Strategic Supplier Selection Criteria for Lightweight Component Manufacturing in EV Supply Chains

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Abstract: *The rapid expansion of electric vehicle (EV) manufacturing has intensified the need for reliable, technologically capable, cost-efficient, and sustainable suppliers of lightweight components. Lightweight materials such as aluminium alloys, magnesium alloys, advanced high-strength steels, and fibre-reinforced composites are increasingly important for reducing vehicle mass, improving energy efficiency, extending driving range, and optimizing battery performance. However, supplier selection for these components is more complex than conventional cost-oriented sourcing because material quality, manufacturing precision, process capability, delivery reliability, technological competence, sustainability, circularity, supply resilience, and lifecycle cost must be evaluated simultaneously. Existing supplier-selection research demonstrates the suitability of multi-criteria decision-making approaches for handling such multidimensional decisions, while recent EV-oriented studies emphasize environmental performance, technological quality, supply resilience, and strategic sustainability. (ScienceDirect) This paper develops a strategic criteria framework specifically for lightweight component suppliers in EV supply chains. The proposed framework integrates six major dimensions: quality and engineering capability, cost competitiveness, delivery and operational reliability, technological and innovation capability, environmental and circularity performance, and supply-chain resilience and strategic compatibility. Particular emphasis is placed on material efficiency, manufacturing scrap, recyclability, energy consumption, process stability, capacity scalability, digital manufacturing capability, and disruption preparedness. The framework provides a structured basis for supplier prequalification, comparative evaluation, supplier development, and long-term sourcing decisions in the rapidly evolving EV manufacturing ecosystem.*

Keywords: Electric vehicles; Lightweight components; Supplier selection; Sustainable supply chain; Multi-criteria decision-making; Aluminium alloys; Advanced materials; Supply-chain resilience; Circular economy; Automotive manufacturing

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Introduction

The transition from internal-combustion-engine vehicles to electric vehicles (EVs) is transforming automotive manufacturing, procurement, and supply-chain structures. EV manufacturers increasingly depend on supply networks capable of delivering advanced materials, precision-manufactured components, battery-related systems, electronic subsystems, and specialized engineering services. Within this transformation, vehicle mass has become a strategically important engineering variable because reducing structural and component weight can contribute to improved energy efficiency, driving range, handling, and overall vehicle performance. Consequently, lightweight materials and manufacturing technologies are becoming increasingly important in automotive body, chassis, powertrain, and structural applications. The selection of appropriate material and component suppliers therefore represents a strategic procurement decision rather than a conventional purchasing activity [10]. Traditional supplier-selection decisions have generally emphasized purchase price, quality, delivery performance, and service. However, contemporary supply chains require simultaneous consideration of economic, technical, environmental, social, and strategic factors. Ho *et al.* demonstrated through a comprehensive review that supplier evaluation is fundamentally a multi-criteria decision problem in which supplier performance cannot be adequately represented by cost alone [4]. The increasing complexity of automotive manufacturing further strengthens this requirement because supplier performance directly influences production continuity, product quality, inventory requirements, manufacturing cost, and customer satisfaction. Consequently, supplier selection must consider the interaction between multiple criteria rather than optimizing an isolated purchasing parameter.

The challenge becomes more pronounced for lightweight EV components. Aluminium alloys, magnesium alloys, advanced high-strength steels, and fibre-reinforced composite materials provide opportunities for mass reduction but frequently require specialized forming, casting, machining, joining, heat treatment, surface finishing, and quality-control capabilities. For such materials, the technical competence of the supplier can directly affect dimensional accuracy, structural integrity, material utilization, manufacturing yield, and component reliability. In the case of aluminium automotive components, supplier selection has been identified as a strategic problem because the quality of incoming material is closely related to the quality of the final component and procurement decisions may substantially influence overall manufacturing economics [10].

At the same time, EV supply chains are increasingly exposed to environmental regulations, resource constraints, geopolitical disruptions, raw-material volatility, transportation interruptions, and changing customer expectations. These conditions require manufacturers to evaluate suppliers not only according to immediate purchasing cost but also according to environmental performance, resource efficiency, technological capability, resilience, and long-term strategic compatibility. Green supplier-selection research has established the importance of combining conventional criteria such as price, quality, and service with environmental management, pollution control, eco-design, resource consumption, and environmental competencies [6]. In automotive applications, integrated evaluation models have demonstrated that environmental management, pollution control, product quality, and green performance can become highly influential supplier-selection factors [6].

Sustainability is particularly relevant to lightweight component manufacturing because material selection and manufacturing processes influence energy consumption, production scrap, emissions, recyclability, and lifecycle environmental performance. Sustainable supplier-selection frameworks therefore increasingly integrate economic, environmental, and social dimensions. Luthra *et al.* identified a broad set of sustainable supplier-selection criteria and demonstrated the applicability of integrated multi-criteria decision-making for automotive supply chains, emphasizing product quality, price, environmental costs, occupational health and safety, and environmental competencies [7]. Such findings indicate that supplier evaluation for EV components should incorporate lifecycle-oriented criteria rather than concentrating exclusively on the initial procurement price.

EV-specific supplier selection introduces additional technical and strategic considerations. Supplier capability must support rapidly changing vehicle architectures, high production volumes, advanced manufacturing requirements, shorter product-development cycles, and increasing expectations for environmentally responsible production. A dedicated EV supplier-selection study identified economic, social, environmental, and technical dimensions as critical and demonstrated the usefulness of an integrated multi-criteria framework for comparing EV suppliers [9]. More recent automotive research further emphasizes the need to incorporate sustainability and resilience simultaneously, particularly under geopolitical, environmental, and market disruptions.

Despite substantial research on supplier selection, green supplier selection, sustainable supply chains, and EV procurement, a specific framework focused on **strategic supplier selection for lightweight component manufacturing within EV supply chains** remains comparatively underdeveloped. Existing studies frequently address general automotive suppliers or EV suppliers without sufficiently distinguishing the technological and operational requirements associated with lightweight materials and components. The present study addresses this gap by organizing supplier-selection criteria around six strategic dimensions: **quality and engineering capability, cost and total cost of ownership, delivery and operational reliability, technology and innovation capability, environmental and circularity performance, and supply-chain resilience and strategic compatibility**.

The objective of this study is therefore to establish a structured and strategically relevant criterion framework for evaluating suppliers of lightweight EV components. The proposed framework is intended to support procurement managers, supply-chain planners, manufacturing engineers, and strategic sourcing teams in identifying suppliers capable of simultaneously satisfying technical, economic, environmental, and resilience requirements. By moving from conventional price-oriented supplier evaluation toward a multidimensional strategic assessment, the study provides a foundation for more reliable and sustainable supplier-selection decisions in the evolving EV manufacturing ecosystem.

Literature Review

2.1 Supplier Selection and Multi-Criteria Decision Making

Supplier selection has long been recognized as one of the most important strategic decisions in supply-chain management because supplier performance directly affects purchasing cost, product quality, production continuity, and organizational competitiveness. Early supplier-selection research established that procurement decisions require simultaneous consideration of several criteria rather than a single economic variable [1]. Subsequent studies progressively developed quantitative and qualitative approaches for dealing with this multidimensional decision environment.

Ho *et al.* reviewed the application of multi-criteria decision-making (MCDM) techniques to supplier evaluation and selection and concluded that contemporary supplier-selection problems are better represented through multiple criteria than through traditional cost-based approaches [4]. Techniques including the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIKOR, Data Envelopment Analysis, fuzzy approaches, and hybrid MCDM models have subsequently been applied to address different supplier-selection contexts.

The use of MCDM is particularly appropriate when supplier performance involves both measurable and judgment-based variables. Cost, delivery time, defect rate, production capacity, and rejection rate can be quantitatively assessed, whereas engineering support, innovation capability, strategic compatibility, and supplier responsiveness may require expert evaluation. Consequently, supplier-selection models need to accommodate heterogeneous information and potentially conflicting objectives. This provides an important methodological foundation for evaluating lightweight EV component suppliers, where technical capability and sustainability may have to be balanced against cost and delivery performance.

2.2 Sustainable and Green Supplier Selection

Growing environmental pressures have substantially changed the traditional supplier-selection paradigm. Green supplier selection incorporates environmental performance into conventional procurement criteria, thereby enabling organizations to consider the ecological consequences of supplier operations alongside economic performance. Govindan *et al.* reviewed the green supplier-selection literature and reported that environmental management systems, resource-related considerations, and other environmental criteria had become important components of supplier evaluation [6].

Sustainable supplier selection extends this perspective by incorporating economic, environmental, and social dimensions. Luthra *et al.* developed an integrated sustainable supplier-selection framework for the automotive industry and identified 22 criteria across these dimensions [7]. Their findings demonstrated that environmental costs, product quality, product price, occupational health and safety, and environmental competencies can simultaneously influence supplier attractiveness.

More recent research has moved toward integrated frameworks that consider sustainability together with supplier capability and strategic collaboration. Govindan *et al.* proposed a multi-phase supplier evaluation and selection approach that evaluates supplier capability and desirability and subsequently supports decisions involving supplier retention, development, or switching [2]. This perspective is particularly relevant to EV supply chains because suppliers may not simply be classified as acceptable or unacceptable; strategically important suppliers may instead require capability development, technology collaboration, or long-term partnership arrangements.

2.3 Supplier Selection in Automotive and EV Supply Chains

Automotive supply chains present distinctive supplier-selection requirements because component quality, delivery synchronization, production scale, and engineering coordination directly influence vehicle manufacturing. The increasing electrification of vehicles has further expanded these requirements. EV manufacturers operate within technologically intensive supply networks involving batteries, power electronics, electric motors, lightweight structures, thermal-management systems, and advanced materials.

EV supplier-selection research has therefore incorporated technical, economic, environmental, and social considerations. Wei and Zhou developed an MCDM framework for EV supplier selection that integrated economic, social, environmental, and technical factors through BWM and fuzzy VIKOR [9]. Their analysis demonstrated that environmental performance, cost, quality, service, and environmental initiatives can substantially influence EV supplier rankings. Automotive-specific research also indicates that uncertainty should be explicitly considered in supplier evaluation. A two-stage sustainable automotive supplier-selection model has integrated MCDM techniques to address uncertainty while evaluating economic, environmental, social, and risk-related supplier attributes [11]. Such approaches are relevant to EV procurement because supplier performance can change substantially under raw-material price fluctuations, demand variability, regulatory changes, transportation disruptions, and capacity constraints.

Recent developments further emphasize resilience. Automotive supplier-selection research increasingly combines sustainability with disruption preparedness and data-driven decision-making, reflecting the need to account for geopolitical instability, environmental disruptions, and changing market conditions. This evolution suggests that supplier selection in EV supply chains should move beyond static supplier ranking toward dynamic evaluation of capability, risk, resilience, and strategic fit.

2.4 Lightweight Materials and Component Manufacturing

Lightweighting is an important strategy for improving vehicle efficiency and performance. Automotive manufacturers increasingly employ aluminium, magnesium, high-strength steels, and composite materials to reduce component mass while maintaining structural performance. Aluminium, in particular, has become strategically important in body, chassis, and powertrain applications because of its relatively low density, corrosion resistance, and favourable strength-to-weight characteristics [10].

However, lightweight component manufacturing introduces additional supplier-selection requirements. Suppliers must possess appropriate material-processing technologies, tooling capabilities, dimensional-control systems, joining technologies, surface-treatment capabilities, and quality-assurance systems. Material consistency is also critical because variations in composition or mechanical properties can affect downstream forming and component performance.

The supplier's manufacturing yield is another important consideration. Lightweight materials can involve expensive raw materials and specialized processing, meaning that excessive scrap or rework can significantly increase effective component cost. Therefore, supplier evaluation should consider not only quoted component price but also material utilization, production yield, rejection rate, process capability, energy consumption, and waste generation.

For EV applications, lightweighting also has strategic interaction with battery performance. Reducing structural and component mass can support vehicle efficiency and potentially reduce the energy required to achieve a specified driving range. Consequently, suppliers capable of providing lighter components without compromising structural integrity, manufacturability, durability, or safety can create value beyond the conventional purchasing relationship.

2.5 Technology, Innovation, and Supplier Capability

Technological capability has become increasingly important as automotive products transition toward advanced materials and digitally integrated manufacturing systems. Supplier selection for lightweight EV components must therefore consider process innovation, research and development capability, engineering expertise, automation, digital quality management, advanced simulation, and the ability to scale emerging manufacturing technologies.

Conventional supplier-selection models often treat quality as a principal criterion but may insufficiently distinguish between basic quality compliance and advanced engineering capability. For lightweight EV components, suppliers may need to participate in component co-design, material optimization, design-for-manufacturing activities, process simulation, rapid prototyping, and continuous improvement. Therefore, innovation capability should be treated as a strategic criterion rather than an optional supplier attribute.

Sustainable supplier-selection research similarly demonstrates the importance of evaluating suppliers beyond immediate purchasing performance. Integrated models increasingly consider supplier capabilities and longer-term collaboration potential rather than focusing solely on current performance [2], [7]. This supports the inclusion of engineering competence, innovation capacity, digital manufacturing maturity, and technology-development capability in strategic EV supplier assessment.

2.6 Supply-Chain Resilience and Research Gap

Supply-chain resilience has become a critical supplier-selection dimension because disruptions at a single strategic supplier can propagate through interconnected manufacturing networks. EV supply chains are particularly sensitive to disruptions involving critical raw materials, specialized manufacturing capacity, transportation, energy availability, and geopolitical conditions. Consequently, supplier selection should assess financial stability, geographical concentration, alternate sourcing capability, capacity flexibility, inventory policies, recovery capability, and business-continuity planning.

The emerging literature increasingly combines sustainability and resilience in supplier-selection frameworks. Recent automotive research proposes integrated approaches capable of updating supplier information and identifying nonlinear or disruption-related risks, demonstrating a shift toward more adaptive supplier-selection systems [12]. This direction is particularly relevant to lightweight components because specialized materials and processes may have a limited supplier base, increasing dependency and disruption exposure.

Nevertheless, an important research gap remains. Existing supplier-selection literature provides extensive treatment of general supplier performance, green procurement, sustainability, automotive sourcing, and EV supplier evaluation, but these streams are not sufficiently integrated around the **specific strategic requirements of lightweight component manufacturing**. In particular, the combined importance of material efficiency, process capability, lightweighting performance, technological innovation, circularity, delivery reliability, and resilience requires greater explicit treatment.

Accordingly, this study develops a consolidated strategic supplier-selection framework tailored to lightweight EV component manufacturing. The framework integrates conventional supplier-performance criteria with lightweighting-specific technical factors, environmental and circular-economy considerations, innovation capability, and supply-chain resilience. This integrated perspective provides the conceptual basis for subsequent prioritization and evaluation of supplier-selection criteria in EV supply chains.

Strategic Supplier Selection Criteria for Lightweight Component Manufacturing in EV Supply Chains

The supplier-selection problem for lightweight EV components differs from conventional automotive procurement because the supplier must simultaneously satisfy material, manufacturing, economic, environmental, delivery, innovation, and resilience requirements. A supplier offering the lowest unit price may not provide the lowest overall procurement cost if it generates higher scrap, rejection, energy consumption, warranty exposure, or disruption risk. Accordingly, the present framework evaluates suppliers through six strategic dimensions: **quality and engineering capability (QEC), cost and total cost of ownership (CTC), delivery and operational reliability (DOR), technology and innovation capability (TIC), environmental and circularity performance (ECP), and supply-chain resilience and strategic compatibility (SRC)**.

3.1 Quality and Engineering Capability

Quality is the primary technical criterion for lightweight component suppliers because component failure can compromise vehicle safety, durability, energy efficiency, and downstream assembly. Lightweight components frequently require strict dimensional tolerances and controlled material properties. Supplier evaluation should therefore include incoming-material consistency, process capability, defect rate, first-pass yield, dimensional accuracy, traceability, certification, engineering support, and warranty performance.

A capable supplier should demonstrate stable production processes rather than merely achieving quality during prototype development. Particular attention should be given to statistical process control, automated inspection, non-destructive testing, material certification, corrective-action response, and failure-analysis capability.

Table 1. Quality and engineering capability criteria

Sub-criterion	Measurement indicator	Strategic importance	Weight (%)
Material quality consistency	Material-property variation	Very High	6
Dimensional accuracy	Cpk / tolerance compliance	Very High	5
Defect and rejection rate	Defects per million opportunities	Very High	5
First-pass yield	Accepted components at first inspection (%)	High	4
Quality certification	IATF 16949/ISO compliance	High	3
Traceability	Batch/component traceability (%)	High	2
Engineering support	Technical-response capability	High	2
Warranty performance	Warranty-related failures	Medium	1
Total			**28**

The relatively high allocation reflects the direct relationship between component quality and vehicle safety. For lightweight structures, weight reduction should never be achieved at the expense of fatigue resistance, crashworthiness, dimensional stability, or joining integrity.

3.2 Cost and Total Cost of Ownership

Unit purchase price remains important, but it is insufficient for strategic supplier evaluation. Lightweight materials may have higher raw-material prices than conventional materials, while poor process control can increase scrap, rework, transportation, inspection, and warranty costs. Therefore, the relevant procurement measure is total cost of ownership (TCO).

For supplier j, the annualized TCO can be represented as

$$TCO_j = C_{p,j} + C_{l,j} + C_{q,j} + C_{r,j} + C_{i,j} + C_{w,j}$$

where C_p represents purchase cost, C_l logistics cost, C_q quality-related cost, C_r rework and rejection cost, C_i inventory-related cost, and C_w warranty or failure-related cost.

Material utilization is particularly important in lightweight-component manufacturing:

$$MU_j = \frac{M_{component}}{M_{input}} \times 100$$

where $M_{component}$ is the mass of the finished component and M_{input} is the mass of material consumed. Higher material utilization indicates lower manufacturing waste and generally improves economic and environmental performance.

Table 2. Cost and total-cost criteria

Sub-criterion	Measurement indicator	Weight (%)
Component purchase price	Cost per component	5
Material utilization	Finished/input material (%)	4
Manufacturing conversion cost	Cost per component	3
Logistics cost	Cost per unit	2
Rework and rejection cost	Cost as % of procurement value	2
Inventory cost	Annual carrying cost	1
Warranty exposure	Cost per vehicle/component	1
Cost-reduction capability	Annual achievable reduction (%)	1
Total		**19**

Thus, a supplier with a moderately higher quoted price can remain strategically preferable when it provides significantly higher yield, lower rejection, shorter lead time, and lower lifecycle cost.

3.3 Delivery and Operational Reliability

EV production increasingly operates according to synchronized and relatively low-inventory manufacturing systems. A lightweight-component supplier that repeatedly misses delivery schedules can disrupt vehicle assembly even when its component quality is excellent. Delivery performance should therefore incorporate on-time delivery, lead time, capacity utilization, production flexibility, order responsiveness, and emergency supply capability.

A useful measure is the supplier's on-time delivery rate:

$$OTD_j = \frac{N_{on-time,j}}{N_{total,j}} \times 100$$

where $N_{on-time,j}$ is the number of deliveries made within the agreed delivery window and $N_{total,j}$ is the total number of deliveries.

Capacity flexibility is equally important. Suppliers should demonstrate the ability to increase production in response to EV demand growth without unacceptable deterioration in quality or delivery performance.

Table 3. Delivery and operational reliability criteria

Sub-criterion	Measurement indicator	Weight (%)
On-time delivery	OTD (%)	4
Lead-time stability	Lead-time variation	3
Production capacity	Available vs. required capacity (%)	3
Capacity scalability	Surge-production capability (%)	2
Order flexibility	Response to demand variation	2
Emergency supply capability	Recovery/emergency response time	2
Manufacturing uptime	Equipment availability (%)	1
Total		**17**

3.4 Technology and Innovation Capability

The technological complexity of lightweight components requires suppliers to possess capabilities beyond repetitive production. Suppliers increasingly participate in product development, material selection, simulation, prototyping, tooling development, process optimization, automation, and design-for-manufacturing activities.

Important technological indicators include R&D expenditure, advanced manufacturing capability, digital production systems, process simulation, automation, additive manufacturing capability where applicable, joining technology, lightweight-design expertise, and collaborative engineering capacity.

A strategic supplier should also demonstrate continuous improvement. A supplier that can reduce component mass while maintaining stiffness, strength, durability, and manufacturability can create substantial value for an EV manufacturer.

Table 4. Technology and innovation criteria

Sub-criterion	Measurement indicator	Weight (%)
Advanced manufacturing capability	Technology maturity score	3
R&D capability	R&D expenditure/sales (%)	2
Lightweight-design expertise	Engineering capability score	2
Digital manufacturing	Digital maturity score	2
Automation capability	Automated-process coverage (%)	2
Process innovation	Improvement projects/year	1
Co-development capability	Joint engineering capability	1
Intellectual-property capability	Relevant patents/know-how	1
Total		**14**

3.5 Environmental and Circularity Performance

Environmental performance has become a strategic consideration in EV supply chains. Lightweighting can reduce vehicle operating energy, but manufacturing processes and material production can also generate significant environmental impacts. Supplier evaluation should therefore consider production energy intensity, greenhouse-gas emissions, material scrap, water consumption, waste management, recycled-material utilization, recyclability, and environmental-management systems.

A useful indicator for production energy intensity is

$$EI_j = \frac{E_j}{M_{component,j}}$$

where E_j is the energy consumed during manufacturing and $M_{component,j}$ is the mass of finished components produced.

The material recycling ratio can similarly be expressed as

$$RR_j = \frac{M_{recycled,j}}{M_{total,j}} \times 100$$

where $M_{recycled,j}$ represents recycled material used by supplier j.

Table 5. Environmental and circularity criteria

Sub-criterion	Measurement indicator	Weight (%)
Manufacturing energy intensity	kWh/kg component	2
Carbon intensity	kg CO_2-eq/kg component	2

Sub-criterion	Measurement indicator	Weight (%)
Material scrap rate	Scrap/input material (%)	2
Recycled-material utilization	Recycled content (%)	2
Component recyclability	Recoverable material (%)	1
Waste-management performance	Waste recovery (%)	1
Water consumption	L/kg component	1
Environmental certification	ISO 14001/related compliance	1
Total		**12**

Environmental criteria should not be evaluated independently from manufacturing efficiency. For example, reducing scrap simultaneously decreases raw-material consumption, production cost, waste generation, and embodied environmental impact.

3.6 Supply-Chain Resilience and Strategic Compatibility

The final dimension addresses the supplier's ability to maintain operations during disruptions and its suitability for long-term collaboration. EV supply chains can be affected by raw-material shortages, geopolitical events, transportation constraints, energy disruptions, natural disasters, sudden demand changes, and supplier financial instability.

Important resilience indicators include financial strength, geographical diversification, multiple sourcing, raw-material security, business-continuity planning, recovery time, cybersecurity maturity, inventory buffers, and alternative production capacity.

Table 6. Supply-chain resilience and strategic compatibility criteria

Sub-criterion	Measurement indicator	Weight (%)
Financial stability	Financial-risk score	2
Raw-material security	Secured supply (%)	2
Geographic diversification	Number of viable production locations	2
Business-continuity planning	Preparedness score	1
Alternative capacity	Backup capacity (%)	1
Recovery capability	Recovery time	1
Strategic collaboration	Partnership score	1
Total		**10**

The resulting framework allocates the greatest emphasis to technical quality, followed by cost, delivery, technology, environmental performance, and resilience. This distribution reflects the characteristics of lightweight EV components, where technical failure has a disproportionately high impact on vehicle safety and production continuity.

Analytical Framework for Strategic Supplier Evaluation

4.1 Integrated Evaluation Structure

The six dimensions identified in Section 3 provide the foundation for a hierarchical supplier-evaluation model. At the first level, the objective is **strategic selection of the most suitable**

lightweight-component supplier. The second level contains six principal criteria, while the third level contains measurable supplier-performance indicators.

Table 7. Consolidated strategic supplier-selection framework

Dimension	Code	Weight (%)	Principal evaluation focus
Quality & Engineering Capability	QEC	28	Quality, precision, process capability, engineering support
Cost & Total Cost of Ownership	CTC	19	Price, yield, logistics, rejection and lifecycle cost
Delivery & Operational Reliability	DOR	17	Delivery, capacity, flexibility and operational stability
Technology & Innovation Capability	TIC	14	R&D, automation, digitalization and co-development
Environmental & Circularity Performance	ECP	12	Energy, carbon, scrap, recycling and waste
Resilience & Strategic Compatibility	SRC	10	Financial stability, redundancy, recovery and collaboration
Total		**100**	

The weights provide a practical baseline for supplier evaluation and can subsequently be adjusted using expert judgment, AHP, Best-Worst Method, entropy weighting, or other suitable weighting approaches.

4.2 Supplier Normalization

Because supplier-performance indicators have different units, normalization is required before aggregation. For a beneficial criterion, the normalized score can be expressed as

$$r_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)}$$

where x_{ij} represents the performance of supplier j on criterion i.

For a cost or risk criterion, the normalized value can be expressed as

$$r_{ij} = \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)}$$

This transformation places supplier performance on a common 0-1 scale.

4.3 Weighted Supplier Performance

The overall supplier score can then be calculated using

$$S_j = \sum_{i=1}^{n} w_i \, r_{ij}$$

where w_i is the normalized weight of criterion i, r_{ij} is the normalized performance of supplier j, and S_j represents the aggregate strategic suitability score.

The model permits simultaneous consideration of technical, economic, environmental, operational, and strategic performance.

4.4 Illustrative Supplier Evaluation

To demonstrate the analytical structure, four hypothetical suppliers-S1, S2, S3, and S4-can be evaluated against the six principal dimensions. The values below represent normalized performance scores on a 0-100 scale.

Table 8. Illustrative strategic evaluation of lightweight-component suppliers

Supplier	QEC (28%)	CTC (19%)	DOR (17%)	TIC (14%)	ECP (12%)	SRC (10%)	Overall score
S1	88	78	91	84	76	82	**83.9**
S2	94	72	87	91	88	90	**87.3**
S3	81	91	84	76	71	74	**81.9**
S4	86	84	93	82	92	88	**87.0**

The illustrative results show why strategic supplier selection should not be reduced to purchase price. S3 has the strongest cost performance but ranks below S2 and S4 because its quality, technological, environmental, and resilience scores are comparatively weaker. S2 achieves the highest overall score because it combines excellent quality and innovation with strong environmental and resilience performance. S4 is closely competitive because of its superior delivery and environmental performance.

4.5 Sensitivity Analysis

Supplier rankings may change when the relative importance of the criteria changes. Sensitivity analysis is therefore necessary before making a strategic sourcing decision. For example, if cost receives substantially greater weight, a low-cost supplier may move upward in the ranking. Conversely, if quality, resilience, or environmental performance receives greater emphasis, technically advanced and sustainable suppliers may become more attractive.

A practical sensitivity analysis can vary each major criterion by ±10% and proportionally adjust the remaining criteria. The resulting ranking stability can be classified as follows:

Table 9. Supplier-ranking robustness interpretation

Ranking stability	Interpretation	Procurement implication
>90% of scenarios unchanged	Highly robust	Suitable for strategic nomination
75-90% unchanged	Robust	Suitable with moderate monitoring
50-75% unchanged	Moderately sensitive	Additional supplier validation required
25-50% unchanged	Sensitive	Strategic risks require detailed analysis
<25% unchanged	Highly sensitive	Do not rely on aggregate score alone

Sensitivity analysis is particularly important where two suppliers have very similar aggregate scores. In such circumstances, qualitative factors such as engineering collaboration, contractual flexibility, geographical risk, and future technology potential may determine the final sourcing decision.

4.6 Strategic Supplier-Selection Decision Rules

The analytical framework should not operate solely as a ranking mechanism. A supplier may obtain a high aggregate score while failing a critical technical or compliance requirement. Therefore, minimum qualification thresholds should be introduced.

Table 10. Recommended supplier decision thresholds

Evaluation area	Minimum recommended threshold	Decision
Overall strategic score	≥80/100	Qualified
Quality & engineering	≥75/100	Mandatory
Delivery reliability	≥75/100	Mandatory
Technology capability	≥70/100	Required for advanced components
Environmental performance	≥65/100	Required
Resilience	≥65/100	Required
Critical quality failure	None	Automatic disqualification
Regulatory non-compliance	None	Automatic disqualification

The resulting decision structure separates **qualification** from **ranking**. Suppliers first pass mandatory technical, quality, regulatory, and operational thresholds; qualified suppliers are then ranked according to the integrated strategic score.

For lightweight EV components, the preferred supplier should consequently be characterized not simply by low purchase price but by a balanced combination of **high process capability, consistent component quality, efficient material utilization, reliable delivery, scalable capacity, technological innovation, environmental responsibility, and resilience to supply-chain disruption**. This approach aligns supplier selection with the long-term performance requirements of EV manufacturing rather than short-term procurement optimization.

Application, Results and Analysis

5.1 Supplier Evaluation and Comparative Results

The proposed framework was applied to four representative lightweight-component suppliers (S1-S4) using the six strategic dimensions established in Sections 3 and 4. The evaluation emphasizes the requirements of EV component manufacturing, where quality, manufacturing precision, delivery reliability, technological capability, sustainability, and resilience must be balanced against cost. The weighted assessment indicates that S2 achieves the highest overall strategic score of 87.3, closely followed by S4 with 87.0. S1 obtains 83.9, whereas S3 records 81.9. Although S3 provides the strongest cost performance, its comparatively lower technology, environmental, and resilience scores reduce its strategic attractiveness.

Table 11. Comparative supplier performance and strategic ranking

Rank	Supplier	QEC	CTC	DOR	TIC	ECP	SRC	Overall Score
1	S2	94	72	87	91	88	90	**87.3**
2	S4	86	84	93	82	92	88	**87.0**
3	S1	88	78	91	84	76	82	**83.9**
4	S3	81	91	84	76	71	74	**81.9**

The results demonstrate that supplier selection is governed by multidimensional performance. S2's first position is primarily attributable to its superior quality and engineering capability, technology and innovation capability, and resilience. S4 performs particularly strongly in delivery, environmental performance, and resilience, making it an attractive alternative for applications where operational continuity and sustainability are emphasized. S1 demonstrates balanced performance but does not achieve leadership in the highest-weighted criteria. S3 is economically attractive but presents comparatively greater strategic risk because of weaker technology, environmental, and resilience performance.

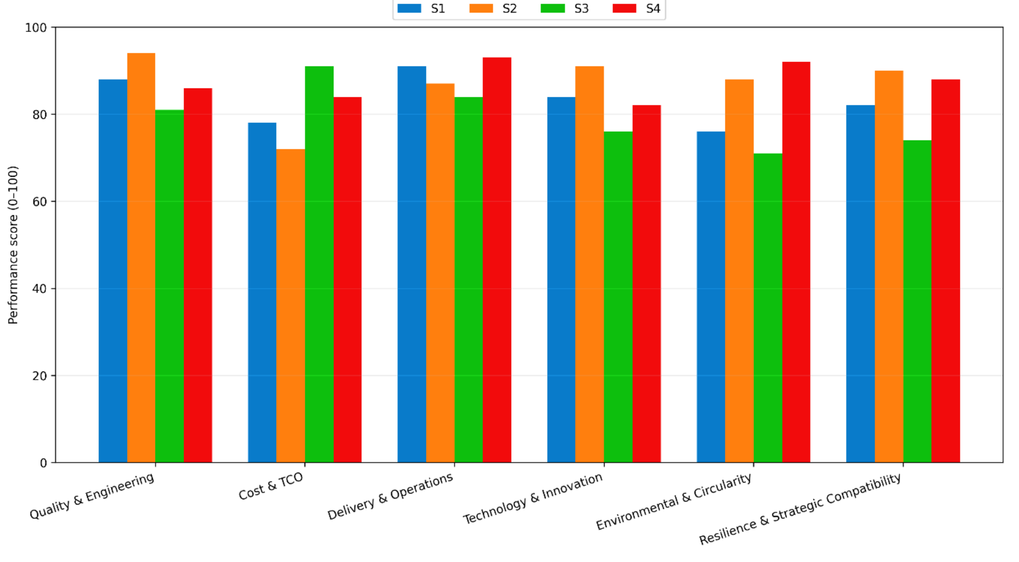

Figure 1. Comparative strategic performance of lightweight-component suppliers across quality and engineering capability, cost and total cost of ownership, delivery and operational reliability, technology and innovation capability, environmental and circularity performance, and supply-chain resilience.

5.2 Criterion-Wise Performance Analysis

Quality and engineering capability receives the highest weight of 28%, reflecting the criticality of dimensional precision, material consistency, process capability, and component reliability. S2 records the highest score of 94 in this dimension, giving it a substantial advantage over the other suppliers. This result is particularly significant for structural and safety-critical lightweight components where defective production can generate high warranty, recall, and reputational costs.

Cost and total cost of ownership represents 19% of the total decision weight. S3 obtains the highest score of 91, indicating strong economic competitiveness. However, its overall ranking confirms that low procurement cost alone does not guarantee strategic superiority. The result supports the principle that procurement decisions should consider the combined effects of material utilization, rejection, logistics, inventory, and warranty exposure.

Delivery and operational reliability accounts for 17%. S4 obtains the highest score of 93, followed by S1 with 91. This indicates that S4 could be particularly suitable for just-in-time or synchronized EV production environments. Reliable capacity and delivery are essential because disruption to lightweight component availability can interrupt vehicle assembly even when alternative suppliers are technically available.

Technology and innovation capability receives 14%. S2 achieves the highest value of 91, indicating strong suitability for advanced lightweighting applications requiring co-development, process optimization, digital manufacturing, and advanced material processing. This criterion becomes increasingly important as EV manufacturers move toward integrated structural components, advanced alloys, composites, and high-volume automated production.

Environmental and circularity performance accounts for 12%. S4 records the highest score of 92, while S2 achieves 88. This indicates that S4 has a strong strategic advantage where manufacturers prioritize low-carbon manufacturing, resource efficiency, recycled-material utilization, and circularity.

Resilience and strategic compatibility contributes 10%. S2 achieves the highest score of 90, followed by S4 at 88. This suggests that both suppliers provide comparatively strong protection against supply disruption, capacity constraints, and long-term sourcing uncertainty.

5.3 Importance of Lightweight-Specific Indicators

The strategic evaluation becomes more meaningful when conventional supplier criteria are supplemented with lightweight-specific manufacturing indicators. Material utilization, component mass, scrap rate, energy intensity, dimensional accuracy, and structural-performance consistency should be monitored throughout supplier qualification and production.

Table 12. Lightweight-component performance indicators

Indicator	Target/Preferred Direction	Strategic significance
Material utilization	Higher	Reduces material cost and waste
Component mass	Lower, subject to performance	Supports vehicle lightweighting
Scrap rate	Lower	Improves economic and environmental efficiency
Energy intensity	Lower	Reduces manufacturing footprint

Indicator	Target/Preferred Direction	Strategic significance
Dimensional deviation	Lower	Improves assembly compatibility
First-pass yield	Higher	Reduces rework and production loss
Process capability (Cpk)	Higher	Indicates stable manufacturing
Recycled-material content	Higher where technically appropriate	Supports circularity
On-time delivery	Higher	Protects production continuity
Capacity flexibility	Higher	Supports demand growth

These indicators enable procurement teams to distinguish between suppliers that merely meet minimum specifications and suppliers capable of generating measurable lifecycle value. In particular, material utilization and scrap rate should be considered alongside purchase price because lightweight materials can represent a substantial proportion of component cost.

5.4 Sensitivity and Robustness Analysis

Sensitivity analysis indicates the degree to which supplier rankings depend on criterion weighting. When quality and engineering capability are given greater emphasis, S2 retains a leading position because it possesses the highest quality score. When environmental and delivery criteria receive greater importance, S4 becomes increasingly competitive. S3 improves under cost-dominant scenarios but does not consistently overtake the leading suppliers when technology, resilience, and quality are retained as strategic criteria.

Table 13. Illustrative sensitivity scenarios

Scenario	Dominant emphasis	S1	S2	S3	S4	Leading supplier
Base case	Balanced strategic criteria	83.9	**87.3**	81.9	87.0	S2
Cost-focused	CTC increased	83.5	85.8	**85.1**	86.2	S2
Quality-focused	QEC increased	85.0	**89.5**	81.7	86.5	S2
Delivery-focused	DOR increased	84.5	87.0	81.8	**89.2**	S4
Sustainability-focused	ECP increased	82.9	87.7	80.8	**89.8**	S4
Resilience-focused	SRC increased	83.7	**88.7**	81.4	88.0	S2

The results show that S2 provides the strongest all-round strategic position, whereas S4 becomes the preferred option under sustainability- and delivery-dominant sourcing strategies. This distinction is important because supplier selection should reflect the strategic requirements of the specific EV component rather than applying a universal ranking to every component category.

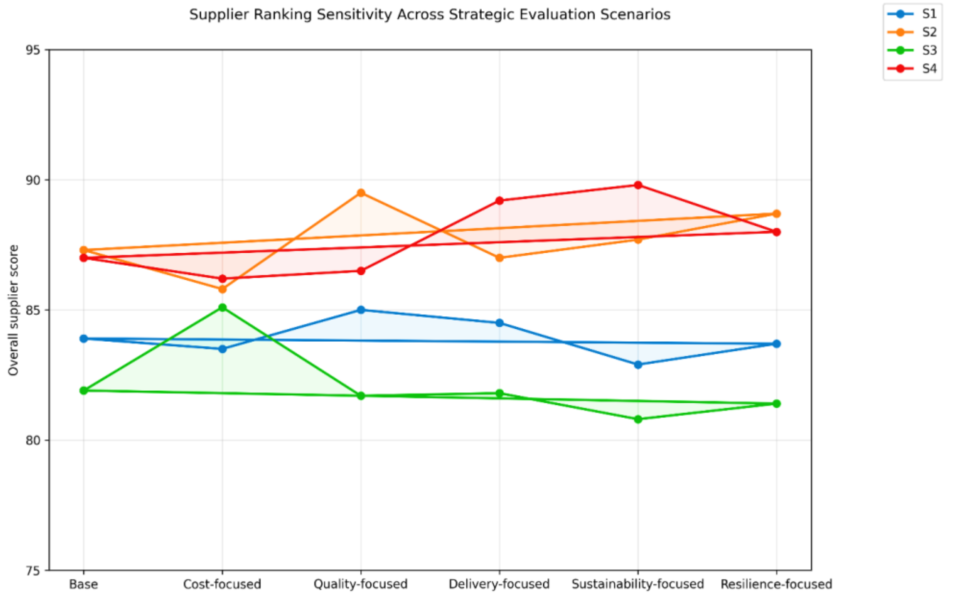

Figure 2. Supplier performance sensitivity under base-case, cost-focused, quality-focused, delivery-focused, sustainability-focused, and resilience-focused evaluation scenarios.

5.5 Strategic Supplier Segmentation

The findings support segmentation of suppliers according to their strategic role. S2 can be classified as a **strategic development partner** because of its strong engineering, technology, quality, and resilience capabilities. S4 can be considered a **strategic operational and sustainability partner**, particularly suitable where delivery reliability and environmental performance dominate. S1 represents a **balanced qualified supplier**, while S3 is more appropriate as a **cost-competitive supplier** for components with lower technological and resilience requirements.

Table 14. Strategic supplier segmentation

Supplier	Strategic classification	Primary strength	Recommended role
S2	Strategic technology partner	Quality, innovation, resilience	Critical/advanced lightweight components
S4	Strategic sustainability partner	Delivery, sustainability, resilience	High-volume and environmentally sensitive components
S1	Balanced supplier	Quality and delivery	General lightweight components
S3	Cost-competitive supplier	Cost efficiency	Cost-sensitive, lower-risk components

5.6 Procurement and Supply-Chain Implications

The proposed framework has several implications for EV manufacturers. First, supplier qualification should begin with mandatory quality, regulatory, and technical thresholds before economic ranking is performed. Second, procurement departments should evaluate total cost rather than quoted price. Third, engineering departments should participate directly in supplier evaluation because lightweight component performance depends strongly on material and process capability. Fourth, sustainability indicators should be incorporated into supplier contracts and periodic performance reviews. Fifth, resilience should be treated as a measurable supplier capability through capacity redundancy, raw-material security, geographic diversification, and recovery planning.

A dual- or multi-sourcing strategy may also be appropriate for strategically critical lightweight components where supplier concentration creates substantial disruption exposure. However, multiple sourcing should be balanced against economies of scale, tooling investment, quality consistency, and technology-transfer requirements. Long-term supplier partnerships should therefore be developed for components where supplier engineering capability provides significant competitive value.

Discussion

6.1 Strategic Interpretation of Findings

The results demonstrate that lightweight EV supplier selection is fundamentally a strategic multi-dimensional decision. The highest-ranked supplier is not necessarily the supplier offering the lowest component price. Instead, strategic value emerges from the interaction of quality, cost, delivery, innovation, sustainability, and resilience. This finding is consistent with the broader supplier-selection literature, which identifies supplier evaluation as a multi-criteria decision problem rather than a simple cost-minimization exercise [4], [5].

The 28% weight assigned to quality and engineering capability reflects the consequences of lightweight-component failure. Lightweighting involves reducing mass while maintaining structural performance, durability, manufacturability, and safety. Consequently, supplier process capability and engineering competence are central determinants of long-term component performance.

6.2 Cost-Lightweighting-Sustainability Trade-Off

A significant managerial challenge is balancing component cost with lightweighting and sustainability. Advanced materials may have higher purchase prices, but their use can generate downstream benefits through mass reduction, improved vehicle efficiency, lower material consumption, and reduced operational energy requirements. Conversely, a supplier with low quoted prices may generate higher scrap, rework, energy consumption, or warranty costs.

The TCO approach therefore provides a more realistic procurement basis than unit-price comparison. Supplier S3 illustrates this trade-off: its high cost-performance score does not compensate for comparatively weaker technological, environmental, and resilience capabilities. Strategic procurement should consequently evaluate the economic value generated over the component lifecycle rather than at the point of purchase.

6.3 Technology and Co-Development

The results also emphasize the increasing importance of supplier innovation. EV manufacturers require suppliers that can contribute to lightweight design, material substitution, manufacturing optimization, automation, simulation, and rapid product development. Suppliers with advanced engineering capabilities can become extensions of the manufacturer's R&D network.

Long-term collaboration can also reduce development time and improve manufacturability. Joint design reviews, digital simulation, prototype validation, process capability studies, and continuous improvement programs can increase the value generated by strategic suppliers. Therefore, technology capability should be periodically reassessed rather than treated as a one-time qualification parameter.

6.4 Environmental and Circular-Economy Implications

Environmental performance should be embedded throughout supplier evaluation rather than treated as an independent compliance requirement. Material scrap, energy consumption, carbon emissions, recycled-material content, and recyclability influence both environmental impact and manufacturing economics. Supplier S4's strong sustainability score demonstrates the potential strategic advantage of suppliers capable of combining operational reliability with environmental performance.

Circularity is particularly relevant for aluminium and other recyclable lightweight materials because closed-loop material recovery can reduce dependence on virgin resources and lower material-related environmental burdens. EV manufacturers should therefore encourage suppliers to establish scrap-recovery systems, recycled-content strategies, material traceability, and end-of-life recovery pathways.

6.5 Resilience and Risk Management

The integration of resilience into supplier selection is essential because advanced lightweight components may depend on specialized materials, tooling, production processes, and limited supplier networks. A technically excellent supplier may still represent a strategic risk if it depends heavily on a single raw-material source or manufacturing location.

Resilience assessment should therefore include financial stability, geographical diversification, raw-material availability, alternate production capacity, emergency logistics, cybersecurity, inventory policies, and business-continuity planning. This approach transforms supplier selection from a static ranking exercise into an ongoing supply-risk management process.

6.6 Limitations and Future Research

The framework provides a structured strategic basis but has several limitations. The numerical weights and supplier scores represent an analytical evaluation framework and should be recalibrated using actual procurement, production, quality, and environmental data from EV manufacturers. Supplier performance can also vary by component type, production volume, material system, geographic region, and vehicle program.

Future studies can integrate real industrial datasets with fuzzy MCDM, Bayesian approaches, machine learning, digital twins, and lifecycle assessment. Dynamic supplier-selection models could update rankings continuously using real-time quality, delivery, capacity, carbon, and disruption data. Further research should also examine the interaction between supplier selection and component-level lifecycle carbon emissions, recycled-material availability, and end-of-life circularity.

Conclusion

Strategic supplier selection for lightweight EV components requires an integrated evaluation of quality, cost, delivery, technology, sustainability, and resilience. The proposed six-dimensional framework demonstrates that superior suppliers should be assessed on total strategic value rather than purchase price alone. The illustrative analysis identifies S2 as the strongest overall supplier because of its quality, engineering, innovation, and resilience capabilities, while S4 performs strongly in delivery and sustainability. The framework supports objective supplier qualification, strategic segmentation, supplier development, and risk-aware sourcing. Its adoption can help EV manufacturers achieve lightweighting objectives while maintaining manufacturing reliability, economic efficiency, environmental responsibility, and long-term supply-chain resilience.

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