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RESEARCH ARTICLE

Smart and Sustainable Supplier Balanced Scorecard: A Novel Hybrid Best-Worst-Based Method

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ABSTRACT
This study's novel smart and sustainable supplier scorecard is based on the best-worst method-enhanced balanced scorecard approach for supplier assessment and monitoring. The proposed smart and sustainable supplier scorecard evaluates suppliers in six dimensions: performance, quality management, risk analysis, environmental management, smartness, and legitimacy. Quantitative indicators and metrics calculate each dimension. The smart and sustainable supplier scorecard is designed for businesses to assess and monitor their suppliers' performance regarding digitization and sustainability and evaluate strategies and initiatives that meet their objectives and targets. Furthermore, we present a case study showing the applicability of the smart and sustainable supplier scorecard. The proposed approach will give organizations a holistic view of their suppliers, allowing them to achieve digitization and sustainability goals. Finally, we discuss the potential benefits and managerial implications of the smart and sustainable supplier scorecard.

Keywords: Supplier assessment, Supplier monitoring, Risk management, Smart and sustainable supply chain management, Balanced scorecard, Best-worst method

1. Introduction

The use of the balanced scorecard (BSC) can provide a comprehensive view of supplier performance, making it critical to any successful supply chain management (SCM) strategy (Hudnurkar *et al*., 2018; Knotts *et al*., 2006). A BCS combines financial and non-financial performance measures in a single scorecard, which guides strategy formulation, implementation, and communication, tracks performance, and provides quick feedback for control and evaluation (Pandey, 2005). BSC can be used as a supplier scorecard, identifying the most critical supplier performance metrics (Kumar *et al*., 2014). The supplier scorecard is a comprehensive supplier evaluation tool that enables organizations to assess the performance of their suppliers concerning key performance indicators (KPIs) (Doolen *et al*., 2006; Hudnurkar *et al*., 2018). Using BSC in supplier assessment has several benefits (Ferreira *et al*., 2016). It enables businesses to monitor the performance of their suppliers (Galankashi *et al*., 2016), identify improvement areas and develop strategies to address any issues (Doolen *et al*., 2006), and build a more collaborative relationship with their suppliers, improving performance and outcomes for both parties (Hudnurkar *et al*., 2018).

This paper proposes a novel approach to smart and sustainable supplier scorecards based on the BSC approach to develop, monitor, and inspect suppliers' impact on a company's production and supply chain effectiveness. By applying the BSC-based approach to smart and sustainable supplier scorecards, companies can gain a more comprehensive view of their suppliers regarding digitization and sustainability.

This study proposes the smart and sustainable supplier scorecard, which evaluates suppliers' performance based on the best-worst method (BWM) enhanced BSC approach. This approach comprises 6 parts representing one of the 4S-score dimensions: performance, quality management, risk analysis, environmental management, smartness, and legitimacy. The score for each dimension is calculated by evaluating the suppliers' performance, quality management system (QMS) development status, risk degree, environmental management system (EMS) development, smartness score, and legitimacy score. The 4S-score is calculated by adding the average dimension scores, and the BWM is used to determine the weights of strategies. The BWM-enhanced BSC

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evaluation matrix is then constructed by integrating the BSC framework with the BWM method. This BWM-enhanced BSC evaluation matrix is then used to calculate the prominence scores of strategies and initiatives.

This paper is organized as follows. Section 2 discusses the conceptual background of supplier assessment and monitoring and summarizes the implementation of the BSC approach in SCM. Section 3 presents a proposed framework for a smart and sustainable supplier scorecard that integrates the BSC approach with the BWM method. This framework includes a set of criteria for assessing and monitoring suppliers and a set of metrics for measuring performance. Section 4 provides the details of the case study, and Section 5 concludes with a discussion of the potential benefits of this approach and the potential implementation challenges.

2. Literature review

A company purchases materials or services from suppliers whose inspection, development, and performance evaluation (crucial for organizational performance) can affect production and supply chain quality. This section examines the literature on supplier evaluation and monitoring, focusing on sustainable supplier evaluation and the implementation of the BSC approach to SCM.

2.1. Supplier assessment and monitoring

Supplier assessment is essential to SCM; it assesses and selects potential suppliers based on multiple criteria such as cost, quality, and reliability (Chen and Wu, 2013). Due to environmental, social, and economic sustainability, supplier evaluation has become increasingly complex in recent years. This shift has resulted in various supplier evaluation methods to ensure the supplier management process is effectively performed (Sundtoft Hald and Ellegaard, 2011). The literature on supplier evaluation criteria and approaches is vast, with many studies published in the past two decades. For example, Govindan *et al*. (2015) analyzed research in international scientific journals and conference proceedings on green supplier selection, finding that EMSs were the most common criterion for green supplier selection. Ho *et al*. (2010) conducted a literature review of multi-criteria decision-making approaches for supplier evaluation and selection, finding that the most prevalently applied techniques were fuzzy-based single-model approaches. Zhang *et al*. (2020) conducted a comprehensive review of studies that aim to develop models and methods to help enterprises assess and select suitable green suppliers, finding that the most commonly used evaluation criteria were environmental, financial, and operational. Simić *et al*. (2017) reviewed the studies that aim to develop models and strategies to help enterprises assess and select suitable green suppliers. They also conducted a bibliometric analysis according to the frequency of supplier selection methods, citation number, publication year, journal, country, and application area. Vörösmarty and Dobos (2020) summarized findings about papers involving supplier selection and evaluation using data envelopment analysis, determining that most papers still focus on supplier selection, with few papers considering sustainability. Finally, Saidy *et al*. (2018) investigated current practices of supplier delivery assessment and the valuation of management decisions regarding underperforming suppliers. They proposed an analytic hierarchy process (AHP)-based method that enables purchasing firms to assess their suppliers and take proactive measures against underachieving suppliers.

Sustainable supplier evaluation is a vital component of the supply chain process, and it has become increasingly important in the modern manufacturing industry (Reuter *et al*., 2010). Identifying, assessing, and treating supplier sustainability risks have become a priority for purchasing and supply management functions (Förstl *et al*., 2010). As the Industry 4.0 environment has grown, managing suppliers more efficiently and effectively has become vital (Esmaeilian *et al*., 2020; Núñez-Merino *et al*., 2020). There is a need to evaluate and monitor suppliers systematically to consider green supply chain performance (De Giovanni and Cariola, 2021). Recent research has proposed several frameworks and methods for assessing and managing suppliers in various industries. For example, Zheng *et al*. (2022) proposed a three-phase model that utilizes the AHP and entropy weight method to determine the weights of evaluation indices. Coşkun *et al*. (2022) suggested an integrated sustainable supplier evaluation and development framework to support chemical manufacturers in managing supplier relationships according to sustainability's economic, environmental, and social dimensions. Chang *et al*. (2021) proposed four dimensions for sustainable supplier evaluation and selection: economic, social, environmental, and institutional sustainability. Lo *et al*. (2021) presented a two-stage multi-criteria decision-making approach for sustainable supplier evaluation and transportation planning in multi-level supply chain networks. Chen and Hu (2022) suggested a method for analyzing enterprise supplier characteristics using data mining and mathematical programming models. Cinnirella *et al*. (2022) proposed an AHP-TOPSIS (technique for order of preference by similarity to ideal solution) method applied to suppliers for a company operating in the waste management sector. Şişman *et al*. (2022) identified criteria for sustainable supplier performance in monitoring and evaluation; they used the interval-valued intuitionistic fuzzy AHP method to calculate the criteria weights. Tolooie *et al*. (2022) suggested an integrated fuzzy decision model for sustainable supplier evaluation and selection. Govindan *et al*. (2023) proposed a theoretical framework to analyze KPIs for developing sustainable collaboration.

2.2. Balanced scorecard (BSC) and its supply chain management (SCM) implementations

BSC is a performance measurement framework widely used in various industries and supply chains (Schiffling and Piecyk, 2014). The BSC framework is based on four perspectives: financial, customer, internal process, and learning and growth (Bigliardi and Bottani, 2010). It provides a comprehensive view of performance, allowing organizations to measure the tangible and intangible aspects of their operations (Barber, 2008). BSC can measure total supply chain performance and incorporate the intangible value-adding aspects of the total value chain, such as customer satisfaction, on-time delivery, and cost reduction (Rahimnia *et al*., 2014). Thus, BSC allows organizations to assess the success of their supply chain operations more comprehensively. The BSC framework is used to evaluate the impact of the alignment between supply chain strategy and environmental uncertainty on supply chain performance (Chang, 2009). BSC is also used for performance measurement that aligns the employees' incentives to motivate collaborative supply chain behavior (Brewer, 2002). Finally, BSC can be used to measure and monitor the supply chain's performance from the perspective of senior supply chain executives (Chia *et al*., 2009). The BSC for sustainable SCM is discussed in the following subsection.

2.2.1. The use of the BSC for sustainable SCM

The use of BSC for sustainable SCM has become increasingly important in recent years (Kim and Rhee, 2012; Reefke and Trocchi, 2013). The growing awareness of environmental issues has led companies to increasingly look for ways to reduce their environmental impact and improve their sustainability performance (Rahimnia *et al*., 2014). BSC is a performance measurement tool that can be used to assess a supply chain's sustainability (Aliakbari Nouri *et al*., 2019); it is a comprehensive framework that considers four key sustainability perspectives: financial, customer, internal business, and the learning and growth perspectives (Jalali Naini *et al*., 2011). The financial perspective focuses on the financial performance of the supply chain, such as profitability, cost savings, and return on investment (Lin *et al*., 2014). The customer perspective examines customer satisfaction, loyalty, and retention (Khan *et al*., 2016). The internal business process perspective concerns the efficiency and effectiveness of the supply chain, such as inventory management, order fulfillment, and delivery performance (Thanki and Thakkar, 2018). Finally, the learning and growth perspective includes the ability of the supply chain to innovate and adapt to changing market conditions (Khaleeli *et al*., 2021). BSC can be used to assess a supply chain's sustainability in several ways (Ferreira *et al*., 2016). For example, a sustainable supply chain scorecard considers economic, social, and environmental indicators (Sislian and Jaegler, 2018). First, it can identify areas of improvement and strength, which can help companies determine issues and make changes to improve their sustainability performance. Second, BSC can be used to measure the performance of the supply chain over time, which can help companies track their progress and identify areas where they must concentrate their efforts. Finally, BSC can be used to compare the performance of different supply chains, allowing companies to identify best practices and areas to learn from other firms.

2.2.2. The use of the BSC for supplier selection and evaluation

The use of BSC for supplier selection and evaluation has become increasingly popular in recent years (AlMaian *et al*., 2016; Galankashi *et al*., 2016; Hudnurkar *et al*., 2018). It provides a comprehensive framework for assessing supplier performance and can be tailored to the buyer company's needs (Doolen *et al*., 2006). BSC can be used to develop a supplier collaborative performance index (Hudnurkar *et al*., 2018) and a supplier scorecard (Doolen *et al*., 2006), which can be used to assess suppliers' performance and determine the extent of collaboration between the buyer company and its suppliers (Brege *et al*., 2008). BSC can evaluate suppliers in four dimensions (Basu *et al*., 2009). First, it can be used to assess the financial performance of suppliers, such as their ability to meet deadlines and provide quality products at competitive prices (Hudnurkar *et al*., 2018). It can assess the customer service provided by suppliers, such as their responsiveness to customer inquiries and their ability to provide timely delivery of products (Galankashi *et al*., 2016). Second, BSC can be used to evaluate the internal business processes of suppliers, such as their ability to manage inventory and meet production deadlines (Doolen *et al*., 2006). Third, BSC can be used to assess suppliers' innovation and learning capabilities, such as their ability to develop new products and services and stay up-to-date with industry trends (Basu *et al*., 2009). Finally, BSC can also be used to develop a supplier collaborative performance index (Hudnurkar *et al*., 2018). This index can quantify the extent of collaboration between the buyer company and its suppliers. The supplier collaborative performance index is based on factors and their indicators that affect collaboration with the supplier, such as the supplier's financial performance, customer service, internal business processes, and innovation and learning capabilities (Galankashi *et al*., 2016). The higher the value of the supplier's collaborative performance index, the better the chance to move to the next level of maturity in the relationship. Furthermore, BSC can be used to develop a supplier scorecard (Doolen *et al*., 2006), which can assess suppliers' performance regarding their ability to meet deadlines, provide quality products at competitive prices, and respond to customer inquiries. The scorecard can assess the internal business processes of suppliers, such as their ability to manage inventory and meet production deadlines (Basu *et al*., 2009).

2.3. Literature gap

The previous sections reviewed the extensive literature on supplier assessment, monitoring, and using the BSC approach in SCM. While the BSC approach has been successfully applied to various SCM contexts, more research is needed on its application to smart and sustainable supplier assessment and monitoring. This paper aims to fill this gap by proposing a novel approach to supplier scorecards based on the BSC approach, emphasizing smartness and sustainability.

The proposed smart and sustainable supplier scorecard is designed to provide a broader view of supplier performance while considering smartness and sustainability. This approach can provide organizations with a comprehensive understanding of supplier performance, enabling them to identify areas of improvement and ensure that suppliers help the organization meet its smartness and sustainability goals. Table 1 summarizes BSC utilizing studies that focus on SCM and addresses the gap in the literature.

Table 1 shows that extensive research used the BSC approach in SCM and supplier assessment and monitoring areas; however, no study utilizes the BSC framework for supplier assessment considering smartness and sustainability. Most studies using the BSC approach for SCM issues have adopted surveys, case studies, or conceptual methodologies; few have used multi-criteria decision-making methods, e.g., AHP, analytic network process (ANP), or decision-making trial and evaluation laboratory (DEMATEL). To the authors' best knowledge, this study is the first attempt to integrate the BSC framework with the BWM.

Table 1. Summary of BSC utilizing studies focusing on SCM

Study	Supply chain focus	Method	Purpose
Doolen *et al.* (2006)	Supplier performance	Case study	To design a supplier scorecard for supplier performance improvement
Knotts *et al.* (2006)	Supplier performance	Survey	To examine the usefulness of BSC in measuring merchandising supplier performance
Sharma and Bhagwat (2007)	Supply chain performance	AHP	To develop an integrated BSC-AHP approach for SCM evaluation
Varma *et al.* (2008)	Supply chain performance	AHP	To suggest a method to evaluate the performance of the petroleum industry supply chain
Chang (2009)	Supply chain performance	Case study	To evaluate the SCM performance of Taiwan industries by using BSC
Chia *et al.* (2009)	Supply chain performance	Survey	To examine how senior supply chain executives measure performance from a BSC perspective
Bigliardi and Bottani (2010)	Supply chain performance	Case study	To develop a BSC model for performance measurement in the food supply chain
Jochem *et al.* (2010)	Process quality and performance	Conceptual	To investigate the alignment of the KPIs with the company's processes having bottlenecks alongside the value chain
Jalali Naini *et al.* (2011)	Supply chain performance	Case study	To propose a performance measurement system using a combination of evolutionary game theory and BSC in environmental SCM
Dhiaf *et al.* (2012)	Supply chain flexibility	Survey	To present a conceptual framework to uncover the effects of different dimensions of supply chain flexibility on global performance
Franceschini and Turina (2012)	Business performance	Case study	To propose a performance dashboard for monitoring the water and sewage service companies
Kim and Rhee (2012)	Green supply chain management performance	Survey	To examine the impact of green SCM critical success factors on BSC-based performance
More and Babu (2012)	Supply chain flexibility	Conceptual	To develop a flexibility scorecard focusing on the flexibility metric in a balanced way
Schloetzer (2012)	Supply chain information sharing	Survey	To examine the influence of hold-ups in supply chains on the extent of process integration and information sharing between partners
Chang *et al.* (2013)	Supply chain integration	Case study	To discuss the integration of the supply chain and performance based on BSC measures
Reefke and Trocchi (2013)	Supply chain sustainability	Conceptual	To facilitate a balanced approach to performance measurement for sustainable supply chains
Lin *et al.* (2014)	Green supply chain management performance	ANP	To propose a hybrid approach to evaluate the performance of a firm's green SCM
Rahimnia *et al.* (2014)	Supply chain performance	Survey	To propose an extended framework to consider the impact of supply chain strategy and environmental uncertainty on supply chain performance
Schiffling and Piecyk (2014)	Organizational performance	Conceptual	To develop a performance measurement framework that considers the key stakeholders of the logistics departments or personnel in humanitarian organizations
Cunha Callado and Jack (2015)	Supply chain performance	Survey	To identify how many metrics are used in BSCs related to specific supply chain roles
Liang (2015)	Supply chain performance	AHP	To measure inter-organizational information systems' performance in the supply chain
AlMaian *et al.* (2016)	Supplier quality	SMART	To describe applying the SMART technique to analyze supplier quality management practices
Aqlan *et al.* (2016)	Supply chain performance	Simulation	To propose a framework to assess supply chain readiness for transformation
Ferreira *et al.* (2016)	Environmental performance of supply chain	Case study	To suggest a model for the assessment of the environmental performance of a supply chain

Table 1. Continued

Study	Supply chain focus	Method	Purpose
Galankashi *et al.* (2016)	Supplier selection	AHP	To propose an integrated BSC-Fuzzy AHP model to select suppliers in the automotive industry
Golrizgashti (2016)	Supply chain value	Case study	To explore the effects of knowledge management applications on value creation in a supply chain
Cunha Callado and Jack (2017)	Supply chain performance	Survey	To explore the actual use of performance metrics in non-integrated supply chains
Chorfi *et al.* (2018)	Supply chain performance	AHP	To introduce a framework based on BSC and the SCOR model integrating the performance measurement systems for public healthcare supply chains

Table 1. Continued

Study	Supply chain focus	Method	Purpose
Hudnurkar *et al.* (2018)	Supplier collaboration performance	AHP	To develop a BSC-based index for quantifying the suitability of suppliers
Susanty *et al.* (2018)	Supply chain performance	Interviews & survey	To evaluate the performance of the relationships between farmers, dairy cooperatives, and industrial milk processors
Thanki and Thakkar (2018)	Lean and green performance of supply chain	ANP & DEMATEL	To propose a BSC and strategy map-based framework for assessing a supply chain's lean and green performance
Aliakbari Nouri *et al.* (2019)	Supply chain sustainability	Delphi method	To provide a framework to assess the sustainability of service supply chains
Anjomshoae *et al.* (2019)	Supply chain performance	AHP	To propose an integrated performance measurement scheme that consolidates KPIs into the performance indicators of humanitarian supply chains
Chandra and Kumar (2019)	Supply chain performance	AHP	To identify the KPIs of a vaccine supply chain
Al Naimi *et al.* (2020)	Supply chain reconfiguration	ANP	To prioritize supply chain reconfiguration variables by using BSC and ANP
Taifa *et al.* (2020)	Supplier performance	Conceptual	To identify and rank the critical success decision criteria for multiple suppliers working as an extended enterprise
Frederico *et al.* (2021)	Supply chain digitization performance	Conceptual	To present a BSC-based theoretical approach regarding performance measurement in supply chains for Industry 4.0
Khaleeli *et al.* (2021)	Business performance	Survey	To explore the potential of using BSC to measure the effect of green marketing, green supply chain, and green human resources on the performance of the firms
Shinkevich *et al.* (2021)	Supply chain digitization performance	Survey	To build a BSC framework for controlling procedures of petrochemical and fuel and energy enterprises in the context of the transition to Industry 4.0
Fernandes *et al.* (2022)	Business performance	Survey	To understand the impact of supply chain quality management dimensions on the organization's performance based on BSC perspectives
Nazari–Ghanbarloo (2022)	Supply chain performance	Simulation	To propose a model combining dynamic BSC with system dynamics to explore an efficient supply chain performance measurement tool
Saroha *et al.* (2022)	Circular supply chain performance	Conceptual	To identify the circular supply chain performance indicators using the modified BSC technique
Saleheen and Habib (2023)	Supply chain performance	Conceptual	To formulate an integrated supply chain performance measurement model
This study	**Supplier assessment and monitoring**	**BWM**	**To propose a method to assess and monitor suppliers considering smartness and sustainability**

3. Methodology

This study's novel smart and sustainable supplier scorecard is based on the BWM-enhanced BSC approach that evaluates suppliers. This section explains the methodological steps of the proposed scorecard, formulating each dimension based on its indicators and metrics.

We propose a novel supplier evaluation score, "4S-score" (Smart and Sustainable Supplier Surveillance), demonstrated in the hexagon shape in Fig. 1.

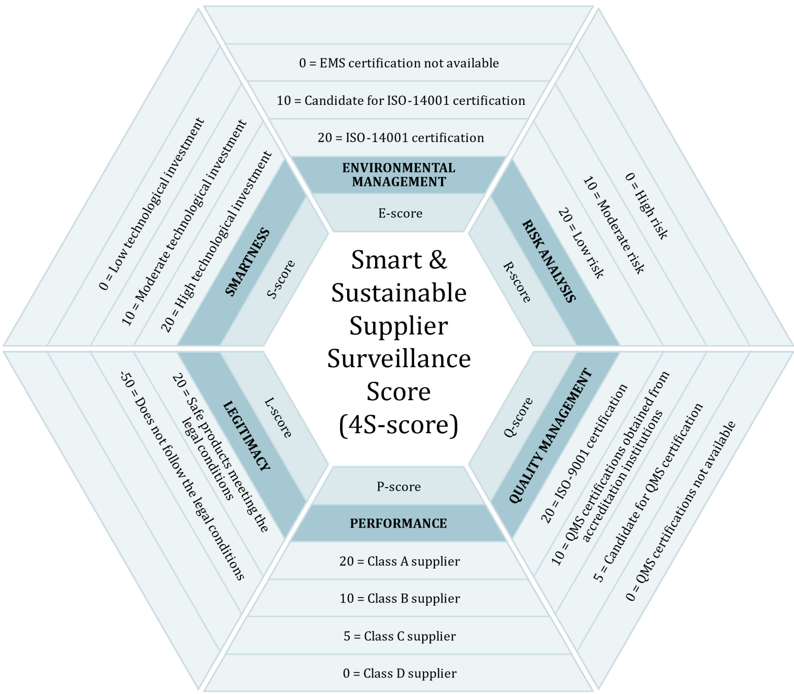

Figure 1. Dimensions of the smart and sustainable supplier surveillance score (4S-score)

The hexagon comprises six parts (wings), each representing one of the 4S-score dimensions: performance, quality management, risk analysis, environmental management, smartness, and legitimacy. The indicator for each dimension is demonstrated within each wing. For example, the performance dimension comprises four parts: class A supplier, class B supplier, class C supplier, and class D supplier.

Scores for each dimension are indicated using initials inside the hexagon: P-score, Q-score, R-score, E-score, S-score, and L-score. These dimensions and 4S-score are calculated by applying the following steps. Fig. 2. illustrates the methodological steps involved in the BWM-enhanced smart and sustainable supplier scorecard approach.

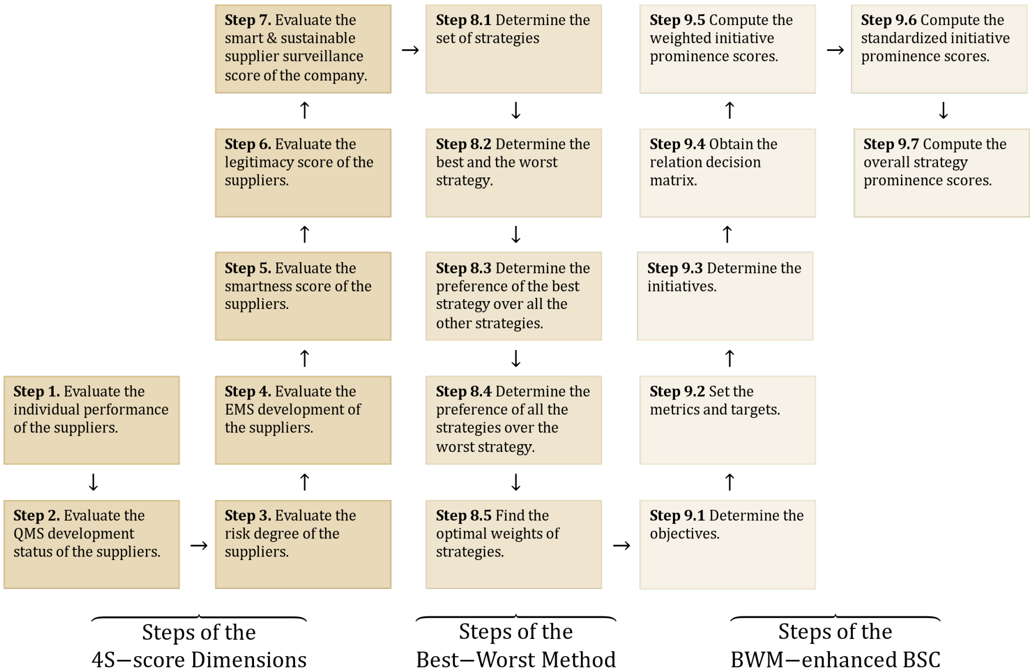

Figure 2. Methodological steps of the BWM-enhanced smart and sustainable supplier scorecard

Step 1: Evaluate the suppliers' individual performance.

Equation 1 computes supplier e's performance score (P_e), which is a function of the supplier performance evaluation score (p_e):

$$P_e = \begin{cases} 20, 85 \leq p_e \leq 100 \\ 15, 70 \leq p_e < 85 \\ 10, 50 \leq p_e < 70 \\ 0, p_e < 50 \end{cases} \tag{1}$$

Suppliers are classified according to their performance scores; evaluation scores (p_e) are 85–100 for class A suppliers, 70–85 for class B suppliers, 50–70 for class C suppliers, and 0–50 for class D suppliers.

The supplier performance evaluation score (p_e) is calculated by weighting the supplier capability score (p_{1e}), supplier shipment score (p_{2e}), and supplier price advantage score (p_{3e}):

$$p_e = 0.50p_{1e} + 0.35p_{2e} + p_{3e}. \tag{2}$$

1.1: Supplier capability score

The supplier capability score (p_{1e}) is calculated using Equation 3, which divides the amount accepted according to the quality acceptance standards during the period (p_{11e}) by the amount received (p_{12e}):

$$p_{1e} = 100 \times \frac{p_{11e}}{p_{12e}}. \tag{3}$$

1.2: Supplier shipment score

The supplier shipment score (p_{2e}) is calculated using Equation 4, which divides the quantity received on time (p_{21e}) by the order quantity (p_{22e}):

$$p_{2e} = 100 \times \frac{p_{21e}}{p_{22e}}. \tag{4}$$

1.3: Supplier price advantage score

Supplier price advantage score (p_{3e}) is calculated using Equation 5, which is a function of the purchasing price of goods (p_{31e}) to the average market price of purchased goods (p_{32e}):

$$p_{3e} = \begin{cases} 15, p_{31e} > p_{32e} \\ 0, p_{31e} \leq p_{32e} \end{cases} \tag{5}$$

Step 2. Evaluate the suppliers' QMS development status.

Equation 6 is used to calculate supplier e's quality management score (Q_e):

$$Q_e = \begin{cases} 20, & \text{Supplier } e \text{ holds ISO-9001 certification.} \\ 10, & \text{Supplier } e \text{ holds a QMS certification from accreditation institutions.} \\ 5, & \text{Supplier } e \text{ is a candidate for QMS certifications.} \\ 0, & \text{QMS certification is not available.} \end{cases} \tag{6}$$

Step 3. Evaluate the suppliers' risk degree.

Equation 6 is used to calculate supplier e's risk degree (R_e):

$$R_e = \begin{cases} 20, & \text{Supplier } e \text{ poses a low risk.} \\ 10, & \text{Supplier } e \text{ poses a moderate risk.} \\ 0, & \text{Supplier } e \text{ poses a high risk.} \end{cases} \tag{7}$$

The suppliers' risk degrees are determined based on the risk matrix in Appendix A; the first column represents the technological level of the supplier's production performance. Moving below the column means the supplier has a proven, reliable, up-to-date technological infrastructure. The second column shows the supplier's delivery performance. Moving below the column indicates that the supplier meets the requirements, reducing the risk. The rows of the risk matrix represent the production complexity of the parts supplied and their criticality for the system in terms of technical characteristics. Moving to the right of the row means the importance and complexity of the supply part increase. The decision-maker determines the supplier's risk according to the degrees of the columns and rows in the risk matrix. The supplier risk is classified into three levels: H for high risk, M for medium risk, and L for low risk.

Step 4. Evaluate the suppliers' EMS development.

Equation 8 calculates supplier e's environmental management score (E_e):

$$E_e = \begin{cases} 20, & \text{Supplier } e \text{ holds ISO-14001 certification.} \\ 10, & \text{Supplier } e \text{ is a candidate for ISO-14001 certification.} \\ 0, & \text{EMS certification is not available.} \end{cases} \tag{8}$$

Step 5. Evaluate the suppliers' smartness score.

Equation 9 calculates supplier e's smartness score (S_e):

$$S_e = \begin{cases} 20, & \text{Supplier } e \text{ has high technological investments.} \\ 10, & \text{Supplier } e \text{ has moderate technological investments.} \\ 0, & \text{Supplier } e \text{ has low technological investments.} \end{cases} \tag{9}$$

Step 6. Evaluate the legitimacy score of the suppliers.

Equation 10 calculates supplier e's smartness score (L_e):

$$L_e = \begin{cases} 20, & \text{Supplier } e \text{ offers safe products and meets legal conditions.} \\ -50, & \text{Supplier } e \text{ does not meet legal conditions.} \end{cases} \tag{10}$$

Step 7. Evaluate the smart and sustainable supplier surveillance score of the company.

The company's smart and sustainable supplier surveillance score (4S-score) is calculated by Equations 11–12. T_e represents the supplier e's score for the dimensions of the supplier scorecard, i.e., performance (P_e), quality management (Q_e), risk analysis (R_e), environmental management (E_e), smartness (S_e), and legitimacy (L_e). The 4S-score is calculated by adding up the average dimension scores ($\overline{P}, \overline{Q}, \overline{R}, \overline{E}, \overline{S}$, and $\overline{L}$), where these scores are the arithmetic mean of supplier E's scorecard dimension scores. The 4S-score represents the metric values of the smart and sustainable supplier scorecard.

$$4S = \overline{P} + \overline{Q} + \overline{R} + \overline{E} + \overline{S} + \overline{L} \tag{11}$$

$$\overline{T}\Sigma_{e=1}^{E}\frac{T_e}{E}, T_e = \{P_e, Q_e, R_e, E_e, S_e, L_e\} \tag{12}$$

Step 8. Determine the weights of strategies by using the BWM.

BWM is a multi-criteria decision-making method that compares the best criteria (alternatives) to the other criteria (alternatives) and all the other criteria (alternatives) to the worst criteria (alternatives). This study utilizes the BWM for weighting the strategies; thus, the method's criteria are substituted with alternative strategies. This process makes a comparison system composed of two comparison vectors, aiming to determine the optimal weights and consistency ratio through a simple optimization model constructed using the comparison system. The BWM comprises five steps (Rezaei, 2015).

Step 8.1: Determine the set of strategies.

In the first step, the decision-makers determine alternative strategies to improve the suppliers according to the scorecard dimension target values. Suppose that A_i (i=1,2,. . . ,m) represents the set strategies.

Step 8.2: Determine the best (e.g., most desirable or most important) and the worst (e.g., least desirable or least important) strategy.

Step 8.3: Determine the preference of the best strategy over all the other strategies by setting a ranking number between 1 and 9.

The resulting best-to-others vector is shown in Equation 13:

$$X_Y = (x_{Y1}, x_{Y2}, \ldots, x_{Ym}) \tag{13}$$

where x_{Ym} indicates the preference for the best strategy, A_Y, over strategy A_i; x_{YY}=1.

Step 8.4: Determine the preference of all the strategies over the worst strategy by setting a ranking number between 1 and 9.

The resulting others-to-worst vector is shown in Equation 14:

$$X_Z = (x_{1Z}, x_{2Z}, \ldots, x_{mZ}) \tag{14}$$

where x_{iZ} indicates the preference for strategy A_i over the worst strategy A_Z. It is clear that x_{ZZ}=1.

Step 8.5: Find the optimal weights of strategies.
$(w_1^*, w_2^*, \ldots, w_m^*)$

The optimal weight for the strategies is the one where for each pair of w_Y/w_i and w_i/w_Z , we have $w_Y/(w_i = x_{Yi})$ and $w_i/(w_Z = x_{iZ})$. To satisfy these conditions for all i, we find a solution that minimizes the maximum absolute differences, $\left|\frac{w_Y}{w_i} - x_{Yi}\right|$ and $\left|\frac{w_i}{w_Z} - x_{iZ}\right|$, for all i. Considering the non-negativity and sum condition for the weights, the following problem results as shown in Equation 15:

$$min \max_i \left\{ \left|\frac{w_Y}{w_i} \underset{s.t.}{-} x_{Yi}\right|, \left|\frac{w_i}{w_Z} - x_{iZ}\right| \sum_i w_i = 1 \right. \tag{15}$$

$w_i \geq 0$, for all$i$.

Equation 15 can be transferred to the following problem, as shown in Equation 16:

$$min\, \xi$$

s.t.

$$\begin{aligned} &\left|\frac{w_Y}{w_i} - x_{Yi}\right| \leq \xi \text{for all } i \\ &\left|\frac{w_i}{w_z} - x_{iW}\right| \leq \xi \text{for all } i \\ &\textstyle\sum_i w_i = 1 \end{aligned} \tag{16}$$

$w_i \geq 0$, for all i.

By solving Equation 16, the optimal weights $(w_1^*, w_2^*, \ldots, w_m^*)$ for each strategy A_i and the consistency ratio (ξ^*) are obtained.

Step 9: Integrate the BSC framework with BWM.

Suppose that x_{ijk} represents the initiative relation score for the initiative B_{ij} (i=1,2,. . . ,m;j=1,2,. . . ,n) of strategy A_i (i=1,2,. . . ,m). It also considers BSC dimensions (D_k) (k=1,2,. . . ,K), i.e., performance, quality management, risk analysis, environmental management, smartness, and legitimacy. Fig. 3 illustrates the BWM-enhanced smart and sustainable supplier scorecard, which comprises the output of calculations that integrate the BSC framework with BWM.

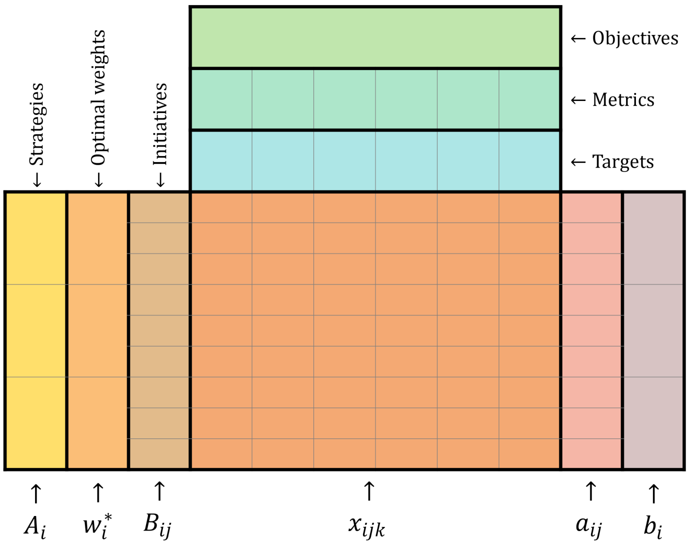

Figure 3. BWM-enhanced smart and sustainable supplier scorecard

Step 9.1: The decision-makers determine the objectives, translating strategic goals to performance targets.

Step 9.2: The metrics and targets are set as the dimensions of the supplier scorecard hexagon. The 4S-score represents the metric values of the smart and sustainable supplier scorecard. The targets are set as the theoretical maximum value of each dimension equals 20.

Step 9.3: The decision-makers determine the initiatives, confirming that each initiative yields a specific strategy.

Step 9.4: Obtain the relation decision matrix.

The initiative relation scores (x_{ijk}) are obtained from decision-makers' evaluations. Decision-makers are asked to evaluate the relation level between the initiatives and BSC dimension with a five-point Likert-type scale (1 = not at all related, 2 = slightly related, 3 = moderately related, 4 = highly related, and 5 = extremely related).

Step 9.5: Compute the weighted initiative prominence scores.

The weighted initiative prominence score (a_{ij}^*) for each initiative is calculated using Equation 15. Optimal weights (w_i^*) are determined via the BWM method in Step 8.5.

$$a_{ij}^* = \Sigma_{k=1}^{K} w_i^* x_{ijk} \tag{17}$$

Step 9.6: Compute the standardized initiative prominence scores.

Equation 16 is used to calculate the standardized initiative prominence score (a_{ij}) for each initiative. The standardization process includes dividing the weighted initiative prominence score (a_{ij}^*) by 5K, where 5 represents the maximum value of the Likert-type scale.

$$a_{ij} = \frac{a_{ij}^*}{5K} \tag{18}$$

The standardized initiative prominence score (a_{ij}) represents the relative effectiveness of an initiative to achieve scorecard dimension targets.

Step 9.7: Compute the overall strategy prominence scores.

Equation 17 is used to calculate the overall strategy prominence score).

$$b_i = \Sigma_{j=1}^{n} \frac{a_{ij}}{n} \tag{19}$$

The overall strategy prominence score (b_i) represents the relative effectiveness of a strategy to achieve scorecard dimension targets. Next, we test the applicability of the proposed approach via a case study.

4. Case study: Calculating the 4S-score of an HVAC company

We implemented the proposed smart and sustainable supplier scorecard method within a company that operates in the air heating, ventilation, and air conditioning (HVAC) industry. HVAC products are used in buildings to regulate temperature and humidity and maintain air quality (Design Buildings, 2023). The global HVAC market reached a value of over 158 billion United States dollars (USD) in 2022 and is expected to reach a value of about 227 billion USD by 2028, with a compound annual growth rate of 6.2% over 2023–2028 (Expert Market Research, 2023). Turkey has recently become a significant player in the global HVAC industry. Turkey is the fifteenth largest exporter of HVAC products globally, with exports totaling over 859 million USD in 2022, a significant increase from 676 million USD in 2021 (Trade Map, 2023). The Turkish HVAC industry is highly competitive, with many products and services available. The government supports the industry with incentives and subsidies for innovation and growth. The Turkish HVAC industry is well-positioned to benefit from the increasing demand for energy efficiency and green technologies. ISKID (2023), The Turkish Air Conditioning Industry Association, reported a 20% increase in split air conditioning production, a 2% increase in domestic sales, and a 20% increase in exports compared to 2022. The domestic market also increased by 15%, and VRF/VRV/VRS product exports increased by 150%. Rooftop air conditioner units increased by 30% in production and 50% in the market compared to the 2022. Heat pumps also increased by 140% in imports from 2017–2022, along with a 40% increase in exports.

ABC (founded in 1967) is one of Turkey's largest cooling/ventilation system manufacturers; due to the company's confidentiality policy, the company is renamed and referred to as ABC. The company produces various products, including cooling towers, industrial air conditioners, heating and cooling appliances, fan coil units, heat recovery exchangers, and air handling units (see Fig. 4). The company exports its products to over 30 countries, including India, the United States, Kazakhstan, Germany, France, Italy, Spain, and the United Kingdom. ABC company works with 140 domestic and 20 international suppliers. The company wants to assess its suppliers in terms of their smart and sustainable practices to comprehend their effects on production and supply chain quality. Fig. 5 illustrates ABC's supply chain network. ABC implements this study's BSC-based approach to a smart and sustainable supplier scorecard with approval from the company's top management. The quantitative data are collected using semi-structured interviews and observations. The 4S-score is calculated through Equation 11 by summing the averages of six-dimension scores. This section presents the result of the case study.

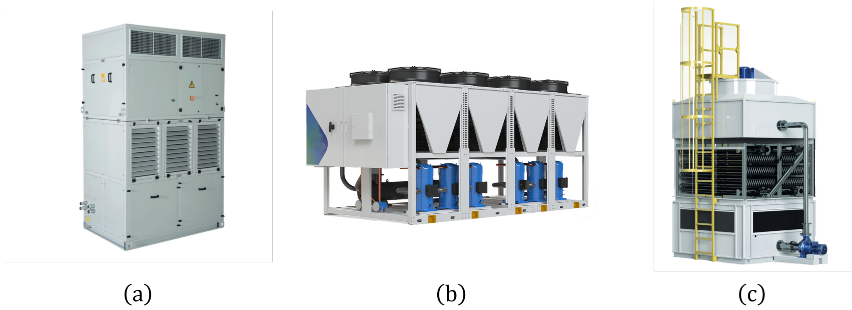

Figure 4. Sample of ABC's products (a: water-cooled industrial type air conditioner; b: air-cooled chiller; c: closed-circuit water cooling tower)

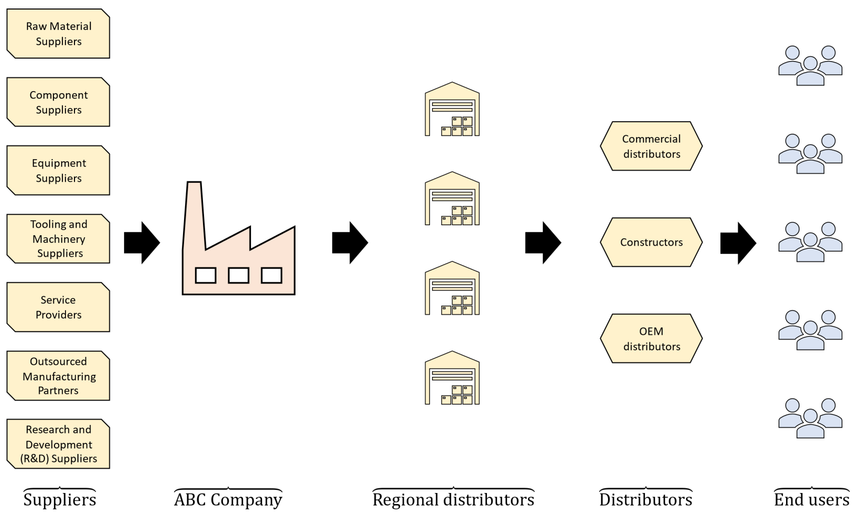

Figure 5. ABC's supply chain network

ABC's strategies and initiatives are determined by three representatives (general manager, operation manager, and finance manager). The case study's strategy and initiative determination process involves the representatives working together to identify the best strategies and initiatives to improve the company's smart and sustainable supplier assessment and monitoring process. The representatives review the SCM literature and research to identify the most effective strategies. They then discuss and evaluate the strategies that suit the company's smart and sustainable supplier assessment goals, considering its resources and capabilities to ensure the strategy is feasible and achievable. Once strategies and initiatives have been identified, the representatives develop a set of implementation initiatives, including setting goals, timelines, and budgets for each strategy. The representatives also consider the risks associated with each strategy and initiative and develop appropriate mitigation stratagems. Table 2 presents the strategies and initiatives adopted by the company representatives in this case study.

Table 2. Strategies and initiatives adopted in this study

Denotation	Strategy/Initiative	Source
$\boldsymbol{A_1}$	**Investment and collaboration strategy**	Klassen and Vachon (2009)
B_{11}	Information sharing with the suppliers	Liu *et al.* (2022)
B_{12}	Capacity sharing with suppliers	Hosseinnezhad *et al.* (2023)
B_{13}	Partner up with the suppliers by investing in shares	Fu *et al.* (2020)
$\boldsymbol{A_2}$	**Training and auditing strategy**	Sperber (1998)
B_{21}	Organize training programs for suppliers	Yu *et al.* (2022)
B_{22}	Set audit visits with firm inspectors to the suppliers' facilities	Asif *et al.* (2022)
B_{23}	Designate a third-party auditor to inspect the suppliers' facilities	Gonzalez–Padron (2016)
$\boldsymbol{A_3}$	**Competitive strategy**	Sillanpää *et al.* (2015)
B_{31}	Explore alternative or substitute parts, products, and technologies	Lu *et al.* (2011)
B_{32}	Sourcing backup suppliers	Yin and Wang (2018)
B_{33}	In-house production of supplied parts/products	Lin *et al.* (2021)
$\boldsymbol{A_4}$	**Risk-hedging strategy**	Gao (2015)
B_{41}	Buffer stock against disruption risk	Silva *et al.* (2022)
B_{42}	Create a supply chain coordination network to tackle the bullwhip effect	Kilubi (2016)
B_{43}	Create a geographically dispersed supply chain network	de Moura *et al.* (2021)
$\boldsymbol{A_5}$	**Sustainability strategy**	Matthess *et al.* (2022)
B_{51}	Require climate change mitigation strategic plan from the suppliers	Cadez and Czerny (2016)
B_{52}	Develop corporate social responsibility (CSR) projects with the suppliers	Bae *et al.* (2021)
B_{53}	Set a joint sustainability committee in collaboration with suppliers	Burke *et al.* (2019)

After determining pairwise comparison vectors, we obtain the criteria weights by solving Equation 16 in Step 8.5 using the GAMS program (see Table 3).

Table 3. Best-to-others and others-to-worst pairwise comparison vectors and criteria weights according to the BWM method

Strategy	Best-to-others	Others-to-worst	Weight
Investment and collaboration strategy	1	7	0.459
Training and auditing strategy	2	5	0.254
Competitive strategy	5	2	0.102
Risk-hedging strategy	4	3	0.127
Sustainability strategy	7	1	0.059

The calculations produce a consistency ratio (ξ^*) of 0.049, suggesting the analysis yields reliable results (Rezaei, 2016).

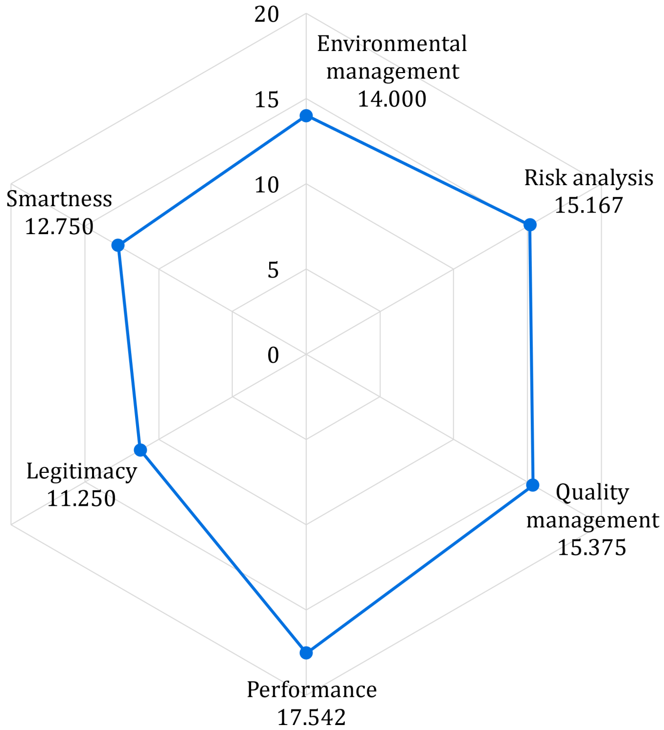

Figure 6. Radar chart of the 4S dimension scores

Fig. 6 demonstrates the dimension scores obtained from the 7 steps of the smart and sustainable supplier scorecard; each dimension's score was evaluated out of 20, and the 4S-score was evaluated out of 120. The highest scoring dimension is performance ($\overline{P}$=17.542), followed by quality management ($\overline{Q}$=15.375), risk analysis ($\overline{R}$=15.167), and environmental management ($\overline{E}$=14.000). The two dimensions with the lowest scores are smartness ($\overline{S}$ =12.750) and legitimacy ($\overline{L}$ =11.250). The sum of the scores for each dimension is calculated as 4S=86.084. The smart and sustainable supplier scorecard in Table 4 uses criteria weights obtained through BWM and dimension scores.

Table 4 presents the case study that applies the smart and sustainable supplier scorecard methodology to an HVAC company. The relation value matrix shows the relationship between the initiatives and metrics on a Likert-scale basis and is filled by the company representatives. The integration of BWM provides the optimal weight scores, representing each strategy's desirability. The optimal weight scores are multiplied with each relation value, and the standardized initiative prominence scores are computed for each initiative. We determine the overall strategy prominence score using the arithmetic mean of the three standardized initiative prominence scores. Investment and collaboration and training and auditing strategies are the most effective, with 0.296 and 0.186 overall prominence scores, respectively.

Table 4. Case study results for the smart and sustainable supplier scorecard

		Objectives	To improve supply chain efficiency and productivity							
		Metrics	**Performance** $\bar{P} = 17.542$	**Quality management** $\bar{Q} = 15.375$	**Risk analysis** $\bar{R} = 15.167$	**Environmental management** $\bar{E} = 14.000$	**Smartness** $\bar{S} = 12.750$	**Legitimacy** $\bar{L} = 11.250$		
		Targets	P→20	Q→20	R→20	E→20	S→20	L→20		
Strategy (A_i)	**Optimal weight** (w_i^*)	**Initiative** (B_{ij})	**Relation value** (x_{ijk})						**Standardized initiative prominence score** (a_{ij})	**Overall strategy prominence score** (b_i)
Investment and collaboration strategy	0.459	Information sharing with the suppliers	3	5	3	1	3	2	0.260	0.296
		Capacity sharing with suppliers	3	5	4	1	2	2	0.260	
		Partner up with the suppliers by investing in shares	4	5	5	2	3	5	0.367	
Training and auditing strategy	0.254	Organize training programs for suppliers	4	4	3	3	3	3	0.169	0.186
		Set audit visits with firm inspectors to the suppliers' facilities	4	4	4	3	3	4	0.186	
		Designate a third-party auditor to inspect the suppliers' facilities	4	4	4	4	3	5	0.203	
Competitive strategy	0.102	Explore alternative or substitute parts, products, and technologies	4	3	2	2	3	2	0.054	0.062
		Sourcing backup suppliers	4	3	1	2	1	2	0.044	
		In-house production of supplied parts/products	5	4	4	4	4	5	0.088	
Risk-hedging strategy	0.127	Buffer stock against disruption risk	4	3	4	1	2	2	0.068	0.079
		Create a supply chain coordination network to tackle the bullwhip effect	5	4	5	2	5	3	0.102	
		Create a geographically dispersed supply chain network	3	3	4	1	2	3	0.068	
Sustainability strategy	0.059	Require climate change mitigation strategic plan from the suppliers	1	2	2	5	3	4	0.033	0.032
		Develop CSR projects with the suppliers	1	2	2	5	2	2	0.028	
		Set a joint sustainability committee in collaboration with suppliers	1	2	3	5	3	5	0.038	

5. Discussion and implications

Our paper primarily contributes to the engineering management literature in the operations and SCM by introducing a six-dimension supplier assessment and monitoring tool. The proposed smart and sustainable supplier scorecard is designed based on the BWM-enhanced BSC approach, which helps company managers and decision-makers evaluate their suppliers' performance by incorporating digitization and sustainability. Several implications for managers can be extracted from the proposed assessment tool and case study. Managers should recognize that a supplier's performance is essential since it relates directly to the company's service level.

Table 4 evaluates and quantifies each strategy by weighting them using BWM. Each strategy comprises three initiatives, and the relation value matrix shows the relationship between each dimension and initiative. These scores are obtained by interviewing company representatives. Each initiative score is multiplied by the optimal weight scores for each strategy, and the sum of these scores is standardized, forming the standardized initiative prominence score for each initiative. The overall strategy prominence scores are determined by averaging standardized initiative prominence scores, implying the most prominent strategies that help the company overcome supplier-related challenges and threats. In our case, the investment and collaboration strategy is the most prominent course of action, followed by the training and auditing strategy; risk-hedging, competitive, and sustainability strategies come after the first two prominent strategies.

Among the initiatives, partnering with the suppliers by investing in shares obtains a higher prominence score; information and capacity sharing with suppliers receives the second higher prominence score. These are followed by designating a third-party auditor to inspect the suppliers' facilities, setting audit visits for the suppliers' facilities with firm inspectors, and organizing training programs for suppliers.

Furthermore, using strategy importance scores, the proposed 4S scorecard determines which strategies and initiatives should be prioritized. Managers can also monitor target values in six dimensions using the proposed BSC.

6. Conclusion

This paper introduces a novel method for a smart and sustainable supplier scorecard. Our approach is based on the BWM-enhanced BSC approach to develop, monitor, and inspect suppliers who impact a company's production and supply chain quality. A supplier scorecard is crucial for assessing a supplier's performance concerning particular metrics, and both small and large businesses use it to manage and monitor the performance of their suppliers. Companies can better understand their suppliers' sustainability and digitization practices by implementing a BSC-based approach.

Our paper's novel smart and sustainable supplier scorecard provides implications for managers and decision-makers in evaluating their suppliers regarding six dimensions: performance, quality management, risk analysis, environmental management, smartness, and legitimacy. Each dimension and its indicators determine the 4S-score; therefore, the insights obtained through implementing the smart and sustainable supplier scorecard guide companies to make better decisions regarding supplier selection processes, leading to a competitive market position.

Despite this paper's contributions to the extant research, our proposed method has some limitations that must be addressed for future research. We implemented our methodology in a company that operates in the HVAC industry and works with 160 suppliers. Upcoming research can broaden the scope to include other businesses from various industries.

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REFERENCES

Al Naimi, M., Faisal, Mohd. N., & Sobh, R. (2020). Prioritization of supply chain reconfiguration variables using balanced score card and analytic network process. *International Journal of Operations and Quantitative Management, 26*(2), 95–119. https://doi.org/10.46970/2020.26.2.2

Aliakbari Nouri, F., Shafiei Nikabadi, M., & Olfat, L. (2019). Developing the framework of sustainable service supply chain balanced scorecard (SSSC BSC). *International Journal of Productivity and Performance Management, 68*(1), 148–170. https://doi.org/10.1108/IJPPM-04-2018-0149

AlMaian, R. Y., Needy, K. L., Alves, T. da C. L., & Walsh, K. D. (2016). Analyzing effective supplier-quality-management practices using simple multiattribute rating technique and value-focused thinking. *Journal of Management in Engineering, 32*(1). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000364

Anjomshoae, A., Hassan, A., & Wong, K. Y. (2019). An integrated AHP-based scheme for performance measurement in humanitarian supply chains. *International Journal of Productivity and Performance Management, 68*(5), 938–957. https://doi.org/10.1108/IJPPM-04-2018-0132

Aqlan, F., Lam, S. S., & Ramakrishnan, S. (2016). Assessment of supply chain readiness for transformation. *International Journal of Business Performance and Supply Chain Modelling, 8*(3), 181–200. https://doi.org/10.1504/IJBPSCM.2016.078562

Asif, M., Searcy, C., & Castka, P. (2022). Exploring the role of industry 4.0 in enhancing supplier audit authenticity, efficacy, and cost effectiveness. *Journal of Cleaner Production, 331*, 129939. https://doi.org/10.1016/j.jclepro.2021.129939

Bae, J., Lund-Thomsen, P., & Lindgreen, A. (2021). Global value chains and supplier perceptions of corporate social responsibility: A case study of garment manufacturers in Myanmar. *Global Networks, 21*(4), 653–680. https://doi.org/10.1111/glob.12298

Barber, E. (2008). How to measure the "value" in value chains. *International Journal of Physical Distribution & Logistics Management, 38*(9), 685–698. https://doi.org/10.1108/09600030810925971

Basu, R., Little, C., & Millard, C. (2009). Case study: A fresh approach of the balanced scorecard in the Heathrow Terminal 5 project. *Measuring Business Excellence, 13*(4), 22–33. https://doi.org/10.1108/13683040911006765

Bigliardi, B., & Bottani, E. (2010). Performance measurement in the food supply chain: A balanced scorecard approach. *Facilities, 28*(5/6), 249–260. https://doi.org/10.1108/02632771011031493

Brege, S., Brehmer, P.O. and Rehme, J. (2008). Managing supplier relations with balanced scorecard. *International Journal of Knowledge Management Studies, 2*(1), 147-161. https://doi.org/10.1504/ijkms.2008.016447

Brewer, P. C. (2002). Aligning supply chain incentives using the balanced scorecard. *Supply Chain Forum: An International Journal, 3*(1), 12-19. https://doi.org/10.1080/16258312.2002.11517094

Burke, J. J., Hoitash, R., & Hoitash, U. (2019). The heterogeneity of board-level sustainability committees and corporate social performance. *Journal of Business Ethics, 154*(4), 1161–1186. https://doi.org/10.1007/s10551-017-3453-2

Cadez, S., & Czerny, A. (2016). Climate change mitigation strategies in carbon-intensive firms. *Journal of Cleaner Production, 112*, 4132–4143. https://doi.org/10.1016/j.jclepro.2015.07.099

Chandra, D., & Kumar, D. (2019). Two-way assessment of key performance indicators to vaccine supply chain system in India. *International Journal of Productivity and Performance Management, 68*(1), 194–230. https://doi.org/10.1108/IJPPM-02-2018-0078

Chang, H. H. (2009). An empirical study of evaluating supply chain management integration using the balanced scorecard in Taiwan. *The Service Industries Journal, 29*(2), 185–202. https://doi.org/10.1080/02642060802294961

Chang, H. H., Hung, C.-J., Wong, K. H., & Lee, C.-H. (2013). Using the balanced scorecard on supply chain integration performance—a case study of service businesses. *Service Business, 7*(4), 539–561. https://doi.org/10.1007/s11628-012-0175-5

Chang, T.-W., Pai, C.-J., Lo, H.-W., & Hu, S.-K. (2021). A hybrid decision-making model for sustainable supplier evaluation in electronics manufacturing. Computers & Industrial Engineering, 156, 107283. https://doi.org/10.1016/j.cie.2021.107283

Chen, P. S., & Wu, M. T. (2013). A modified failure mode and effects analysis method for supplier selection problems in the supply chain risk environment: A case study. *Computers & Industrial Engineering, 66*(4), 634-642. https://doi.org/10.1016/j.cie.2013.09.018

Chen, T., & Hu, L. (2022). *Enterprise supplier evaluation model based on entropy weight method in calculus learning* (pp. 440–447). https://doi.org/10.1007/978-3-031-04809-8_39

Chia, A., Goh, M., & Hum, S. (2009). Performance measurement in supply chain entities: Balanced scorecard perspective. *Benchmarking: An International Journal, 16*(5), 605–620. https://doi.org/10.1108/14635770910987832

Chorfi, Z., Benabbou, L., & Berrado, A. (2018). An integrated performance measurement framework for enhancing public health care supply chains. *Supply Chain Forum: An International Journal, 19*(3), 191–203. https://doi.org/10.1080/16258312.2018.1465796

Cinnirella, V., Carpitella, S., Coco, A., Frangiamore, D. D. M., & de Geronimo, R. P. (2022). Sustainable suppliers evaluation in the waste management sector: The case of a leading Sicilian enterprise. *IFAC-PapersOnLine, 55*(11), 66–71. https://doi.org/10.1016/j.ifacol.2022.08.050

Coşkun, S. S., Kumru, M., & Kan, N. M. (2022). An integrated framework for sustainable supplier development through supplier evaluation based on sustainability indicators. *Journal of Cleaner Production, 335*, 130287. https://doi.org/10.1016/j.jclepro.2021.130287

Cunha Callado, A. A., & Jack, L. (2015). Balanced scorecard metrics and specific supply chain roles. *International Journal of Productivity and Performance Management, 64*(2), 288–300. https://doi.org/10.1108/IJPPM-05-2014-0071

Cunha Callado, A. A., & Jack, L. (2017). Relations between usage patterns of performance indicators and the role of individual firms in fresh fruit agri-food supply chains. *Journal of Applied Accounting Research, 18*(3), 375–398. https://doi.org/10.1108/JAAR-04-2016-0037

De Giovanni, P., & Cariola, A. (2021). Process innovation through industry 4.0 technologies, lean practices and green supply chains. Research in Transportation Economics, 90, 100869. https://doi.org/10.1016/j.retrec.2020.100869

de Moura, R. L., Gonzalez, A., Franqueira, V. N. L., Neto, A. L. M., & Pessin, G. (2021). Geographically dispersed supply chains: A strategy to manage cybersecurity in industrial networks integration. In A*dvances in Cybersecurity Management* (pp. 97–116). Springer International Publishing. https://doi.org/10.1007/978-3-030-71381-2_6

Designing Buildings. (2023, March 7). *Heating ventilation and air conditioning HVAC*. Retrieved May 12, 2023, from https://www.designingbuildings.co.uk/wiki/Heating_ventilation_and_air_conditioning_HVAC

Dhiaf, M. M. , Benabdelhafid, A., & Jaoua, F. (2012). Supply chain flexibility and balanced scorecard: Conceptual model and empirical study in Tunisian companies launched upgrading program. *Polish Journal of Management Studies, 5*(1), 34–58.

Doolen, T., Traxler, M. M., & McBride, K. (2006). Using scorecards for supplier performance improvement: Case application in a lean manufacturing organization. *Engineering Management Journal, 18*(2), 26–34. https://doi.org/10.1080/10429247.2006.11431691

Esmaeilian, B., Sarkis, J., Lewis, K., & Behdad, S. (2020). Blockchain for the future of sustainable supply chain management in Industry 4.0. *Resources, Conservation and Recycling, 163*, 105064. https://doi.org/10.1016/j.resconrec.2020.105064

Expert Market Research. (2023). *Global HVAC market report and forecast 2023-2028*. Retrieved May 16, 2023, from https://www.expertmarketresearch.com/reports/hvac-market

Fernandes, A. C., Vilhena, E., Oliveira, R., Sampaio, P., & Carvalho, M. S. (2022). Supply chain quality management impact on organization performance: Results from an international survey. *International Journal of Quality & Reliability Management, 39*(2), 630–646. https://doi.org/10.1108/IJQRM-05-2020-0159

Ferreira, L. M. D. F., Silva, C., & Azevedo, S. G. (2016). An environmental balanced scorecard for supply chain performance measurement (Env_BSC_4_SCPM). *Benchmarking: An International Journal, 23*(6), 1398–1422. https://doi.org/10.1108/BIJ-08-2013-0087

Foerstl, K., Reuter, C., Hartmann, E., & Blome, C. (2010). Managing supplier sustainability risks in a dynamically changing environment—sustainable supplier management in the chemical industry. *Journal of Purchasing and Supply Management, 16*(2), 118–130. https://doi.org/10.1016/j.pursup.2010.03.011

Franceschini, F., & Turina, E. (2012). Proposal for a performance dashboard for the monitoring of water and sewage service companies (WaSCs). *Water Resources Management, 26*(1), 63–80. https://doi.org/10.1007/s11269-011-9901-3

Frederico, G. F., Garza-Reyes, J. A., Kumar, A., & Kumar, V. (2020). Performance measurement for supply chains in the Industry 4.0 era: A balanced scorecard approach. *International Journal of Productivity and Performance Management, 70*(4), 789–807. https://doi.org/10.1108/IJPPM-08-2019-0400

Fu, H., Li, K., & Fu, W. (2020). Investing in suppliers with capacity constraints in a decentralized assembly system. *Computers & Industrial Engineering, 142*, 106332. https://doi.org/10.1016/j.cie.2020.106332

Galankashi, M. R., Helmi, S. A., & Hashemzahi, P. (2016). Supplier selection in automobile industry: A mixed balanced scorecard–fuzzy AHP approach. *Alexandria Engineering Journal, 55*(1), 93–100. https://doi.org/10.1016/j.aej.2016.01.005

Gao, L. (2015). Collaborative forecasting, inventory hedging and contract coordination in dynamic supply risk management. *European Journal of Operational Research, 245*(1), 133–145. https://doi.org/10.1016/j.ejor.2015.02.048

Golrizgashti, S. (2016). Effect of knowledge management on supply chain value, empirical evidence from Iran. *International Journal of Business Performance and Supply Chain Modelling, 8*(2), 97–129. https://doi.org/10.1504/IJBPSCM.2016.077165

Gonzalez-Padron, T. L. (2016). Ethics in the supply chain: Follow-up processes to audit results. *Journal of Marketing Channels, 23*(1–2), 22–33. https://doi.org/10.1080/1046669X.2016.1147341

Govindan, K., Kaul, A., Darbari, J. D., & Jha, P. C. (2023). Analysis of supplier evaluation and selection strategies for sustainable collaboration: A combined approach of best–worst method and TOmada de Decisao Interativa Multicriterio. *Business Strategy and the Environment*. https://doi.org/10.1002/bse.3374

Govindan, K., Rajendran, S., Sarkis, J., & Murugesan, P. (2015). Multi criteria decision making approaches for green supplier evaluation and selection: A literature review. *Journal of Cleaner Production, 98*, 66–83. https://doi.org/10.1016/j.jclepro.2013.06.046

Ho, W., Xu, X., & Dey, P. K. (2010). Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Journal of Operational Research, 202*(1), 16–24. https://doi.org/10.1016/j.ejor.2009.05.009

Hosseinnezhad, D., Nugroho, Y. K., & Heavey, C. (2023). Horizontal collaboration between suppliers to mitigate supply chain disruption: A secure resource sharing strategy. *Computers & Industrial Engineering, 177*, 109088. https://doi.org/10.1016/j.cie.2023.109088

Hudnurkar, M., Rathod, U., Jakhar, S. K., & Vaidya, O. S. (2018). Development of a balanced scorecard-based supplier collaborative performance index. *International Journal of Productivity and Performance Management, 67*(2), 401–425. https://doi.org/10.1108/IJPPM-05-2016-0084

ISKID. (2023, April 28). *2022 Turkey HVAC'R Industry report*. ISKID. Retrieved May 17, 2023, from https://iskid.org.tr/en/2022-turkey-hvacr-industry-report/

Jalali Naini, S. G., Aliahmadi, A. R., & Jafari-Eskandari, M. (2011). Designing a mixed performance measurement system for environmental supply chain management using evolutionary game theory and balanced scorecard: A case study of an auto industry supply chain. *Resources, Conservation and Recycling, 55*(6), 593–603. https://doi.org/10.1016/j.resconrec.2010.10.008

Jochem, R., Menrath, M., & Landgraf, K. (2010). Implementing a quality-based performance measurement system. *The TQM Journal, 22*(4), 410–422. https://doi.org/10.1108/17542731011053334

Khaleeli, M., Faisal, R., & Anwar, S. (2021). The effect of green marketing, green supply chain and green human resources on business performance: Balanced scorecard approach. *Uncertain Supply Chain Management*, 133–138. https://doi.org/10.5267/j.uscm.2020.11.001

Khan, S. A. R., Dong, Q. L., & Yu, Z. (2016). Research on the measuring performance of green supply chain management: In the perspective of China. *International Journal of Engineering Research in Africa, 27*, 167–178. https://doi.org/10.4028/www.scientific.net/JERA.27.167

Kilubi, I. (2016). The strategies of supply chain risk management – a synthesis and classification. *International Journal of Logistics Research and Applications, 19*(6), 604–629. https://doi.org/10.1080/13675567.2016.1150440

Kim, J., & Rhee, J. (2012). An empirical study on the impact of critical success factors on the balanced scorecard performance in Korean green supply chain management enterprises. *International Journal of Production Research, 50*(9), 2465–2483. https://doi.org/10.1080/00207543.2011.581009

Klassen, R. D., & Vachon, S. (2009). Collaboration and evaluation in the supply chain: The impact on plant-level environmental investment. *Production and Operations Management, 12*(3), 336–352. https://doi.org/10.1111/j.1937-5956.2003.tb00207.x

Knotts, T. L., Jones, S. C., & Udell, G. G. (2006). Using a "balanced approach" to measure merchandising supplier performance. *Measuring Business Excellence, 10*(1), 4–13. https://doi.org/10.1108/13683040610652177

Kumar, S., C. Clemens, A., & W. Keller, E. (2014). Supplier management in a manufacturing environment. *International Journal of Productivity and Performance Management, 63*(1), 127–138. https://doi.org/10.1108/IJPPM-12-2012-0137

Liang, Y.-H. (2015). Performance measurement of interorganizational information systems in the supply chain. *International Journal of Production Research, 53*(18), 5484–5499. https://doi.org/10.1080/00207543.2015.1026614

Lin, F., Qin, X., Pu, X., Zhu, W., & Zhuo, X. (2021). Effects of in-house production on channel structures in a co-opetitive supply chain under supply uncertainty. *Omega, 103*, 102426. https://doi.org/10.1016/j.omega.2021.102426

Lin, Y., Tseng, M.-L., Chiu, A. S. F., & Wang, R. (2014). Implementation and performance evaluation of a firm's green supply chain management under uncertainty. *Industrial Engineering and Management Systems, 13*(1), 15–28. https://doi.org/10.7232/iems.2014.13.1.015

Liu, W., Long, S., Wei, S., Xie, D., Wang, J., & Liu, X. (2022). Smart logistics ecological cooperation with data sharing and platform empowerment: An examination with evolutionary game model. *International Journal of Production Research, 60*(13), 4295–4315. https://doi.org/10.1080/00207543.2021.1925173

Lo, H.-W., Liaw, C.-F., Gul, M., & Lin, K.-Y. (2021). Sustainable supplier evaluation and transportation planning in multi-level supply chain networks using multi-attribute- and multi-objective decision making. *Computers & Industrial Engineering, 162*, 107756. https://doi.org/10.1016/j.cie.2021.107756

Lu, M., Huang, S., & Shen, Z.-J. M. (2011). Product substitution and dual sourcing under random supply failures. *Transportation Research Part B: Methodological, 45*(8), 1251–1265. https://doi.org/10.1016/j.trb.2010.09.005

Matthess, M., Kunkel, S., Xue, B., & Beier, G. (2022). Supplier sustainability assessment in the age of Industry 4.0 – insights from the electronics industry. *Cleaner Logistics and Supply Chain, 4*, 100038. https://doi.org/10.1016/j.clscn.2022.100038

More, D., & Babu, A. S. (2012). Strategic approach to manage supply chain flexibility: A proposal. *International Journal of Logistics Systems and Management, 11*(4), 492–521. https://doi.org/10.1504/IJLSM.2012.046703

Nazari-Ghanbarloo, V. (2022). A dynamic performance measurement system for supply chain management. *International Journal of Productivity* *and Performance Management, 71*(2), 576–597. https://doi.org/10.1108/IJPPM-01-2020-0023

Núñez-Merino, M., Maqueira-Marín, J. M., Moyano-Fuentes, J., & Martínez-Jurado, P. J. (2020). Information and digital technologies of Industry 4.0 and Lean supply chain management: A systematic literature review. *International Journal of Production Research, 58*(16), 5034–5061. https://doi.org/10.1080/00207543.2020.1743896

Pandey, I. M. (2005). Balanced scorecard: Myth and reality. Vikalpa: *The Journal for Decision Makers, 30*(1), 51–66. https://doi.org/10.1177/0256090920050105

Rahimnia, F., Keyvanipoor, S., & Moghadasian, M. (2014). Analysis of BSC perspectives as related to the alignment of environmental uncertainty and supply chain strategy. *Benchmarking: An International Journal, 21*(6), 903–916. https://doi.org/10.1108/BIJ-11-2012-0075

Reefke, H., & Trocchi, M. (2013). Balanced scorecard for sustainable supply chains: Design and development guidelines. *International Journal of Productivity and Performance Management, 62*(8), 805–826. https://doi.org/10.1108/IJPPM-02-2013-0029

Reuter, C., Foerstl, K., Hartmann, E., & Blome, C. (2010). Sustainable global supplier management: the role of dynamic capabilities in achieving competitive advantage. *Journal of Supply Chain Management, 46*(2), 45–63. https://doi.org/10.1111/j.1745-493X.2010.03189.x

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega, 53*, 49–57. https://doi.org/10.1016/j.omega.2014.11.009

Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega, 64, 126-130. https://doi.org/10.1016/j.omega.2015.12.001

Saidy, C., Pinna, C., Wilson, Z., Panavas, L., Harik, R., & Bayoumi, A. M. (2018). Literature review of current practices of supplier's assessment and valuation of decisions regarding underperforming suppliers. *International Journal of Product Lifecycle Management, 11*(3), 245–267. https://doi.org/10.1504/IJPLM.2018.094719

Saleheen, F., & Habib, Md. M. (2023). Embedding attributes towards the supply chain performance measurement. *Cleaner Logistics and Supply Chain, 6*, 100090. https://doi.org/10.1016/j.clscn.2022.100090

Saroha, M., Garg, D., & Luthra, S. (2022). Analyzing the circular supply chain management performance measurement framework: The modified balanced scorecard technique. *International Journal of System Assurance Engineering and Management, 13*(S2), 951–960. https://doi.org/10.1007/s13198-021-01482-4

Schiffling, S., & Piecyk, M. (2014). Performance measurement in humanitarian logistics: A customer-oriented approach. *Journal of Humanitarian Logistics and Supply Chain Management, 4*(2), 198–221. https://doi.org/10.1108/JHLSCM-08-2013-0027

Schloetzer, J. D. (2012). Process integration and information sharing in supply chains. *The Accounting Review, 87*(3), 1005–1032. https://doi.org/10.2308/accr-10216

Sharma, M. K., & Bhagwat, R. (2007). An integrated BSC-AHP approach for supply chain management evaluation. *Measuring Business Excellence, 11*(3), 57–68. https://doi.org/10.1108/13683040710820755

Shinkevich, A. I., Shaimieva, E. S., Nurgaliev, R. K., & Gumerova, G. I. (2021). *The modeling of operating activities of petrochemical and fuel and energy enterprises in industry 4.0. 27*(4), 1–11.

Sillanpää, I., Shahzad, K., & Sillanpää, E. (2015). Supplier development and buyer-supplier relationship strategies - a literature review. *International Journal of Procurement Management, 8*(1/2), 227–250. https://doi.org/10.1504/IJPM.2015.066283

Silva, P. M., Gonçalves, J. N. C., Martins, T. M., Marques, L. C., Oliveira, M., Reis, M. I., Araújo, L., Correia, D., Telhada, J., Costa, L., & Fernandes, J. M. (2022). A hybrid bi-objective optimization approach for joint determination of safety stock and safety time buffers in multi-item single-stage industrial supply chains. *Computers & Industrial Engineering, 168*, 108095. https://doi.org/10.1016/j.cie.2022.108095

Simić, D., Kovačević, I., Svirčević, V., & Simić, S. (2017). 50 years of fuzzy set theory and models for supplier assessment and selection: A literature review. *Journal of Applied Logic, 24*, 85–96. https://doi.org/10.1016/j.jal.2016.11.016

Sislian, L., & Jaegler, A. (2018). A sustainable maritime balanced scorecard applied to the Egyptian Port of Alexandria. *Supply Chain Forum: An International Journal, 19*(2), 101-110). https://doi.org/10.1080/16258312.2018.1481716

Şişman, T., Kiriş, S. B., & Yilmaz, D. (2022). Sustainable supplier evaluation in an automotive company using fuzzy multi-criteria decision-making methods. *International Journal of Information Technology & Decision Making*, 1–47. https://doi.org/10.1142/S0219622022500833

Sperber, W. H. (1998). Auditing and verification of food safety and HACCP. *Food Control, 9*(2–3), 157–162. https://doi.org/10.1016/S0956-7135(97)00068-6

Sundtoft Hald, K., & Ellegaard, C. (2011). Supplier evaluation processes: the shaping and reshaping of supplier performance. *International Journal of Operations & Production Management, 31*(8), 888-910. https://doi.org/10.1108/01443571111153085

Susanty, A., Bakhtiar, A., Puspitasari, N. B., & Mustika, D. (2018). Performance analysis and strategic planning of dairy supply chain in Indonesia. *International Journal of Productivity and Performance Management, 67*(9), 1435–1462. https://doi.org/10.1108/IJPPM-10-2017-0250

Taifa, I. W. R., Hayes, S. G., & Stalker, I. D. (2020). Development of the critical success decision criteria for an equitable order sharing in an extended enterprise. *The TQM Journal, 32*(6), 1715–1742. https://doi.org/10.1108/TQM-05-2019-0138

Thanki, S., & Thakkar, J. (2018). A quantitative framework for lean and green assessment of supply chain performance. *International Journal of Productivity and Performance Management, 67*(2), 366–400. https://doi.org/10.1108/IJPPM-09-2016-0215

Tolooie, M., Alvandi, M., & Arani, M. S. (2022). Sustainable supplier evaluation and selection in developing countries: An integrated fuzzy framework. *International Journal of Integrated Supply Management, 15*(2), 151–183. https://doi.org/10.1504/IJISM.2022.121952

Trade Map - List of exporters for the selected product: *8415 air conditioning machines comprising a motor-driven fan and elements for changing the temperature and humidity, incl. Those machines in which the humidity cannot be separately regulated; parts thereof.* (2023). ITC Trade Map. Retrieved May 17, 2023, from https://www.trademap.org/Country_SelProduct_TS.aspx?nvpm=1%7c%7c%7c%7c%7c8415%7c%7c%7c4%7c1%7c1%7c2%7c2%7c1%7c2%7c1%7

Varma, S., Wadhwa, S., & Deshmukh, S. G. (2008). Evaluating petroleum supply chain performance. A*sia Pacific Journal of Marketing and Logistics, 20*(3), 343–356. https://doi.org/10.1108/13555850810890093

Vörösmarty, G., & Dobos, I. (2020). A literature review of sustainable supplier evaluation with Data Envelopment Analysis. *Journal of Cleaner Production, 264*, 121672. https://doi.org/10.1016/j.jclepro.2020.121672

Yin, Z., & Wang, C. (2018). Strategic cooperation with a backup supplier for the mitigation of supply disruptions. *International Journal of Production Research, 56*(12), 4300–4312. https://doi.org/10.1080/00207543.2017.1410246

Yu, V. F., Qiu, M., & Gupta, J. N. D. (2022). Improving supplier capability through training: Evidence from the Chinese Automobile Industry. *Computers & Industrial Engineering, 163*, 107825. https://doi.org/10.1016/j.cie.2021.107825

Zhang, L.-J., Liu, R., Liu, H.-C., & Shi, H. (2020). Green supplier evaluation and selections: A state-of-the-art literature review of models, methods, and applications. *Mathematical Problems in Engineering, 2020*, 1–25. https://doi.org/10.1155/2020/1783421

Zheng, M., Li, Y., Su, Z., Fan, Y. Van, Jiang, P., Varbanov, P. S., & Klemeš, J. J. (2022). Supplier evaluation and management considering greener production in manufacturing industry. *Journal of Cleaner Production, 342*, 130964. https://doi.org/10.1016/j.jclepro.2022.130964

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Appendix 1. Risk matrix

Level of suppliers	Production Technologies	On-time Delivery Performance						
Level of suppliers	Transformation of the entire production process on new production technologies, new supplier	They cause huge deficits in production	**M**	**H**	**H**	**H**		
	New technology is used in production	Problematic on-time deliveries	**L**	**M**	**H**	**H**		
	At the stage of installation of proven new production technology	Several problems have occurred during on-time deliveries so far	**L**	**M**	**M**	**H**		
	Proven production technology is used	On-time deliveries have been carried out without any problems so far	**L**	**L**	**M**	**M**		
			Standard parts and services such as catering and cleaning	Basic parts	More complex parts	System/module safety-related parts	Expected/desired level from the supplier in terms of technical know-how	**Location of supplied part/ module at the production level**
			Simple manufacturing supply parts	Simple supply parts with low complexity to manufacture	Parts with medium complexity to manufacture	Parts with complex production processes	At what stage of the production chain?	
			The effect of deviations on function/visuality is very low	The effect of deviations on function/visuality is low	The effect of deviations on function/visuality is moderate	The effect of deviations on function/visuality is significant	Department requests - Technical requirement: functional risk, materials - Visual requirements: voids, surface roughness, color	

H. Division/Supplier: High-Risk Initiation
M. Division/Supplier: Medium Risk Initiation
L. Division/Supplier: Low-Risk Initiation