

# Validation of Green Supplier Ranking Results Using a Model Comparison and Scenario Analysis Approach (MCDM) Based on Rough Sets

Hossein. Poursmaeil<sup>1</sup>, Majid. Bagherzadeh Khajeh<sup>1\*</sup>, Kamaleddin. Rahmani<sup>1</sup>, Alireza. Bafandeh Zende<sup>1</sup>,  
Mohammad. Pasban<sup>1</sup>

<sup>1</sup> Department of Management, Ta.C., Islamic Azad University, Tabriz, Iran

\* Corresponding author email address: bagerzadeh@iaut.ac.ir

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## ABSTRACT

Environmental protection and sustainable development, as strategic imperatives, have made green supplier selection a key issue in manufacturing supply chains. Accordingly, the aim of this study was to validate a green supplier selection model based on a multi-objective programming approach and rough sets within the context of the automotive industry (Iran Khodro Company). In terms of purpose, this research was applied-developmental, and in terms of methodology, it was descriptive. The statistical population consisted of Iran Khodro Company and all of its affiliated parts suppliers. Data were collected using a researcher-developed questionnaire as well as documents and records obtained from the company and its suppliers. Based on the Morgan table for sample size determination, 66 respondents were selected to complete the questionnaire, while at the decision-making stage, 18 qualified suppliers were examined. The validity of the measurement instrument was assessed using content validity (through the relevant index/coefficient), and its reliability was evaluated using Cronbach's alpha. In the validation phase, the quality of the measurement model was first assessed through confirmatory factor analysis. The results indicated that the model fit indices were within acceptable ranges, with the values of  $CMIN/\chi^2$ , RMSEA, and RMR being reported. In addition, the factor loadings of all items associated with the extracted components—including information exchange, types of environmental certifications, recycling, sustainable design, and procurement of environmentally friendly raw materials—were greater than 0.5, and the t-statistics for all measurement paths exceeded 1.96 at the 95% confidence level. Therefore, the construct validity of the model was confirmed. Finally, using the integrated multi-objective programming and rough set model, the selected suppliers were ranked and selected in terms of price, quality, service level, and environmental components, and practical recommendations were proposed to facilitate more effective implementation of the model.

**Keywords:** Supplier selection, multi-objective programming, rough sets, confirmatory factor analysis, Iran Khodro

## 1. Introduction

Environmental sustainability has become a central concern in contemporary supply chain management because firms increasingly face simultaneous pressures to maintain economic performance, comply with environmental expectations, reduce resource consumption, and respond to stakeholder demands for responsible production. These pressures have shifted supply chain management from a predominantly cost- and efficiency-oriented discipline toward a broader strategic framework in which environmental performance, green innovation, resource efficiency, and interorganizational coordination are treated as essential dimensions of competitiveness. Green supply chain management (GSCM) reflects this transformation by integrating environmental considerations into procurement, supplier relationships, production processes, logistics, information exchange, product design, and end-of-life activities. Recent studies indicate that green supply chain practices can contribute not only to ecological outcomes but also to sustainable competitive advantage, organizational resilience, and long-term operational performance when they are supported by suitable strategic capabilities and innovation mechanisms (Asiedu et al., 2026; Liu et al., 2026). Accordingly, organizations operating in environmentally sensitive and resource-intensive industries increasingly view green supply chain management as a strategic necessity rather than a peripheral environmental initiative.

The growing importance of GSCM is particularly evident in manufacturing industries, where purchasing and supplier-related activities represent a substantial proportion of total production cost and environmental impact. Environmental performance at the focal-firm level is highly dependent on the practices adopted by upstream suppliers, because suppliers influence the environmental characteristics of raw materials, components, production technologies, packaging, energy consumption, emissions, waste generation, and recycling potential. Therefore, environmental orientation cannot be implemented effectively within organizational boundaries alone and requires cooperation with supply chain partners. Evidence suggests that supplier integration, customer orientation, and the use of green information systems can significantly support green innovation and strengthen the environmental performance of manufacturing networks (Mahmoudzadeh & Mahmoudzadeh, 2023). Similarly, buyer environmental orientation can shape green innovation through its influence on supplier behavior and

resource allocation, although the availability and use of supplier slack resources may affect the strength of this relationship (Yang & Jiang, 2023). These findings highlight that green performance is an interorganizational phenomenon and that supplier-related decisions must be aligned with the broader environmental strategy of the focal firm.

Green supplier selection has therefore emerged as one of the most important decisions within sustainable supply chain management. Traditional supplier selection models have generally emphasized criteria such as price, quality, delivery reliability, production capacity, and service level. Although these criteria remain important, contemporary green supplier selection requires the incorporation of additional dimensions, including environmental management capability, environmental certification, waste reduction, pollution control, energy efficiency, use of environmentally friendly materials, clean technology, reverse logistics, recycling, green design, and environmental information exchange. The inclusion of such criteria significantly increases the complexity of supplier evaluation because decision makers must simultaneously consider economic, operational, and environmental objectives. In this context, green supplier selection becomes a multi-criteria and often multi-objective decision problem characterized by conflicting priorities, heterogeneous information, and varying degrees of uncertainty.

The complexity of green supplier selection has encouraged the development of increasingly sophisticated multi-criteria decision-making approaches. In practice, managers rarely evaluate suppliers on the basis of a single criterion, and many decision attributes are qualitative, imprecise, or dependent on managerial judgment. As a result, hybrid decision models have been widely employed to combine managerial preferences with analytical techniques. For example, a hybrid fuzzy decision-making framework has been proposed for green-agile supplier selection in the medical device industry, demonstrating the usefulness of integrating environmental and agility-related criteria under uncertainty (Alamroshan et al., 2022). Likewise, a green-resilient supplier selection model based on the fuzzy best–worst method has shown how resilience and environmental criteria can be jointly incorporated into supplier assessment (Hailiang et al., 2023). These approaches reflect a broader methodological trend toward combining multi-criteria decision-making methods with fuzzy, optimization, and uncertainty-handling techniques to improve the robustness of supplier selection decisions.

Another important methodological issue is the incorporation of managerial opinion into supplier selection models. Quantitative optimization models can provide structured and replicable results, but they may fail to capture the subjective preferences, strategic priorities, and contextual knowledge of managers if decision makers are not adequately represented in the modeling process. Research has therefore emphasized the integration of managerial judgments into green supplier selection through techniques such as Quality Function Deployment and interactive fuzzy programming (Khattak et al., 2022). This is particularly important in complex industrial environments, where the relative importance of criteria such as environmental certification, quality, service level, cost, and recycling capability may vary according to organizational strategy, regulatory expectations, and operational constraints. From this perspective, a suitable green supplier selection model should not only provide mathematically optimized results but should also reflect the real priorities of the organization and the practical knowledge of experts involved in purchasing and supplier evaluation.

Beyond supplier selection itself, green supply chain management has increasingly been linked to innovation capability and organizational sustainability. Firms that integrate environmental considerations into supply chain processes are more likely to develop green innovations, reduce resource consumption, and improve sustainable performance. Green business strategy and artificial intelligence capabilities, for example, may enhance sustainable performance through knowledge integration, green innovation, and GSCM mechanisms (Liu et al., 2026). Similarly, big data analytics and artificial intelligence have been associated with stronger sustainable performance through their contribution to green supply chain practices in manufacturing firms (Rashid et al., 2025). These developments suggest that green supplier evaluation should be understood within a broader transition toward digitally enabled and knowledge-intensive supply chains, where information quality, technological capabilities, and interorganizational knowledge exchange play increasingly important roles.

The role of information and knowledge is particularly relevant in supplier evaluation. Effective green supply chain management requires transparent and reliable information regarding suppliers' environmental practices, production processes, resource consumption, certifications, pollution levels, and sustainability initiatives. Information exchange can reduce uncertainty, improve coordination, support

monitoring, and facilitate collaborative environmental improvement. Furthermore, the strategic use of green information systems can strengthen the relationship between supply chain integration and green innovation, particularly in automotive manufacturing contexts (Mahmoudzadeh & Mahmoudzadeh, 2023). In this regard, information exchange should be considered a distinct and measurable dimension of supplier environmental performance rather than a merely supporting administrative function.

Environmental certification represents another important dimension of green supplier assessment. Certifications and environmental management standards provide external signals regarding suppliers' commitment to environmental policies, control procedures, regulatory compliance, and continuous improvement. Although certifications alone cannot guarantee superior environmental performance, they can serve as useful screening mechanisms when combined with behavioral and operational indicators. Evaluating the existence and diversity of environmental certifications may therefore help purchasing organizations distinguish between suppliers that have formalized environmental management practices and those that rely primarily on informal or reactive approaches. This is especially important in large supply networks where direct monitoring of every environmental activity is costly and difficult.

Recycling and reverse-flow activities have also become increasingly significant in the transition toward circular and low-carbon supply chains. Supplier recycling capability can influence waste reduction, material recovery, production efficiency, and the environmental footprint of final products. Similarly, sustainable product and component design can reduce material intensity, improve recyclability, facilitate disassembly, and support cleaner production. These dimensions are particularly relevant in industries such as automotive manufacturing, where large quantities of metals, polymers, electronic components, fluids, packaging materials, and energy-intensive inputs are used throughout the production cycle. Current decarbonization research in automotive-related supply chains emphasizes that emission reduction requires coordinated interventions across material sourcing, production, technology selection, and upstream supply relationships (Shen et al., 2025). Thus, supplier selection based on environmental performance can serve as a practical mechanism for supporting broader industrial decarbonization objectives.

The strategic significance of GSCM is further supported by evidence linking it to energy efficiency and resource productivity. Green supply chain practices and green

technology innovation can contribute to reductions in firms' energy consumption intensity, thereby improving both environmental and economic performance (Wang et al., 2025). Likewise, environmental orientation may enhance sustainable organizational outcomes when its effects are transmitted through green supply chain management and green innovation, particularly under institutional pressure (Niromand et al., 2025). Such findings indicate that green supplier selection should not be viewed as an isolated purchasing decision. Rather, it is part of a wider organizational system in which supplier quality, environmental strategy, innovation, regulatory pressures, and resource efficiency are interconnected.

Institutional and organizational conditions also influence the success of green supply chain initiatives. Identifying key success factors for the implementation of GSCM in national and sectoral contexts is essential because environmental practices are shaped by industry structure, regulatory systems, institutional pressures, managerial capabilities, and organizational resources (Zarei et al., 2025). In developing economies, firms may face additional challenges, including limited environmental infrastructure, uneven supplier capabilities, resource constraints, and differences in the maturity of management systems. Consequently, supplier evaluation frameworks must be adapted to the characteristics of the industrial environment in which they are applied rather than directly transferring criteria and thresholds from other contexts.

Organizational capabilities also play an important role in determining whether green supply chain practices translate into sustainable outcomes. Dynamic capabilities, supply chain agility, and innovation can strengthen the ability of firms to respond to environmental pressures and align supply chain practices with Sustainable Development Goals (Olaleye et al., 2025). Green ambidexterity, involving the simultaneous pursuit of exploitative and exploratory green innovation, has likewise been identified as an important mechanism linking green supply chain management to sustainable competitive advantage (Asiedu et al., 2026). From a managerial perspective, these findings reinforce the need to select suppliers not only on the basis of current performance but also according to their capacity for adaptation, learning, technological improvement, and environmental innovation.

Human and organizational factors further affect green supply chain performance. Inclusive leadership and a supportive green psychological climate can foster employee green creativity, which in turn contributes to more

sustainable supply chain performance (Rasheed et al., 2026). This indicates that sustainability performance depends not only on formal systems and technologies but also on organizational culture, leadership, and employee engagement. Although supplier selection models typically emphasize observable operational criteria, the broader organizational context may influence suppliers' ability to sustain environmental improvements over time. Therefore, supplier evaluation systems should be sufficiently comprehensive to capture both measurable environmental outcomes and organizational practices that support continuous improvement.

Financial and interorganizational mechanisms also shape green innovation across supply chains. Supply chain finance can influence breakthrough green innovation by facilitating resource access and knowledge spillovers between core firms and other supply chain members (Huang et al., 2026). Similarly, environmental orientation can improve financial performance through mechanisms related to green supplier management and relational capital (Farahabadi & Heydarpour, 2023). These findings suggest that supplier relationships are not merely transactional arrangements but can function as channels for knowledge transfer, financial support, innovation diffusion, and collaborative environmental improvement. Thus, a robust supplier selection approach should support the identification of suppliers that can contribute to long-term strategic and environmental objectives rather than merely minimize short-term purchasing cost.

The complexity of such supplier relationships increases the importance of systematic prioritization and ranking methods. Multi-criteria decision-making is particularly suitable for problems in which numerous indicators must be evaluated simultaneously and where trade-offs exist among competing objectives. In broader management settings, structured ranking and prioritization of strategic components have been used to support policy making and resource allocation, demonstrating the value of systematic decision frameworks when multiple strategic factors must be considered (Samadzadeh et al., 2022). In green supplier selection, such structured methods can improve transparency, reduce arbitrary judgments, and provide a traceable basis for comparing supplier alternatives.

Nevertheless, a persistent methodological challenge concerns uncertainty and imprecision in supplier evaluation data. Environmental performance data may be incomplete, heterogeneous, or subject to varying interpretations across experts. Conventional crisp scoring approaches may

therefore generate misleadingly precise rankings and may not adequately represent uncertainty in the available information. Rough set theory provides a useful framework for addressing such situations because it can model vagueness and indiscernibility directly from observed data without requiring predefined probability distributions or membership functions. When integrated with multi-objective programming, rough sets can help construct supplier selection models that simultaneously consider competing objectives and uncertainty in decision information. This combination is particularly appropriate for industrial supplier evaluation, where decision makers must balance price, quality, service, and environmental performance while working with incomplete or imprecise information.

Another important issue is the validation of the resulting supplier ranking. Many supplier selection studies focus primarily on model construction and the generation of a final ranking, while comparatively less attention is given to determining whether the ranking remains stable across alternative model specifications, weighting structures, or decision scenarios. Yet, from a managerial perspective, a ranking is useful only when decision makers can have sufficient confidence that minor changes in assumptions do not produce substantially different outcomes. Model comparison and scenario analysis can therefore strengthen the credibility of supplier selection results by examining whether rankings remain consistent under alternative analytical conditions. Such validation is especially important when supplier selection decisions have long-term implications for purchasing contracts, production continuity, environmental compliance, and supply chain resilience.

This issue is highly relevant to the automotive industry, where supplier networks are extensive, technically complex, and environmentally consequential. Automotive manufacturers rely on numerous specialized suppliers for components, materials, technologies, and services, and supplier-related environmental performance can directly affect the sustainability profile of the final vehicle production system. In the Iranian automotive industry, and particularly within Iran Khodro Industrial Group, previous research has already highlighted the importance of supplier integration, green information systems, and customer orientation in advancing green innovation ([Mahmoudzadeh & Mahmoudzadeh, 2023](#)). However, the practical problem of selecting and ranking suppliers on the basis of combined economic, operational, and environmental criteria continues

to require decision models that are both analytically rigorous and empirically validated.

Accordingly, there is a clear need for an integrated green supplier selection framework that can accommodate multiple conflicting objectives, address uncertainty in supplier evaluation, validate the measurement structure of environmental criteria, and assess the robustness of supplier rankings through comparative and scenario-based analysis. Such an approach can improve the credibility of supplier evaluation while also providing managers with a more defensible basis for procurement and environmental decision making. By combining confirmatory validation of green supply chain criteria with multi-objective programming, rough set theory, and ranking validation, the resulting framework can contribute both methodologically and practically to sustainable supplier management in large manufacturing organizations.

Therefore, the aim of this study is to validate the results of green supplier ranking in Iran Khodro Company through a model-comparison and scenario-analysis MCDM approach based on rough sets and multi-objective programming.

## 2. Methods and Materials

In terms of purpose, this study was applied-developmental, and in terms of research design, it employed a descriptive-survey approach. Specifically, the components and criteria affecting green supplier selection were first extracted based on the theoretical foundations and previous studies. They were then measured and validated within the conceptual model using the designated data collection instrument. Given the nature of the research problem, the statistical population consisted of two main groups. The first group included parts manufacturers that produce components for Iran Khodro Company and, because of their involvement in environmental issues and their organizational capacity—defined as having at least 50 employees—were capable of providing data related to green supply chain components. The second group consisted of experts, specialists, and managers from Iran Khodro Company who possessed sufficient knowledge and experience in green supply chain management and environmental issues and were involved in the process of evaluating and purchasing components from suppliers. Based on these criteria, 21 eligible parts manufacturing companies were initially identified, of which 18 ultimately

provided the required data through their cooperation with the study.

To determine the sample size for the questionnaire respondents, including experts and managers involved in purchasing and evaluating components as well as identifying environmental criteria, the Morgan sample size determination approach was used because of the limited number of eligible individuals. Accordingly, the required sample size based on the Morgan table was estimated at 80 respondents. However, considering practical implementation conditions and accessibility to respondents, the final sample size was set at 66 individuals based on the operational constraints of the study and the feasibility of data collection. Simple random sampling was employed in this phase, subject to the requirement that respondents have at least three years of relevant work experience. Therefore, the questionnaires developed for Studies 1, 2, and 3 were distributed among the selected sample, and the collected data were subsequently used as the basis for analysis. As noted previously, for the decision-making phase and implementation of the green supplier selection model, data relating to 18 selected suppliers that met the predefined eligibility criteria were used. Other otherwise eligible companies were excluded from the final analysis because they did not cooperate in the data collection process.

With respect to the instruments and procedures used for data collection, three complementary sources were employed in this study. First, library research was conducted to review the literature and theoretical framework, identify concepts related to green supply chain management, and establish the theoretical foundations of the relevant components and criteria. Second, a researcher-developed questionnaire was used to collect quantitative data from managers, experts, and specialists regarding environmental components and criteria and to determine the weights assigned to the model objectives. Third, documentary evidence was used to support and supplement the required data through information available within the industry and accessible records from the selected companies. The items included in the researcher-developed questionnaire were formulated on the basis of the research literature and findings of previous studies. The environmental criteria and items were subsequently organized into a set of indicators and subcriteria, including recycling system management capacity, pollution reduction capacity, level of environmentally friendly material use, access to clean technologies, environmental information management systems, internal control processes, types of environmental

certifications, continuous monitoring, environmental planning, environmental policies, reverse logistics, energy consumption, wastewater generation, air pollution, solid waste generation, employee training, sustainable design, procurement of environmentally friendly raw materials and technologies, information exchange, environmentally responsible partners, top management support, sustainable packaging, and related indicators.

Furthermore, to ensure the quality of the measurement instrument, the validity and reliability of the questionnaire were assessed. Instrument validity was examined through content validity using the relevant index or coefficient, whereas reliability was assessed using Cronbach's alpha to verify the internal consistency of the questionnaire items.

At the data analysis stage, the data were processed using LISREL software, given the nature of the model and the objective of validating the identified components. To confirm the conceptual structure and assess the degree of correspondence between the measurement model and the empirical data, confirmatory factor analysis (CFA) was first conducted. Model quality was evaluated using a set of goodness-of-fit indices, including CMIN/df (normed chi-square), GFI, AGFI, CFI, RMSEA, and RMR. Subsequently, to determine whether each item adequately represented its corresponding component, the factor loadings of the items and their statistical significance based on the t-statistic were examined. Acceptable factor loadings, according to the criteria adopted in the study, together with t-values significant at the 95% confidence level, indicated confirmation of the relationships between the main components and their measurement items. Finally, after construct validity had been confirmed, the decision-making model based on multi-objective programming and rough sets was implemented to rank and select the qualified suppliers in terms of price, quality, service level, and environmental criteria. Practical recommendations were then developed based on the resulting findings.

### 3. Findings and Results

Confirmatory factor analysis (CFA) was conducted to validate the main components of green supply chain evaluation among automotive parts suppliers and to determine whether the observed items adequately represented their corresponding latent constructs. The measurement model consisted of five main components: information exchange, environmental certifications, recycling, sustainable design, and procurement of

environmentally friendly raw materials. Model fit was evaluated using the normed chi-square (CMIN/df), Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Root Mean Square Residual (RMR). Values of CMIN/df below 3.00,

GFI, AGFI, and CFI above 0.90, RMSEA below 0.09, and RMR below 0.05 were considered indicative of acceptable model fit. Furthermore, standardized factor loadings greater than 0.50 were considered acceptable, while t-values greater than 1.96 indicated statistical significance at the 95% confidence level.

**Table 1**

*Main Components and Corresponding Questionnaire Items*

| Main Component                                        | Questionnaire Items | Code |
|-------------------------------------------------------|---------------------|------|
| Information Exchange                                  | 1–7                 | A1   |
| Environmental Certifications                          | 8–13                | A2   |
| Recycling                                             | 14–20               | A3   |
| Sustainable Design                                    | 21–26               | A4   |
| Procurement of Environmentally Friendly Raw Materials | 27–29               | A5   |

As shown in Table 1, the green supply chain measurement model comprised five principal components. Information exchange was measured using seven items, environmental certifications using six items, recycling using seven items, sustainable design using six items, and procurement of environmentally friendly raw materials

using three questionnaire items. These components represented the major environmental dimensions incorporated into the supplier evaluation framework and were subsequently subjected to confirmatory factor analysis to assess their measurement quality and construct validity.

**Table 2**

*Goodness-of-Fit Indices for the Confirmatory Factor Analysis Models*

| Main Component                                        | Code | CMIN/df | GFI  | AGFI | CFI  | RMSEA | RMR   |
|-------------------------------------------------------|------|---------|------|------|------|-------|-------|
| Information Exchange                                  | A1   | 0.069   | 1.00 | 1.00 | 1.00 | 0.001 | 0.004 |
| Environmental Certifications                          | A2   | 0.003   | 1.00 | 1.00 | 1.00 | 0.000 | 0.000 |
| Recycling                                             | A3   | 0.006   | 1.00 | 1.00 | 1.00 | 0.002 | 0.002 |
| Sustainable Design                                    | A4   | 0.008   | 1.00 | 1.00 | 1.00 | 0.008 | 0.004 |
| Procurement of Environmentally Friendly Raw Materials | A5   | 0.011   | 0.99 | 0.99 | 0.99 | 0.008 | 0.008 |

The results presented in Table 2 demonstrate satisfactory goodness of fit for all five confirmatory measurement models. The CMIN/df values ranged from 0.003 to 0.069 and were therefore substantially below the recommended threshold of 3.00. The GFI, AGFI, and CFI values ranged from 0.99 to 1.00, exceeding the minimum acceptable criterion of 0.90 across all constructs. Similarly, RMSEA values ranged from 0.000 to 0.008, remaining well below the

threshold of 0.09, while RMR values ranged from 0.000 to 0.008 and were below the recommended maximum of 0.05. Collectively, these indices indicate that the measurement models for information exchange, environmental certifications, recycling, sustainable design, and procurement of environmentally friendly raw materials exhibited an acceptable fit to the observed data and provided empirical support for the proposed measurement structure.

**Table 3**

*Standardized Factor Loadings and Corresponding t-Values for the Measurement Model*

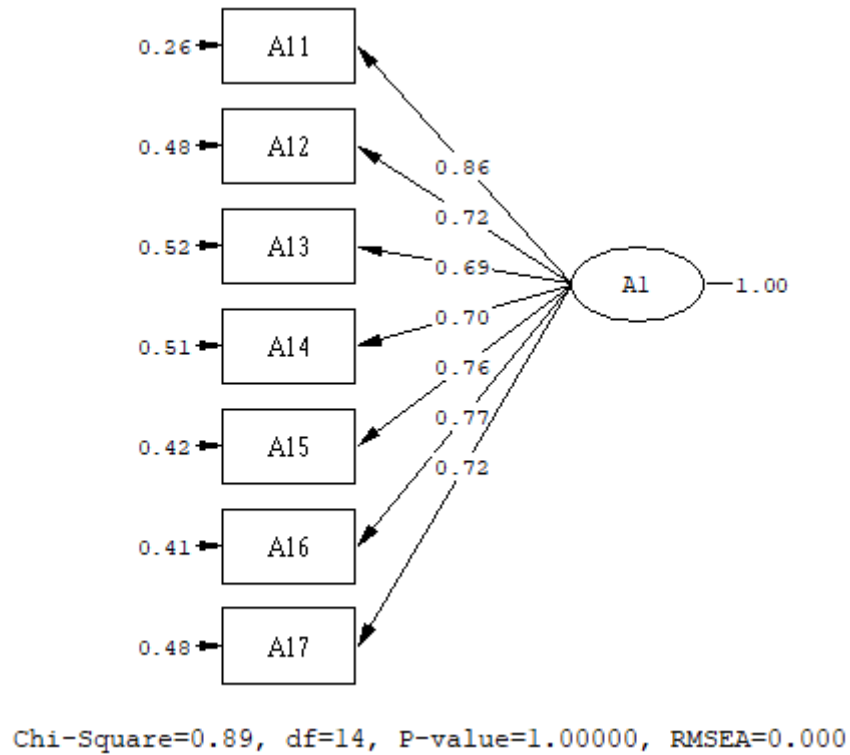
| Component                                             | Path     | Factor Loading | t-Value | Result    |
|-------------------------------------------------------|----------|----------------|---------|-----------|
| Information Exchange                                  | A1 → A11 | 0.86           | 24.74   | Confirmed |
| Information Exchange                                  | A1 → A12 | 0.72           | 18.91   | Confirmed |
| Information Exchange                                  | A1 → A13 | 0.69           | 19.73   | Confirmed |
| Information Exchange                                  | A1 → A14 | 0.70           | 19.77   | Confirmed |
| Information Exchange                                  | A1 → A15 | 0.76           | 19.45   | Confirmed |
| Information Exchange                                  | A1 → A16 | 0.77           | 19.82   | Confirmed |
| Information Exchange                                  | A1 → A17 | 0.72           | 20.35   | Confirmed |
| Environmental Certifications                          | A2 → A21 | 0.89           | 19.29   | Confirmed |
| Environmental Certifications                          | A2 → A22 | 0.88           | 19.20   | Confirmed |
| Environmental Certifications                          | A2 → A23 | 0.81           | 20.39   | Confirmed |
| Environmental Certifications                          | A2 → A24 | 0.72           | 20.44   | Confirmed |
| Environmental Certifications                          | A2 → A25 | 0.78           | 20.27   | Confirmed |
| Environmental Certifications                          | A2 → A26 | 0.92           | 19.98   | Confirmed |
| Recycling                                             | A3 → A31 | 0.63           | 18.80   | Confirmed |
| Recycling                                             | A3 → A32 | 0.69           | 20.00   | Confirmed |
| Recycling                                             | A3 → A33 | 0.57           | 17.68   | Confirmed |
| Recycling                                             | A3 → A34 | 0.66           | 18.64   | Confirmed |
| Recycling                                             | A3 → A35 | 0.71           | 20.40   | Confirmed |
| Recycling                                             | A3 → A36 | 0.52           | 18.65   | Confirmed |
| Recycling                                             | A3 → A37 | 0.74           | 19.47   | Confirmed |
| Sustainable Design                                    | A4 → A41 | 0.90           | 21.24   | Confirmed |
| Sustainable Design                                    | A4 → A42 | 0.80           | 20.92   | Confirmed |
| Sustainable Design                                    | A4 → A43 | 0.84           | 19.90   | Confirmed |
| Sustainable Design                                    | A4 → A44 | 0.92           | 19.68   | Confirmed |
| Sustainable Design                                    | A4 → A45 | 0.84           | 19.67   | Confirmed |
| Sustainable Design                                    | A4 → A46 | 0.77           | 19.59   | Confirmed |
| Procurement of Environmentally Friendly Raw Materials | A5 → A51 | 0.90           | 21.24   | Confirmed |
| Procurement of Environmentally Friendly Raw Materials | A5 → A52 | 0.80           | 20.92   | Confirmed |
| Procurement of Environmentally Friendly Raw Materials | A5 → A53 | 0.84           | 19.90   | Confirmed |
| Procurement of Environmentally Friendly Raw Materials | A5 → A54 | 0.92           | 19.68   | Confirmed |
| Procurement of Environmentally Friendly Raw Materials | A5 → A55 | 0.84           | 19.67   | Confirmed |
| Procurement of Environmentally Friendly Raw Materials | A5 → A56 | 0.77           | 19.59   | Confirmed |

As reported in Table 3, all standardized factor loadings exceeded the minimum acceptable value of 0.50, ranging from 0.52 to 0.92. For the information exchange component, factor loadings ranged from 0.69 to 0.86, with t-values between 18.91 and 24.74. The environmental certifications component exhibited factor loadings ranging from 0.72 to 0.92 and t-values ranging from 19.20 to 20.44. For recycling, standardized loadings ranged from 0.52 to 0.74, while the corresponding t-values ranged from 17.68 to 20.40. The sustainable design component showed comparatively strong factor loadings ranging from 0.77 to 0.92, with t-values

ranging from 19.59 to 21.24. Likewise, the reported factor loadings for procurement of environmentally friendly raw materials ranged from 0.77 to 0.92, with t-values between 19.59 and 21.24. All t-values were substantially greater than the critical value of 1.96 at the 95% confidence level. Therefore, all measurement paths were statistically significant, and the observed items adequately represented their corresponding latent constructs. Taken together with the goodness-of-fit results, these findings support the construct validity of the five-component green supplier evaluation measurement model.

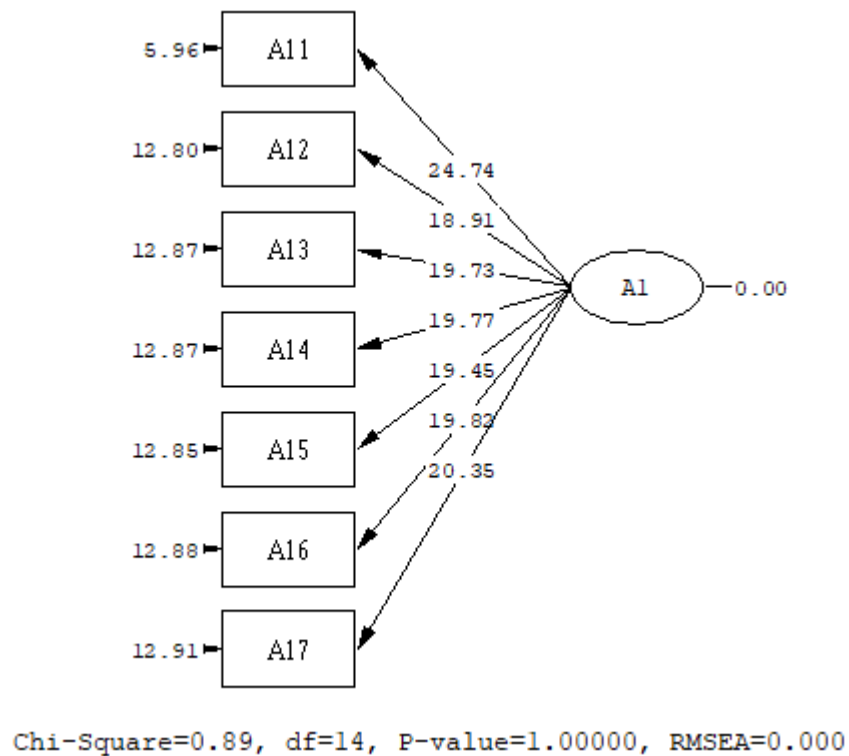
**Figure 1**

*Standardized Factor Loadings for the Information Exchange Component*



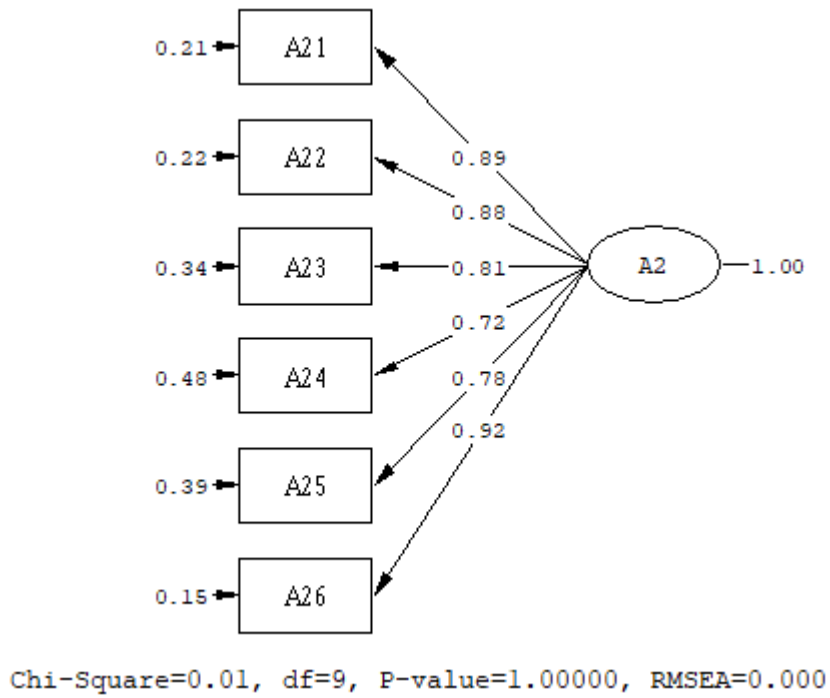
**Figure 2**

*t-Values for the Factor Loadings of the Information Exchange Component*



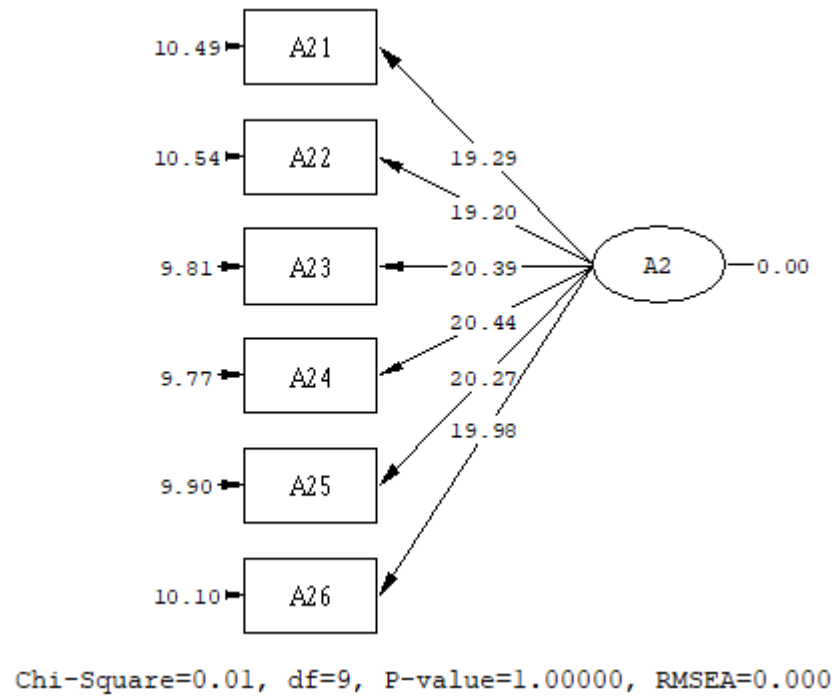
**Figure 3**

*Standardized Factor Loadings for the Environmental Certifications Component*



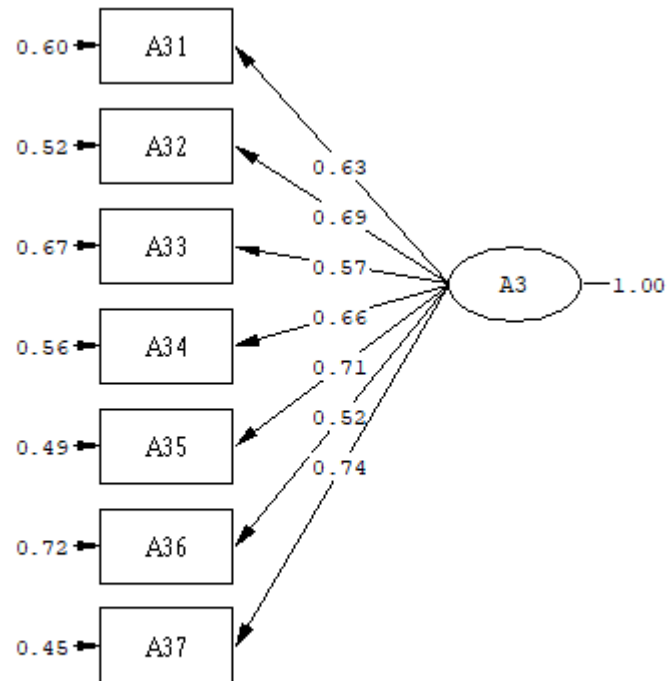
**Figure 4**

*t-Values for the Factor Loadings of the Environmental Certifications Component*



**Figure 5**

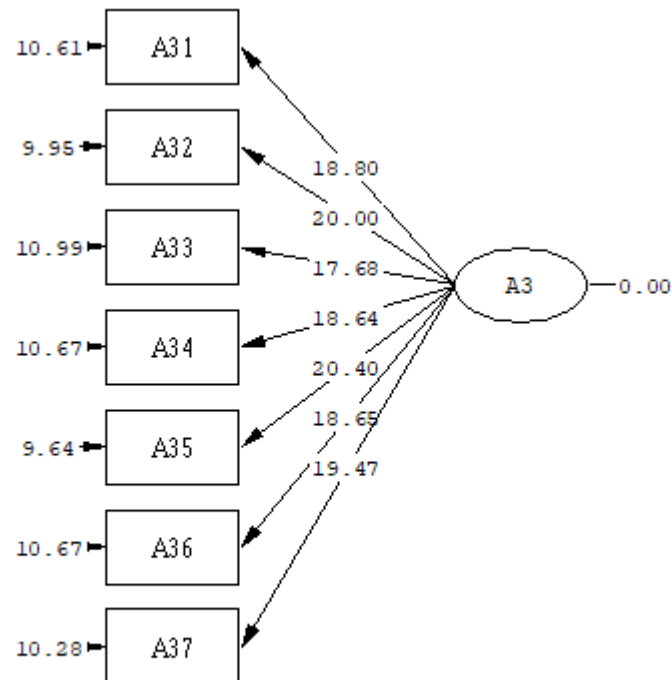
*Standardized Factor Loadings for the Recycling Component*



Chi-Square=0.07, df=14, P-value=1.00000, RMSEA=0.000

**Figure 6**

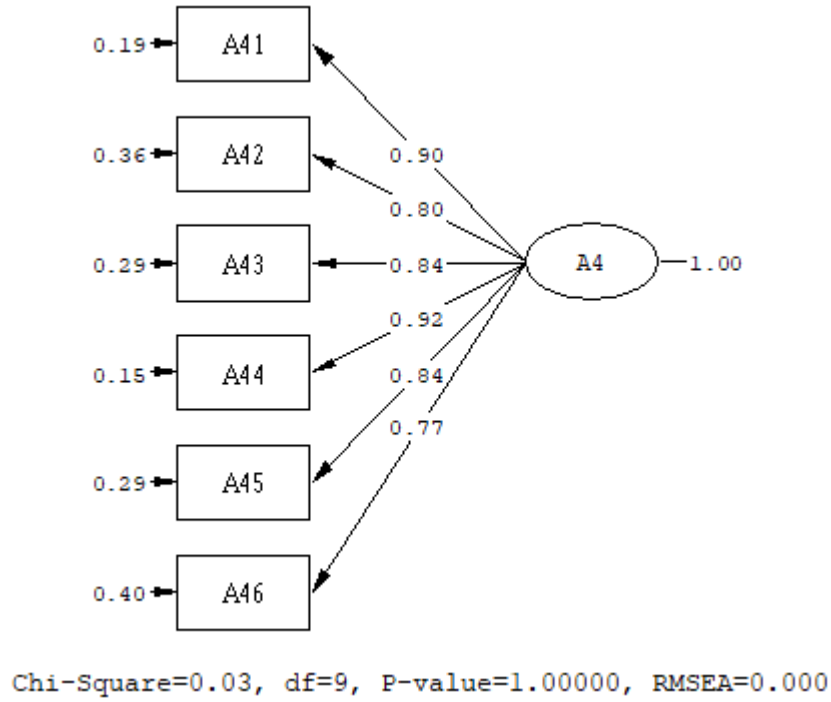
*t-Values for the Factor Loadings of the Recycling Component*



Chi-Square=0.07, df=14, P-value=1.00000, RMSEA=0.000

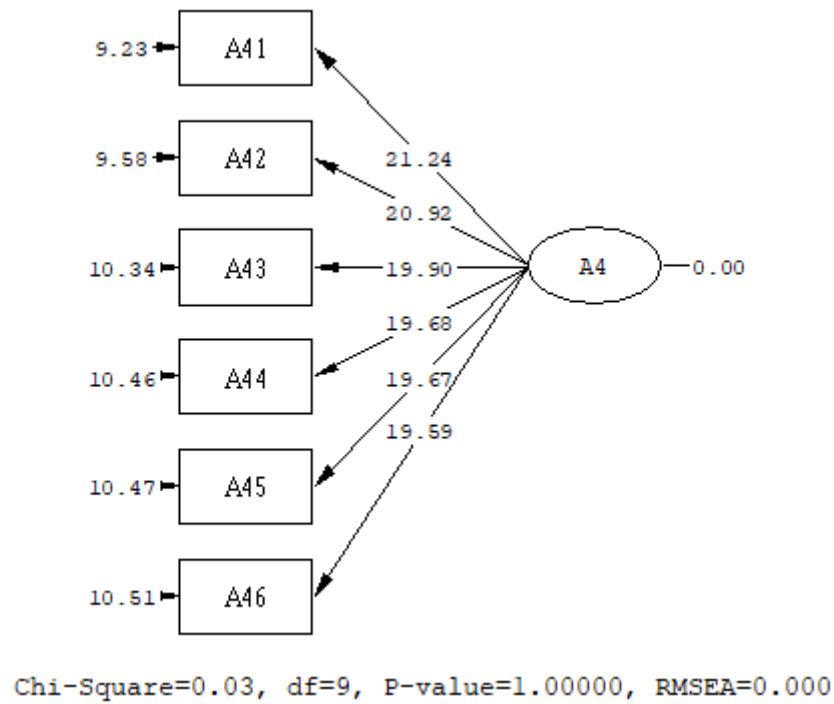
**Figure 7**

*Standardized Factor Loadings for the Sustainable Design Component*



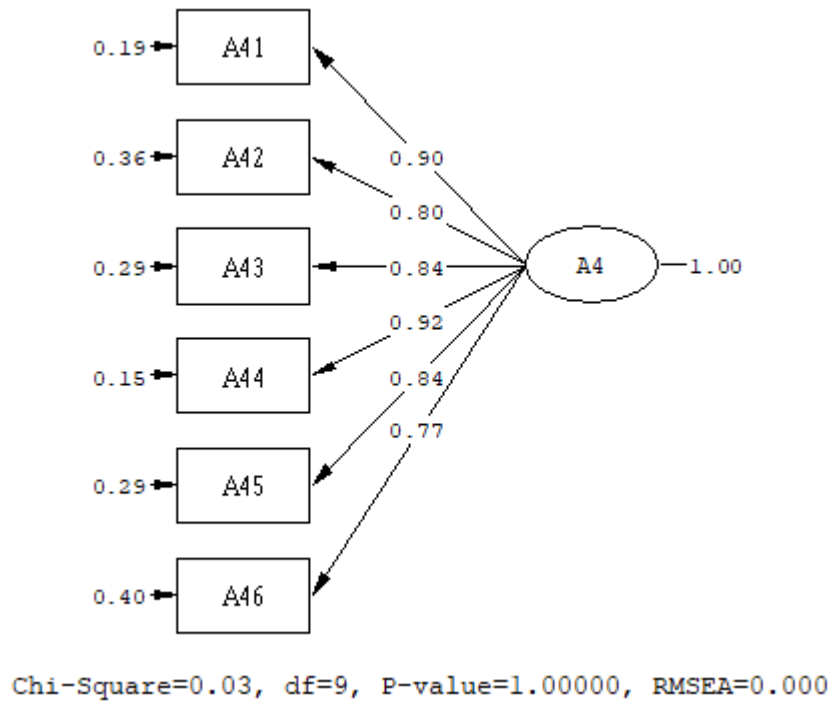
**Figure 8**

*t-Values for the Factor Loadings of the Sustainable Design Component*



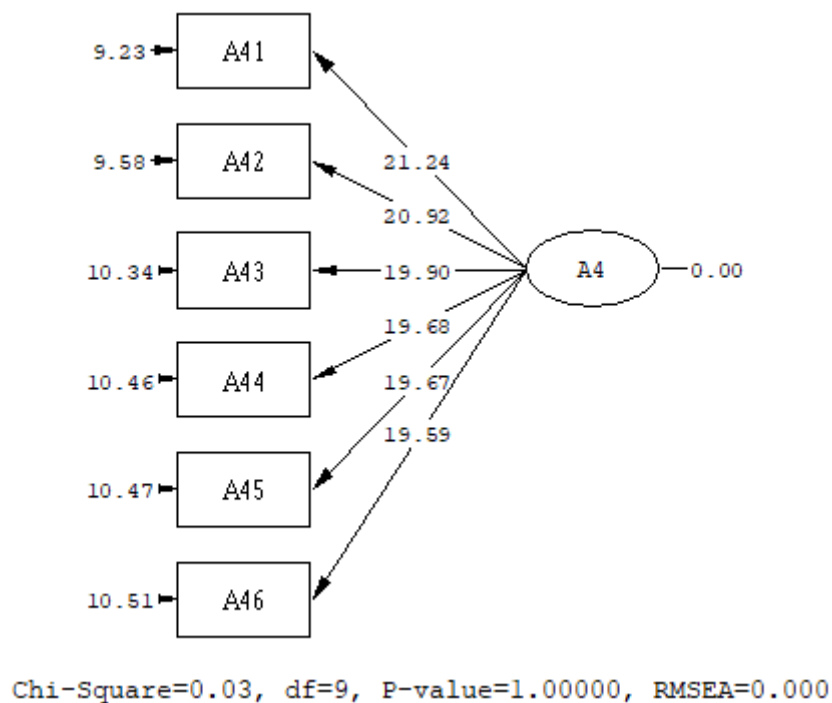
**Figure 9**

*Standardized Factor Loadings for the Procurement of Environmentally Friendly Raw Materials Component*



**Figure 10**

*t-Values for the Factor Loadings of the Procurement of Environmentally Friendly Raw Materials Component*



#### 4. Discussion and Conclusion

The present study aimed to validate the results of green supplier ranking through a multi-criteria decision-making framework based on multi-objective programming and rough sets, with particular emphasis on the automotive supply chain of Iran Khodro Company. The findings first confirmed the adequacy of the measurement model for the five principal dimensions of green supplier evaluation, namely information exchange, environmental certifications, recycling, sustainable design, and procurement of environmentally friendly raw materials. The confirmatory factor analysis results showed that all goodness-of-fit indices were within acceptable ranges. The CMIN/df values for all constructs were substantially below the recommended threshold of 3.00, while GFI, AGFI, and CFI values ranged between 0.99 and 1.00. Similarly, RMSEA and RMR values remained markedly below their respective maximum acceptable thresholds. In addition, all standardized factor loadings exceeded 0.50, and all corresponding t-values were greater than 1.96. These results collectively indicate that the observed indicators adequately represented the intended latent constructs and that the measurement structure underlying the green supplier evaluation model possessed satisfactory construct validity.

The confirmation of information exchange as a valid component of green supplier evaluation is particularly important because environmental supply chain performance depends heavily on the quality, timeliness, and transparency of information exchanged between focal firms and suppliers. The present findings suggest that information exchange is not merely an auxiliary coordination mechanism, but a measurable and central dimension of supplier environmental capability. This result is consistent with research emphasizing the role of green information systems and supplier integration in facilitating green innovation and strengthening interorganizational environmental performance (Mahmoudzadeh & Mahmoudzadeh, 2023). In manufacturing supply chains, the effective transmission of information concerning material specifications, environmental requirements, certifications, emissions, waste, and process changes can reduce uncertainty and improve the alignment of suppliers with the environmental priorities of the focal firm. The findings also correspond with the argument that buyer environmental orientation can influence suppliers' responses and green innovation outcomes through the way resources and expectations are

communicated across organizational boundaries (Yang & Jiang, 2023). Therefore, the strong measurement performance observed for information exchange in this study reinforces the strategic significance of communication and information integration in green supplier management.

The findings also confirmed environmental certifications as a distinct and statistically valid component of supplier assessment. All factor loadings related to this dimension were high, and their t-values indicated strong statistical significance. This suggests that environmental certifications provide meaningful information in differentiating suppliers according to the formalization of their environmental practices. Such certifications can signal the existence of structured environmental management systems, internal monitoring processes, regulatory compliance mechanisms, and organizational commitment to continuous environmental improvement. This finding is compatible with the broader green supplier selection literature, in which environmental management practices, formal standards, and certification-related criteria are frequently included as central dimensions of supplier screening and ranking. Hybrid green supplier selection models have similarly emphasized the need to combine conventional performance criteria with environmental indicators when evaluating suppliers under uncertainty (Alamroshan et al., 2022). Likewise, green-resilient supplier selection research has demonstrated that environmental and organizational capabilities must be assessed simultaneously if supplier evaluation is to reflect the multidimensional nature of sustainable performance (Hailiang et al., 2023).

Recycling was also validated as an important dimension of the green supplier evaluation model. Although the recycling construct exhibited a somewhat wider range of factor loadings than some of the other components, all values remained above the acceptable threshold, and all corresponding t-statistics were significant. This indicates that the capacity to manage recycling activities, reduce waste, and support material recovery represents a meaningful dimension of green supplier performance. The result is theoretically consistent with the increasing emphasis on circularity, resource efficiency, and waste minimization within sustainable supply chains. Recycling contributes not only to environmental impact reduction but also to lower material consumption, improved resource productivity, and reduced disposal costs. In this sense, its inclusion in supplier evaluation extends purchasing decisions beyond immediate price and delivery considerations toward longer-term environmental

consequences. This interpretation is aligned with evidence showing that green supply chain management and green technological innovation can reduce firms' energy and resource intensity and thereby improve sustainable performance (Wang et al., 2025). It is also compatible with findings indicating that environmental orientation can improve sustainable performance through green supply chain management and green innovation mechanisms (Niromand et al., 2025).

The validation of sustainable design as another major component of the model is also noteworthy. Sustainable design showed consistently strong factor loadings, indicating that the associated items were closely related to the latent construct. This result suggests that supplier assessment should account for design-related environmental capabilities in addition to operational performance. Sustainable design can reduce material use, facilitate product disassembly, improve recyclability, support cleaner manufacturing, and reduce environmental burdens over the product life cycle. This issue is highly relevant in the automotive sector, where component design decisions affect material intensity, recyclability, emissions, energy consumption, and end-of-life management. The present finding is consistent with recent analyses of decarbonization pathways in automotive-related supply chains, which emphasize that meaningful reductions in environmental impact require coordinated changes in material sourcing, product and component design, production processes, and upstream supplier practices (Shen et al., 2025). Thus, the confirmation of sustainable design within the measurement model supports the view that design capability should be incorporated systematically into green supplier selection.

The results further supported the inclusion of procurement of environmentally friendly raw materials as a core element of green supplier evaluation. This dimension captures the extent to which suppliers rely on materials and technologies that reduce environmental impacts and support environmentally responsible production. The significance of this construct reflects the fact that environmental performance is partly embedded in upstream material choices and cannot be addressed exclusively through downstream operational improvements. By selecting suppliers that use cleaner technologies and environmentally preferable materials, focal firms can reduce the environmental burden transferred through the supply chain and strengthen the sustainability profile of their final products. This result is in line with research demonstrating the strategic importance of green supply chain practices in

facilitating green innovation and sustainable competitive advantage (Asiedu et al., 2026). It is also compatible with studies indicating that green business strategy, green supply chain management, and green innovation jointly contribute to improved sustainable performance (Liu et al., 2026).

Beyond confirming the individual constructs, the overall findings support the broader methodological rationale for using multi-criteria and multi-objective approaches in green supplier selection. Supplier evaluation in the present study involved economic, service-related, quality-related, and environmental dimensions that cannot be meaningfully reduced to a single criterion. This supports the use of structured decision models capable of addressing trade-offs among competing objectives. Previous research has similarly shown that green supplier selection often requires hybrid analytical approaches because decision makers must consider multiple criteria while dealing with uncertainty and qualitative managerial judgments (Alamroshan et al., 2022; Hailiang et al., 2023). The present study extends this reasoning by integrating rough sets with multi-objective programming, thereby providing a framework that can simultaneously account for uncertainty in supplier information and conflicting organizational objectives.

The findings are also consistent with research emphasizing the importance of incorporating managerial opinion into supplier selection. Green supplier evaluation is not purely a mechanical optimization exercise because the relative importance of criteria may vary according to organizational strategy, environmental priorities, supply risk, and industry conditions. The use of expert judgments and structured weighting in the present framework reflects this practical requirement. Previous work has shown that the integration of managerial opinion through Quality Function Deployment and interactive fuzzy programming can improve the relevance of green supplier selection models by ensuring that analytical outputs remain aligned with organizational priorities (Khattak et al., 2022). In a similar manner, the present study demonstrates that a valid measurement model can provide a reliable foundation for subsequent multi-objective decision analysis.

The results can also be interpreted in light of the broader role of organizational and technological capabilities in sustainable supply chains. Green supplier management increasingly operates within data-intensive and technology-enabled environments. Big data analytics and artificial intelligence can strengthen sustainable performance through green supply chain practices by improving information processing, forecasting, and coordination (Rashid et al.,

2025). Likewise, the combination of green business strategy, AI capability, knowledge integration, and green innovation can enhance sustainable organizational performance (Liu et al., 2026). The high relevance of information exchange observed in this study is therefore consistent with a wider shift toward digitally integrated supplier networks, where supplier selection and monitoring increasingly depend on reliable environmental data and cross-organizational knowledge flows.

The present findings also have implications for innovation and competitive advantage. Green supplier selection should not be understood solely as a compliance-oriented purchasing activity. Instead, it can serve as a strategic mechanism for identifying supply chain partners capable of contributing to environmental innovation, resilience, and long-term competitiveness. Green ambidexterity innovation has been identified as an important mechanism through which green supply chain management can generate sustainable competitive advantage (Asiedu et al., 2026). Similarly, dynamic capabilities, innovation, and supply chain agility can help organizations strengthen green supply chain management within the broader framework of sustainable development goals (Olaleye et al., 2025). The supplier selection model validated in this study therefore has implications beyond short-term procurement efficiency, because the selected suppliers may influence the focal firm's future innovation capability and adaptability.

The significance of organizational context should also be emphasized. The successful implementation of green supply chain management is shaped by institutional pressures, managerial capacity, organizational resources, and sector-specific characteristics. Research conducted in Iran has shown that environmental orientation can affect sustainable performance through green supply chain management and green innovation, while institutional pressure can influence the strength of these relationships (Niromand et al., 2025). Similarly, context-specific research on the implementation of green supply chain management has highlighted the importance of identifying key success factors appropriate to the institutional and industrial environment (Zarei et al., 2025). The present study contributes to this perspective by validating a supplier evaluation framework within Iran's automotive industry rather than assuming that a generic international model can be transferred without empirical assessment.

The automotive context is especially important because automotive firms depend on extensive and heterogeneous supplier networks, and environmental impacts are

distributed across numerous upstream production stages. The validation of the five dimensions in this study suggests that green supplier assessment in this industry should extend beyond basic environmental compliance toward a broader evaluation of communication, certification, recycling, sustainable design, and green material procurement. This interpretation is supported by research on automotive decarbonization, which emphasizes that supply chain-level environmental improvement requires coordination across materials, technologies, production systems, and supplier relationships (Shen et al., 2025). It also aligns with findings from Iran Khodro Industrial Group indicating that supplier integration and green information systems contribute to green innovation (Mahmoudzadeh & Mahmoudzadeh, 2023).

The results can further be interpreted through the lens of relational and financial mechanisms. Green supplier management may improve firm outcomes by strengthening relational capital and facilitating joint environmental initiatives. Previous research has shown that environmental orientation can affect financial performance through green supplier management and relational capital (Farahabadi & Heydarpour, 2023). Moreover, supply chain finance can contribute to green breakthrough innovation through knowledge spillovers between core firms and other supply chain members (Huang et al., 2026). These findings reinforce the view that supplier selection creates long-term relational consequences. Selecting environmentally capable suppliers may enhance not only immediate operational performance but also collaborative innovation, information sharing, and access to resources needed for environmental transformation.

The present findings also correspond with evidence emphasizing the human and organizational foundations of sustainable supply chain performance. Inclusive leadership and a green psychological climate can foster employee green creativity, which subsequently contributes to sustainable supply chain outcomes (Rasheed et al., 2026). Although the current study focused on supplier evaluation criteria rather than employee-level mechanisms, this evidence is relevant because supplier environmental capability ultimately depends on organizational systems, leadership, employee behavior, and internal commitment to environmental improvement. Therefore, the significant measurement of dimensions such as environmental certification, sustainable design, and information exchange may reflect deeper organizational capabilities that support long-term sustainability.

Finally, the use of ranking validation, model comparison, and scenario-oriented analysis is important because supplier rankings can otherwise become overly dependent on a particular weighting structure or model specification. Strategic supplier decisions typically involve substantial financial, operational, and environmental consequences, making ranking stability an important consideration. Structured prioritization methods have been shown to improve the transparency and defensibility of strategic decision making in other management contexts (Samadzadeh et al., 2022). In green supplier selection, the combination of validated measurement criteria with multi-objective programming and rough-set-based analysis can provide a more robust foundation for decision making because it considers both the quality of the constructs being measured and the uncertainty inherent in supplier assessment. Overall, the findings support the theoretical and practical relevance of an integrated green supplier selection framework in which environmental criteria are empirically validated before being incorporated into ranking and optimization procedures.

The present study has several limitations that should be considered when interpreting its findings. First, the empirical setting was limited to Iran Khodro Company and a relatively small group of automotive parts suppliers, which may restrict the generalizability of the findings to other manufacturing sectors or supply chain environments. Second, the final questionnaire sample consisted of 66 respondents, and only 18 suppliers were included in the decision-making stage because some eligible firms did not cooperate with the study. Third, part of the data was based on managerial and expert judgments, which may be influenced by subjective perceptions, organizational experience, or response bias. Fourth, the study focused on a specific set of economic, operational, and environmental criteria, while other dimensions such as social sustainability, carbon footprint, supply risk, technological readiness, and lifecycle performance were not incorporated explicitly. Finally, the supplier evaluation reflects the conditions observed during the study period, whereas supplier capabilities and environmental performance may change over time.

Future studies are recommended to replicate the proposed model in other automotive companies and in industries such as steel, petrochemicals, electronics, pharmaceuticals, construction, and food production to examine its external validity. Larger samples of suppliers and decision makers could be used to improve the statistical precision of the

measurement model and enable subgroup comparisons. Future research may also extend the framework by integrating social sustainability indicators, carbon emissions, lifecycle assessment measures, resilience, circular economy indicators, digital readiness, and supply disruption risk. Longitudinal research could evaluate whether supplier rankings remain stable over time and whether suppliers improve their environmental performance following evaluation. Researchers may also compare rough-set-based models with fuzzy, grey, probabilistic, machine-learning, or hybrid MCDM techniques and conduct formal sensitivity and scenario analyses to examine the robustness of rankings under alternative weights, thresholds, and strategic priorities.

Managers should institutionalize green supplier evaluation as a recurring part of procurement and supplier development rather than treating it as a one-time selection activity. Purchasing departments should establish a standardized evaluation system covering information exchange, environmental certifications, recycling capability, sustainable design, and environmentally friendly material procurement alongside conventional criteria such as price, quality, and service level. Suppliers with weaker environmental performance should be given explicit improvement targets and monitored through periodic audits and performance reviews. Iran Khodro and similar manufacturers should also strengthen environmental data-sharing systems, require verifiable environmental documentation, support supplier training, and create incentives for cleaner technologies, recyclable materials, and sustainable design practices. In addition, procurement decisions should be supported by scenario analysis so that managers can evaluate how supplier rankings change when strategic priorities shift between cost, quality, service, and environmental performance.

### Authors' Contributions

Authors contributed equally to this article.

### Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

### Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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The authors report no conflict of interest.

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## Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

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