 131, 134, 135, 152, 161, 193, 211]	23	





TABLE 3: Criteria weighting methods used in the literature.

Classification	Weighting methods	References	Frequency
Subjective weighting methods	Direct given	[20, 45, 46, 56, 77, 78, 153]	7
		[22–26, 39, 42, 43, 47, 49, 68, 69, 74, 112, 115, 116, 123, 124, 126, 127,	
	<i>Expert judgement</i>	135, 136, 140, 152, 156–158, 161, 166, 167, 172, 173, 182, 183, 209]	35
	<i>AHP</i>	[20, 50, 51, 72, 81–85, 125, 164, 168, 178–181, 187–193]	23
	<i>ANP</i>	[21, 41, 52, 86–90, 97–99]	11
	<i>BWM</i>	[17–19, 48, 58, 114, 142, 184, 193, 194]	10
	<i>QFD</i>	[29, 57, 149, 195]	4
	<i>Fuzzy AHP</i>	[73, 97, 138]	3
	<i>DEMATEL</i>	[37, 44, 162]	3
	<i>Fuzzy preference programming</i>	[30, 59]	2
	<i>Full consistency method</i>	[133]	1
	<i>SWARA</i>	[198]	1
	<i>PIPERECIA</i>	[197]	1
	<i>Simos method</i>	[75]	1
	<i>Subjective GRA</i>	[139]	1
	<i>Subjective TOPSIS</i>	[117]	1
	<i>Fuzzy DEMATEL</i>	[199]	1
	<i>DEMATEL, ANP</i>	[36, 54, 55, 60, 66, 110, 186]	7
	<i>Fuzzy DEMATEL, fuzzy ANP</i>	[120]	1
	<i>ISM, ANP</i>	[163]	1
<i>DEMATEL, QFD</i>	[159]	1	
<i>ANP, QFD</i>	[160]	1	
<i>SWARA, QFD</i>	[130]	1	
<i>BWM, FGCM</i>	[38]	1	
Objective weighting methods	<i>DEA</i>	[92–96, 100–109]	15
	<i>Entropy method</i>	[27, 28, 61, 65, 67, 128, 155, 165, 185]	9
	<i>Choquet integral</i>	[80, 143–146]	5
	<i>Maximizing deviation method</i>	[35, 70]	2
	<i>Ordered weight</i>	[141, 150]	2
	<i>Hesitant fuzzy entropy measure</i>	[76]	1
	<i>Divergence measure method</i>	[134]	1
	<i>Grey incidence entropy</i>	[40]	1
	<i>Objective GRA</i>	[122]	1
	<i>Objective TOPSIS (incomplete weight)</i>	[79]	1
	<i>LINMAP</i>	[149]	1
	<i>Relative preference relation</i>	[64]	1
	<i>Preference selection index</i>	[137]	1
	<i>Time sequence weight</i>	[151]	1
	<i>Delphi method</i>	[208]	1
Combination weighting methods	<i>AHP and entropy method</i>	[32, 63, 71, 121]	4
	<i>Expert judgement and entropy method</i>	[34, 131]	2
	<i>Entropy method and divergence measure method</i>	[132]	1
	<i>Expert judgement and maximizing distance method</i>	[33]	1
	<i>Expert judgement and maximizing deviation method</i>	[118]	1
	<i>Expert judgement and statistical variance method</i>	[31]	1
	<i>Direct given and ordered weight</i>	[147]	1

TABLE 4: Green supplier evaluation methods used in the literature.

Evaluation methods	References	Frequency
Fuzzy sets ( <i>TFNs</i> )	[17, 25, 26, 28, 30, 34, 36, 37, 42, 43, 50, 59, 67,	44
Fuzzy sets ( <i>TrFNs</i> )	69, 81, 89, 100, 117, 123–125, 137, 142, 152, 158, 161, 162, 164, 165, 168, 171, 172, 177–181, 187, 188, 190, 192, 193, 196, 209]	
Interval type-2 fuzzy sets	[63, 106, 110, 112, 140, 148, 173, 183, 184, 195]	10
Intuitionistic fuzzy sets	[19, 22, 48, 64, 84, 115, 116, 131, 143, 149]	10
Heterogeneous information	[18, 23, 24, 33, 60, 121, 134, 155, 157]	9
Hesitant fuzzy sets	[46, 54, 73, 80, 122, 144]	6
Interval-valued fuzzy sets	[35, 76, 77, 132, 150]	5
Grey numbers	[49, 126–128]	4
Interval-valued intuitionistic uncertain linguistic sets	[38, 39, 41, 114]	4
Interval-valued intuitionistic fuzzy sets	[149, 156, 193]	3
Neutrosophic sets	[146, 151, 166]	3
Rough sets	[21, 52]	2
Cloud model theory	[68, 197]	2
Interval-valued Pythagorean fuzzy sets	[79, 138]	2
Picture fuzzy sets	[27, 108]	2
Interval-valued intuitionistic trapezoidal fuzzy sets	[56, 61]	2
Interval type-2 trapezoidal fuzzy sets	[57]	1
2-Tuple linguistic variables	[47]	1
Interval 2-tuple linguistic variables	[153]	1
Hesitant 2-tuple linguistic variables	[147]	1
Interval neutrosophic sets	[145]	1
Probability hesitant fuzzy sets	[29]	1
Interval-valued hesitant fuzzy sets	[78]	1
Continuous interval-valued linguistic term set	[70]	1
Z-numbers	[119]	1
Rough cloud model	[182]	1
$q$ -Rung interval-valued orthopair fuzzy sets	[198]	1
Ordered weighted hesitant fuzzy sets	[31]	1
Single-valued complex neutrosophic sets	[118]	1
Single-valued triangular neutrosophic sets	[65]	1
Hesitant fuzzy linguistic term sets	[20]	1
Double hierarchy hesitant linguistic term sets	[45]	1
Hesitant fuzzy linguistic term sets	[154]	1
Hesitant fuzzy linguistic term sets	[176]	1
Hesitant fuzzy linguistic term sets	[197]	1
Hesitant fuzzy linguistic term sets	[174]	1

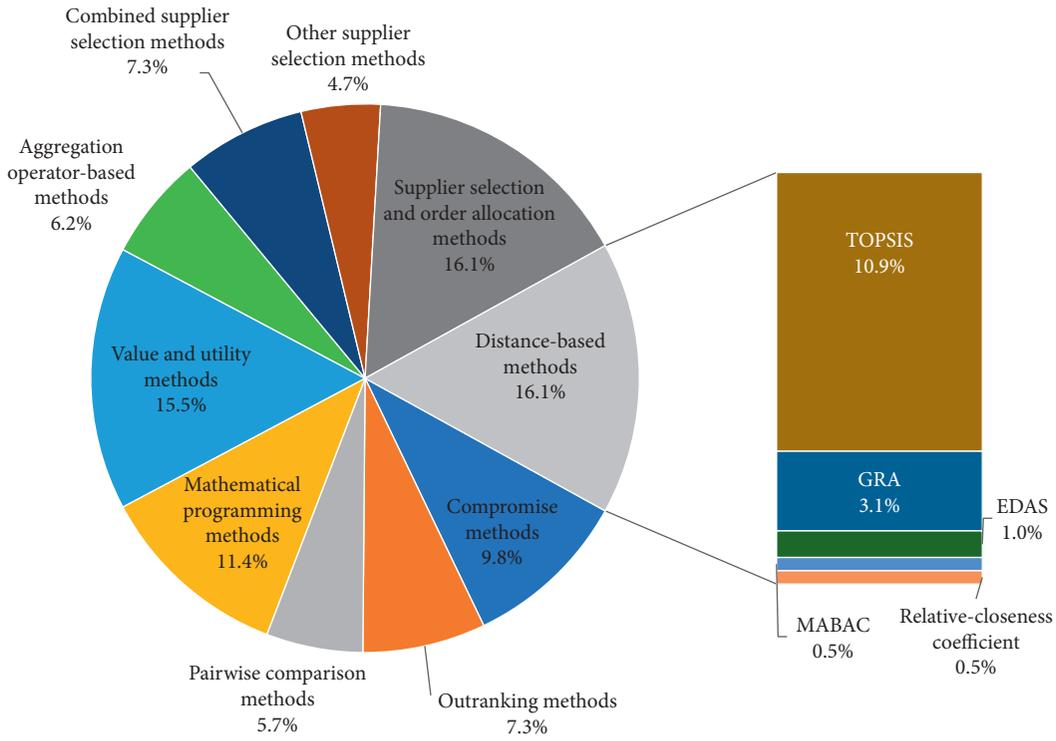


FIGURE 3: Green supplier selection methods in the reviewed literature.

TABLE 5: Top 10 influential papers.

Papers	Average citation	Total citation
Qin et al. [115]	75	224
Banaeian et al. [158]	68	135
Hashemi et al. [41]	44	222
Lee et al. [81]	41	454
Yazdani et al. [159]	41	123
Kuo et al. [99]	34	341
Shen et al. [26]	34	235
Govindan et al. [75]	20	61
Tsai and Hung [206]	15	167
Tseng [43]	13	113

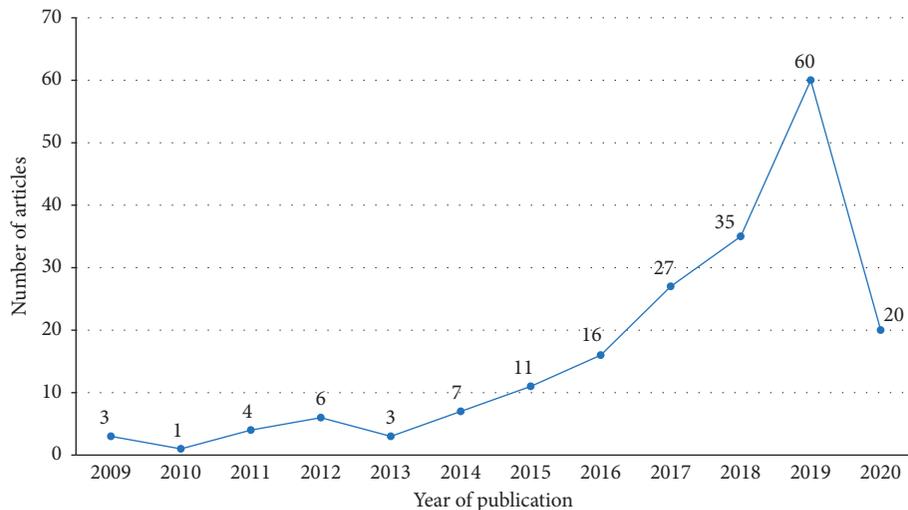


FIGURE 4: Distribution of articles by the publication year.

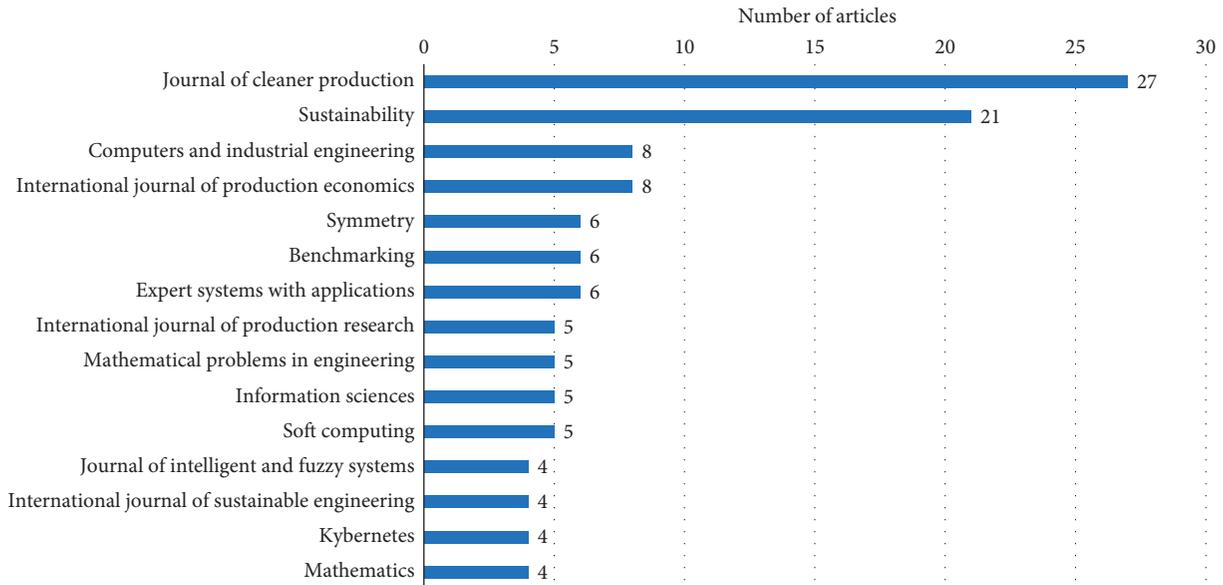


FIGURE 5: Distribution of articles by the publication journal.

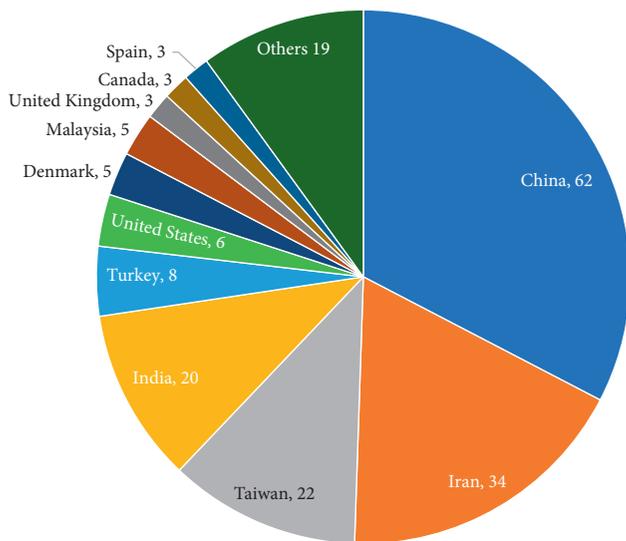


FIGURE 6: Distribution of articles with respect to the country.

items in 2009; 63.2% of the articles in the area are published in the three years (2017–2019). This can be attributed to the fact that sustainability has become a more and more significant portion in enterprise operation management due to growth of customer environmental consciousness, stringent governmental regulations, and stress from inside and outside stakeholders. In addition, some literature reviews of green supply chain management have been published in 2015 focusing on bibliometric and network analysis [4], modelling techniques [6, 12], and theoretical framework development [6]. Nowadays, it is a challenging task for academicians and practitioners to evaluate and select the most appropriate green suppliers in different stages of product life cycle. Thus, it is anticipated that the number of research studies on the GSES will increase quickly in the next years.

Figure 5 displays the journals with more than four papers on the GSES. It can be seen that the *Journal of Cleaner Production* is the leading journal in GSES problems with 27 published articles, followed by *Sustainability* with 21 articles. Besides, *Computers and Industrial Engineering* and *International Journal of Production Economics* have published 8 articles in this field. Figure 6 depicts the number of the reviewed publications on the basis of the country of origin. As can be seen from the figure, more than 71.5% of the considered publications (138 articles) are derived from four countries and regions (China, Iran, Taiwan, and India), and China with 62 articles is ranked as the first based on the number of articles followed by Iran with 34 articles. Figure 7 shows the applied field distribution of the selected articles. The result demonstrates that the proposed GSES methods have been utilized in a variety of fields, and the top four application domains are automobile industry (53 articles), electronics industry (25 articles), manufacturing industry (20 articles), and food industry (19 articles), respectively. Furthermore, the GSES methods have been commonly used in construction, energy and chemical, and home appliance industries.

## 5. Future Research Recommendations

This review study demonstrates that GSES has attracted a lot of attention from scholars and a variety of GSES models have been proposed mainly from the aspects of performance assessment, evaluation criteria weighting, and alternative suppliers ranking. Based on the results of this review, many opportunities can be identified for future research, and the following ones are promising directions:

- (1) Considering the performance information of alternative suppliers is usually vague, uncertain, or even incomplete, so it is suggested to use the latest uncertainty theories to effectively manipulate uncertainties from human judgements, manage

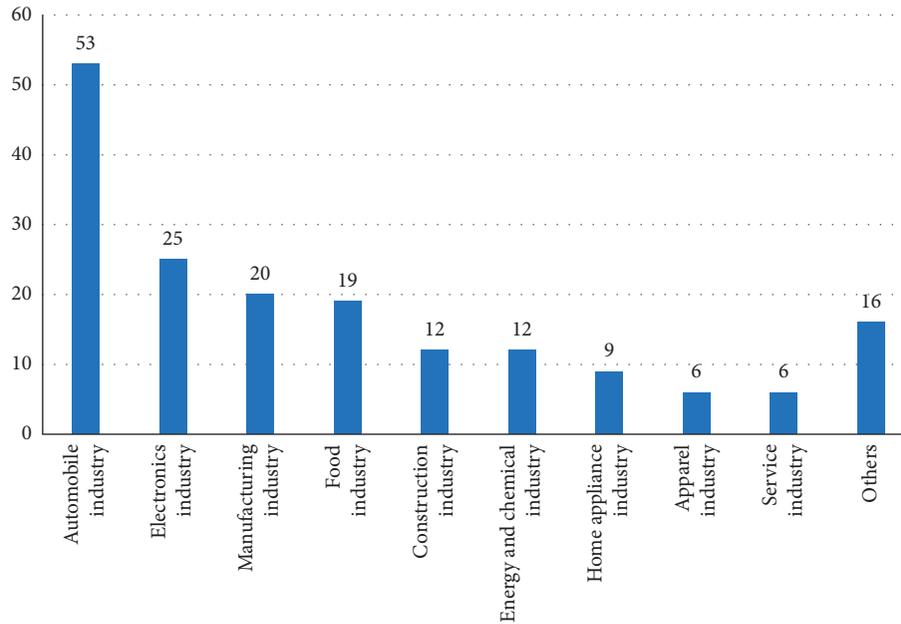


FIGURE 7: Distribution of articles by the application area.

incomplete performance evaluations and heterogeneous evaluation data, and bring an organized method to characterize decision makers' experience and knowledge for GSES.

- (2) Decision makers in the GSES may have different experience, backgrounds, and interests, and thus conflict opinions are unavoidable in the green supplier evaluation process. Thus, as another direction for future studies, consensus methods are suggested to be proposed to solve conflict judgments of decision makers, which will improve group consistency and lead to efficiency improvement in the GSES process.
- (3) A variety of weighting methods have been adopted to specify the weights of evaluation criteria in the GSES studies. In the future, it is suggested to explore new subjective weighting, objective weighting, and combination weighting methods. Besides, in some situations, the criteria weight information may be incomplete. Therefore, incomplete weighting approaches should be proposed for obtaining the weights of criteria in the future. In addition, in the reviewed articles, the criteria weights are constant for all alternative green suppliers. It is suggested for the future study to assign different sets of criteria weights for different alternatives in the GSES.
- (4) The literature review shows that some scholars started to focus on the determination of decision makers' weights [16, 20, 21, 51, 55]. As a result, the techniques to acquire the weights of decision makers are suggested to be studied in the future research. Particularly, it would be very meaningful to dynamically assigning decision makers' weights based on their given evaluation information for alternative suppliers.

- (5) It is found that MCDM methods are the most popular tools for determining the priority ranking of green suppliers. Future research can be targeted towards applying other MCDM methods such as MACBETH, UTASTAR, and THESEUS to support decision-making in the GSES. Also, to combine the superiorities of different MCDM approaches, future research is suggested to propose GSES models by using multiple or integrated MCDM methods.
- (6) In recent years, data have started to be generated on a large volume in the GSCM field. It has been expected that the amount of data will continue to increase largely due to the complexity of GSES problems. Therefore, with regard to the presentation of a large number of criteria and alternatives, we suggest to propose modify methods to handle such data in the GSES.
- (7) Another possible direction for future work would be to employ techniques such as intelligent algorithms and system dynamics to efficiently solve GSES problems. For instance, deep learning algorithms can be employed to learn criteria weights from the evaluation data of decision makers on every green supplier. Also, MCDM methods can be empowered by neural networks to consider fluctuations in the ranking of alternative suppliers in the way changes occur in the human brain.

## 6. Conclusions

With the increasing awareness on environmental issues and growing pressure from internal and external stakeholders, companies are adopting GSCM in their supply chain practices to achieve positive outcomes on environmental, social, and economic aspects. In response, a lot of models have been developed for evaluating and selecting green

suppliers in the literature. In this study, we conducted a comprehensive review of the publications that concern quantitative models for supporting green supplier selection. A total of 193 articles published in peer-reviewed journals between 2009 and 2020 were identified as relevant to this review from the Scopus database. According to the GSES methods being proposed, the chosen articles were classified into ten categories, i.e., distance-based methods, compromise methods, outranking methods, pairwise comparison methods, mathematical programming methods, aggregation operator-based methods, value and utility methods, combined methods, other green supplier selection methods, and SSOA methods. Further, we find that the TOPSIS and the DEA are the two most popular methods applied to determine the ranking orders of candidate sustainable suppliers. Second, it is discovered that the most frequently used green evaluation criteria are quality, resource consumption, price, green design, environmental management system, and greenhouse gas emission. The subjective weighting, objective weighting, and combination weighting methods are all adopted in prior researches to calculate the important weights of green evaluation criteria. Moreover, the criteria weights are mostly obtained on the basis of decision makers' expert judgements. The analysis of green supplier evaluation methods showed that fuzzy set theory is the most preferred approach employed to handle fuzzy and imprecise performance evaluation information. This review study provides academics and practitioners with a guideline and insight into further proposing and applying the GSES approaches to help firms improve environmental sustainability and gain higher competitive performance.

## Conflicts of Interest

The authors declare no conflicts of interest.

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