

International Journal of Logistics Systems and Management

ISSN online: 1742-7975 - ISSN print: 1742-7967
<https://www.inderscience.com/ijlsm>

Criteria for success in end-of-life tire recycling supply chains

Abdullah Riad, Majed Hadid, Mohammed Matar, Adel Elomri, Laoucine Kerbache

DOI: [10.1504/IJLSM.2026.10081350](https://doi.org/10.1504/IJLSM.2026.10081350)

Article History:

Received:	07 January 2026
Last revised:	29 January 2026
Accepted:	04 April 2026
Published online:	06 October 2026

Criteria for success in end-of-life tire recycling supply chains

Abdullah Riad and Majed Hadid*

Division of Engineering Management and Decision Sciences,
College of Science and Engineering,
Hamad Bin Khalifa University,
Qatar Foundation, Doha, Qatar
Email: abab52072@hbku.edu.qa
Email: mahadid@hbku.edu.qa
*Corresponding author

Mohammed Matar

Bright Future Tyre Recycling Factory,
Doha, Qatar
Email: mohammedmatar94@outlook.com

Adel Elomri and Laoucine Kerbache

Division of Engineering Management and Decision Sciences,
College of Science and Engineering,
Hamad Bin Khalifa University,
Qatar Foundation, Doha, Qatar
Email: aelomri@hbku.edu.qa
Email: lakerbache@hbku.edu.qa

Abstract: Waste tires, or end-of-life (EoL) tires, present environmental and public-health risks worldwide, particularly when stockpiled in unmanaged disposal sites prone to fires and toxic emissions. This study investigates criteria enabling the conversion of EoL tires into higher-value products within recycling supply chains. The analysis is empirically grounded in experience from Qatar, a rapidly developing economy that has transformed large-scale landfill tire accumulations in line with sustainability goals. Using the decision-making trial and evaluation laboratory (DEMATEL) method, the study identifies and prioritises critical success factors, showing that communication and coordination among municipal authorities, recycling firms, and commercial institutions exert the strongest influence on system performance ($R_i + C_i = 8.87$). These criteria demonstrate transferability to regions facing similar tire management challenges and support adoption of extended producer responsibility (EPR) frameworks. The study provides strategic insights to guide decision-making, optimise operations, reduce tire leakage, and strengthen circular economy outcomes.

Keywords: tire recycling; supply chain management; decision-making trial and evaluation laboratory; DEMATEL; waste management.

Reference to this paper should be made as follows: Riad, A., Hadid, M., Matar, M., Elomri, A. and Kerbache, L. (2026) 'Criteria for success in end-of-life tire recycling supply chains', *Int. J. Logistics Systems and Management*, Vol. 55, No. 6, pp.1–23.

Biographical notes: Abdullah Riad is a PMP-certified PhD student at Hamad Bin Khalifa University, where he also earned his Master's degree. His research focuses on robotic surgery and sustainable supply chain management for scrap materials. He is also the Deputy Manager at Bright Future Tyre Recycling Factory, overseeing logistics and production operations.

Majed Hadid is a Postdoctoral Fellow in Engineering Management and Decision Science at Hamad Bin Khalifa University. He holds a PhD in Logistics and Supply Chain Management from HBKU and an MSc in Engineering Management from Qatar University. His research focuses on service operations and supply chain networks using simulation, optimisation, and data analytics.

Mohammed Matar is the General Manager of Bright Future Tyre Recycling Factory. He holds a master's degree from Qatar University, where his research focused on sustainable rubber materials and the impact of sawdust content on the mechanical properties of reclaimed tire rubber. His work contributes to sustainable material development in the rubber industry.

Adel Elomri is an Associate Professor of Logistics and Supply Chain Management at Hamad Bin Khalifa University. He holds a PhD and MSc in Operations Management from CentraleSupélec Paris and a BSc in Industrial Engineering from the National Engineering School of Tunisia. His research focuses on supply chain modelling, healthcare operations, smart logistics, and sustainable supply chains.

Laoucine Kerbache is a Professor of Logistics and Supply Chain Management at Hamad Bin Khalifa University and a founding member of the Engineering Management and Decision Science Division. He holds a PhD, MSc, and BSc in Industrial Engineering and Operations Research from the University of Massachusetts Amherst. His research focuses on operations research, logistics, supply chain management, and optimisation of industrial and service systems.

1 Introduction

In the late 18th century, cars made their debut on the world stage. Soon after, pneumatic tires, crafted entirely from natural rubber, came into use. However, this development posed a significant threat to the environment due to widespread deforestation. To address this issue, synthetic rubber, blended with various additives, emerged as the solution, forming the basis of the tires we rely on today. The proliferation of cars, spurred by mass production and fierce competition among manufacturers, led to a notable decline in car prices.

Modern tires typically consist of approximately 19% natural rubber, 24% synthetic rubber (a plastic polymer), and a combination of metals and other compounds. However, the manufacturing process generates a concerning byproduct: end-of-life (EoL) tires, which pose a significant environmental hazard as one of the leading contributors to plastic pollution worldwide. Manufacturing vehicle tires requires roughly 7 gallons of oil per car tire and 22 gallons per truck tire (DiCamillo, 2017). Accumulated EoL tires,

whether in legal or illegal dump sites, present a serious risk of uncontrollable fires, releasing toxic emissions such as zinc and chlorine. Moreover, they produce microplastics that infiltrate waterways and oceans, endangering marine ecosystems. According to Kole et al. (2017), tires account for 10% of the total microplastic waste in the world's oceans.

China, for instance, grapples with massive stockpiles of tires, with approximately 14 million tons sitting in landfills, only half of which are utilised, and with an annual growth rate of 8%. This situation is exacerbated by the absence of a comprehensive management system and numerous logistical barriers (Hu et al., 2021).

Facilitating the recycling of tires accumulated in landfills can contribute to achieving specific targets outlined in the United Nations Sustainable Development Goals (SDGs) (*THE 17 GOALS*, n.d.). For instance, recycling waste tires into valuable materials boosts economic growth and strengthens industries, especially in developing countries, by diversifying and supporting the economy (target 9.3). It also mitigates environmental and health risks associated with tire landfills, such as contamination and pollution, leading to cleaner environments and healthier communities better suited to maintaining resilient infrastructure (targets 9.6, 3.9, and 12.4). By focusing on effective tire management, tires can be repurposed for various applications, like civil engineering projects or industrial fuel, supporting a circular economy that emphasises recycling and reuse (target 12.5). This approach enhances resilience to climate-related disruptions and improves infrastructure durability. For example, rubberised asphalt made from recycled tires can make roads more resistant to temperature fluctuations and heavy rainfall, which are increasing due to climate change (target 13.1). Moreover, incorporating waste brick powder (WBP) and waste tire rubber (WTR) into concrete production effectively reduces carbon dioxide emissions while maintaining adequate compressive strength, fostering more sustainable and resilient infrastructure (Sinkhonde and Bezabih, 2024).

The objective of this study is to identify the key criteria for successful treatment of stockpiled tires in landfills, using a successful case study from Qatar as a reference. These criteria will then be prioritised based on input from experts actively involved in the field. By sharing these insights, the study aims to guide decision-makers in other countries facing similar issues with stockpiled tires. This will help them prioritise investments and focus funding on the most critical aspects of infrastructure to address the problem effectively.

The article examines the current supply chain of EoL tires in Qatar, identifying the key stakeholders involved in the system. After pinpointing these stakeholders, they will be interviewed for response analysis. Field research has been conducted to identify the key organisations involved in tire recycling from landfills. One representative from each organisation has been selected to provide input for the decision-making trial and evaluation laboratory (DEMATEL) analysis.

2 Literature review

The global production of waste tires is estimated at 1.5 billion whole tires annually, a number expected to rise due to inadequate recycling infrastructure and processing coordination (Mashiri et al., 2015). To address this issue, many authorities have implemented stringent regulations to curb tire stockpiling and landfill use, driven by increasing environmental awareness worldwide. These regulations create opportunities

for researchers to explore sustainable solutions and alternative uses for waste tires. Recent studies emphasise the role of circular economy facilitators, such as circularity brokers, in connecting supply chain actors and enabling the adoption of sustainable tire recycling practices, particularly in emerging economies (Ratsimandresy and Miemczyk, 2024).

Turning to managerial perspectives, certain studies addressed the economic aspects of tire manufacturing, elucidating the value of each manufacturing step and exploring strategies to optimise tire utilisation through practices like tire retreading (Ferrer, 1997). Additionally, research has scrutinised the influence of green supply chain practices on organisational performance within the Indian rubber industry. Utilising regression analysis, some studies found the positive impact of waste reduction and effective supplier relationship management (SRM) on business performance (Dubey et al., 2014). Notably, some investigations have focused on economic evaluations related to remanufacturing, reuse, and recycling disassembly operations (Johnson and Wang, 1998). Further, recent reviews highlight advanced thermochemical processes such as pyrolysis and gasification to convert EoL tires into energy and value-added products, providing both environmental and economic benefits (Han et al., 2024). In addition, lifecycle assessment studies indicate that integrating renewable energy sources in recycling operations can significantly reduce global warming potential, land use, and water consumption associated with ELT processing (Sudan et al., 2025).

Recent research has proposed a streamlined comparative life cycle assessment (cLCA) method to facilitate decision-making in tire recycling. By focusing on key impact categories such as greenhouse gas emissions and land use, this approach enables policymakers to efficiently compare innovative recycling technologies with conventional methods (Dekker et al., 2024). These studies introduce systematic methodologies for generating optimal disassembly sequences aimed at maximising material recovery profits and enhancing the EoL tire supply chain. In addition, simulation-based approaches, particularly Monte Carlo methods, have been introduced to capture uncertainties in CLSC systems and provide more realistic assessments of cost, profit, and environmental performance (Aydin et al., 2024). Moreover, multi-objective models integrating techno-political frameworks have been developed to optimise reverse logistics for ELTs, balancing economic, environmental, and social objectives while incorporating extended producer responsibility (EPR) regulations (Castañeda-Rodríguez and Espinoza Pérez, 2025).

Given the study's emphasis on supply chain quality, it is crucial to address legislative frameworks for the latest regulations on tire waste management. In Malaysia, for instance, Abas and Wee (2014) highlighted specific legislation aimed at enhancing tire waste management services and public cleanliness. Similarly, within the European Union (EU), significant developments have been made through directive policies focused on managing waste landfill and EoL vehicle tires, as noted by Sienkiewicz et al. (2012). Notably, these policies have proven effective, leading to a notable increase in recycling rates from 80% in 2006 to an impressive 95% by 2013, as reported by Karger-Kocsis et al. (2013). Comparative study also underscore how digital technologies and Industry 4.0 integration within circular supply chains can further optimise resource management and enhance recycling efficiency (Zhu et al., 2026).

The success of these initiatives has spurred the development of three key systems: a tax system, a free market system, and the implementation of EPR. Particularly, EPR mandates importers to take responsibility for tire recycling, a strategy that has

demonstrated efficacy. For instance, in countries like Portugal, waste recycling rates have surged from 69% to an outstanding 98% due to the implementation of such measures, as evidenced by Niza et al. (2014). Case studies from China, Togo, and Poland further illustrate how EPR, supported by government legislation, financial incentives, and collaborative stakeholder engagement, drives effective tire recycling practices across diverse economic contexts (Narra et al., 2025; Nowaczek et al., 2025).

Apparently, the implementation of the EPR system within the EU has yielded substantial benefits, as evidenced by numerous comparative studies. A comprehensive review conducted by Leong et al. (2023) sheds light on the comparative analysis of countries adopting the EPR system and its impact on enhancing the 4R (recycled, recovered, retreaded, and reused) management of rubber solid waste. Italy and Romania, both of which have embraced the EPR system, provide compelling examples. In 2012, Italy successfully collected 403,000 tons of used tires, with 18.1% being reused and the remainder being allocated to recycling (36.1%), energy recovery (57.9%), and landfilling (6%). Conversely, Romania collected 46,000 tons of EoL, with 43.5% being recycled and the remaining utilised for energy recovery (56.5%). Remarkably, despite differing economic contexts, regulations, and legislation, both nations have demonstrated significant progress (Torretta et al., 2015). Similarly, modelling and simulation studies demonstrate how strategic planning of remanufacturing networks and vehicle allocation improves cost-efficiency and sustainability performance of EoL tire management systems (Manupati et al., 2024).

It is worth noting that outside the EU, countries such as Colombia have attempted to implement similar systems. However, governance issues have hindered the project's success, albeit with an increase in recycled tire waste following implementation. Notably, the burden of waste tire management, both operationally and financially, fell solely on tire manufacturers, leading to limited engagement from other stakeholders in the tire production chain (Park et al., 2018). Evidence from West Africa highlights that successful EPR implementation must adapt to local economic and infrastructural conditions to be effective, such as combining import levies, manufacturer responsibility mechanisms, and government incentives (Narra et al., 2025).

DEMATEL represents a robust methodology capable of leveraging collective expertise to manage causal connections among criteria. Therefore, some studies have used it to address challenges hindering the EoL tire supply chain. Feng et al. (2018) introduced a sustainable model aimed at enhancing product reliability through a comprehensive approach to decision-making. This model integrates sophisticated techniques like the DEMATEL-based analytical network process (ANP). Its effectiveness was demonstrated through a case study involving shredded waste tires. However, Hu et al. (2021) presented an integrated supply chain management system that considers the entire life cycle of EoL tires, focusing on stakeholders' perspectives. Thirteen barriers are identified across three supply chain stages: EoL tire collection, treatment, and sales/use of '4R' products. Using the DEMATEL method, the study examines causal-effect relationships among these barriers, with assessments conducted by experts from industry associations, tire manufacturers, and a recycling enterprise. Similarly, Hsieh et al. (2024) and Zhu et al. (2026) refined these frameworks to incorporate circular economy supply chains (CESCs), emphasising factors like optimising production processes, digital facilitation, and stakeholder coordination for improved remanufacturing outcomes.

Table 1 Studies analysing the recycling of EoL tires using the DEMATEL

<i>Study</i>	<i>Domain</i>	<i>Aim</i>	<i>Case study</i>	<i>Focus</i>	<i>Life-cycle stages covered</i>	<i>Methodology</i>
Feng et al. (2018)	EoL tire supply chain	Developing a multi-criteria decision-making model for product optimisation	N/A	Environmental protection, economic profit, and security	All	DEMATEL-based analytical network process
Hu et al. (2021)	EoL tire supply chain	Developing an integrated supply chain management system for EoL tires	China	Key barriers for recycling across life-cycle stages	Collection, treatment, and sales and use	Grey-DEMATEL
Houbao et al. (2022)	EoL tire supply chain	Identifying key drivers for implementing the EPR system	China	Legislative support and long-term strategies	Management with a focus on the EPR system	Grey-DEMATEL
Hsieh et al. (2024)	EoL tire supply chain	Creating a framework for integrating circular economy supply chains	-	Remanufacturing and recycling processes	Management with a focus on remanufactured products	Fuzzy-DEMATEL
This study	EoL tire supply chain	Prioritising success criteria for EoL tire recycling in landfills	Qatar	Criteria of success for recycling	Management with a focus on landfills	DEMATEL

Notes: EoL: end-of-life; ERP: extended producer responsibility

Moreover, to examine the motivating forces behind the EPR system within the Chinese tire industry, Houbao et al. (2022) identified the primary driving factors through a combination of literature review, expert interviews, and on-site investigations. Subsequently, employing the Grey Decision-Making and Trial Evaluation Laboratory (Grey-DEMATEL) method, the study quantifies and analyses the interconnections among these factors.

Hsieh et al. (2024) highlighted the lack of practical industry research, particularly in the rubber recycling sector, and presented a study that refines existing frameworks by identifying key factors for remanufacturing within CESC. Through expert surveys and the fuzzy DEMATEL method, important aspects and criteria are identified, emphasising the need for industries to prioritise factors like optimising production processes and improving resource efficiency when implementing CESC for remanufactured products.

The literature revealed that obstacles impeding the seamless movement of tires from end users to authorised disposal sites (factories or approved landfills) pose a global challenge. Evidently, Qatar has encountered similar barriers in the past. However, following the successful clearance of EoL tires from two major landfills, this achievement served as inspiration for this study to elucidate success criteria. These insights are reinforced by research on circular supply chain resilience and technological facilitation, which suggests that strategic stakeholder engagement and digital integration are critical for operational success across regions (Han et al., 2024; Zhu et al., 2026).

This article aims to compile success criteria for establishing a sustainable and efficient EoL tire supply chain in Qatar, leveraging insights from literature sources and stakeholders' perspectives. The study also seeks to underscore legislative criteria and parameters aimed at enhancing service quality within the EoL tire supply chain. Additionally, it prioritises these criteria based on their importance, drawing upon expert opinions from the private sector. Notably, this study represents the first systematic attempt to address success criteria in this field. It also believes that this legislation can be applied to countries in the region suffering from the same problem of accumulated tires (ex. Kuwait). Moreover, it will be considered as a threshold step for governments having difficulties implementing the EPR system.

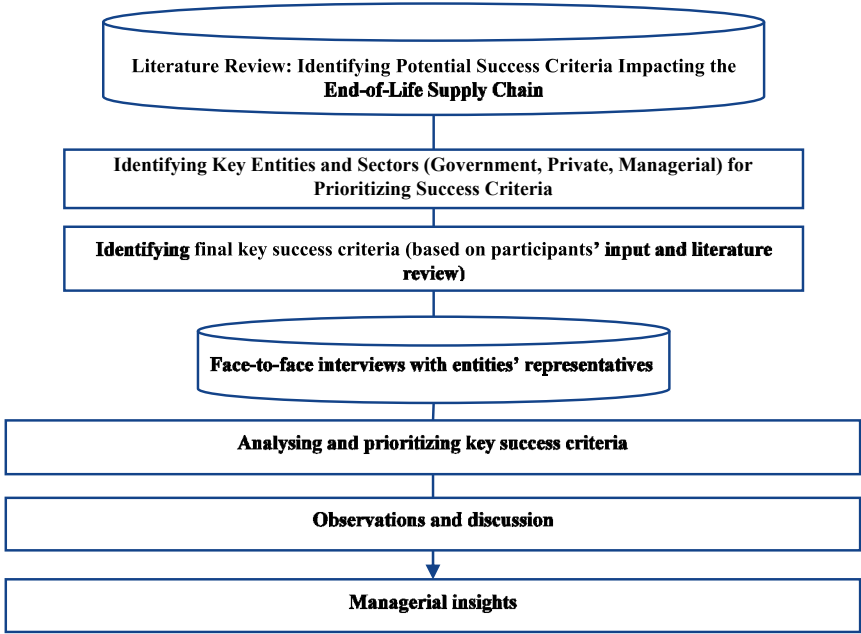
3 Methodology

This journal paper aims to prioritise key success criteria for recycling tires accumulated in landfills through a structured methodology. As shown in Figure 1, the process begins with a comprehensive literature review to identify relevant success criteria and assess prior studies in the field. Following this, key entities and sectors, including governmental and private stakeholders, are identified for their roles in influencing the DEMATEL process. The final success criteria are refined based on insights from the literature and participant input. Face-to-face interviews with representatives from these entities are conducted to gather detailed information, which then analysed to prioritise the criteria. Finally, the results are discussed to develop managerial insights that can guide effective decision-making in tire recycling within landfills.

In the following subsections, the data collection process is outlined, focusing on interviews with private sector experts in EoL tire recycling in Qatar, which informed the development of the DEMATEL model. The DEMATEL method is then described,

detailing how it was used to analyse the interrelationships between key success factors by constructing causal diagrams and evaluating their influence within the system.

Figure 1 Comprehensive methodology framework (see online version for colours)



3.1 Data collection

This study exclusively addressed insights from the private sector, which possesses a deep understanding of the complex operational mechanisms and cost dynamics associated with EoL tire recycling. Notably, Qatar’s absence of tire manufacturers underscores the significance of incorporating their perspectives, which could have significantly enriched the research. Consequently, a series of comprehensive face-to-face interviews were conducted with experts from enterprises, as outlined in Table 2. Notably, four enterprises actively contribute to circular economy legislation under the Waste Recycling and Treatment Department. The DEMATEL model was intricately crafted based on the experiences of these enterprises, given their proficiency in producing high-value products requiring advanced technology, environmental consciousness, and the ability to fulfil local needs instead of merely exporting raw materials. Moreover, this direction aligns with Qatar’s future vision of supporting factories that support sustainable technologies and offer a diverse array of end-products.

Bright Future Tyre Recycling Factory (BFF) stands out as one of the rare facilities employing devulcanisation to process tires, yielding intermediate raw materials crucial for manufacturing various rubber components, steel wire, and crumb rubber utilised in asphalt mixtures. Boasting the capacity to treat upwards of 1,680 metric tons of tires each month, BFF operates with a workforce of over 200 employees.

The state-of-the-art recycling facility specialises in the production of rubber granules, shredded parts, rubber tiles, and rubber interlock products. Commencing operations in 2014, the factory boasts a treating capacity exceeding 3300 metric tons per month.

Founded in 2015, Golden Rubber specialises in the processing of rubber cuts and shreds, showcasing expertise in this niche area. With a treating capacity of up to 1680 metric tons monthly, the organisation employs approximately 150 dedicated individuals.

Established in 2003, Al Suwaidi Tyre Retreading stands as the sole provider of tire retreading services in the country. With a monthly capacity of retreading 1320 tires (equivalent to 110 metric tons), it plays a pivotal role in the market. However, recent years have seen a decline in retreading facilities, with three factories closing down in 2020. This shift can be attributed to the influx of Chinese tires offering competitive pricing, coupled with the challenges of high production costs. As a result, Al Suwaidi Tyre Retreading remains the solitary entity in the retreading sector.

Table 2 Background of the evaluators

	<i>Organisation</i>	<i>Role</i>	<i>Years in industry</i>
1	Bright Future Factory	GM/Owner	Since 2016
2	Modern Recycling Factory	Operations Manager	Since 2014
3	Golden Rubber	GM	Since 2015
4	Al Suwaidi Tyre Retreading	Sales/operations manager	5 years

The interviews conducted with enterprise representatives, as highlighted in Table 2, aimed to gather insights on the success criteria for the evacuation of two main landfills in Qatar. In addition to the criteria obtained from these interviews, further criteria have been extracted from relevant literature sources. This comprehensive approach ensures a well-rounded understanding of the factors contributing to the success of this endeavour.

3.2 Decision-making trial and evaluation laboratory

DEMATEL, unlike traditional techniques such as the analytic hierarchy process, this method, one of the structural modelling techniques, can identify the interdependence of system elements through a causal diagram. The causal diagram depicts the basic concept of contextual relationships and the strengths of influence among the elements using digraphs rather than directionless graphs, DEMATEL method in this study followed the same model constructed by (Shieh et al., 2010).

Step 1 Create an average matrix. Each respondent was asked to rate the direct influence of any two factors using an integer score between 0 and 3, representing ‘no influence’, ‘low influence’, ‘medium influence’, and ‘high influence’, respectively.

$$a_{ij} = \frac{1}{H} \sum_{k=1}^H x_{ij}^k \quad (1)$$

x_{ij} indicated the degree each evaluator approves for factor i affecting factor j . The diagonal values are set to zero $i = j$. An $n \times n$ non-negative matrix can be created for each respondent as $X^k = x_{ij}^k$, k belongs to $\{1, H\}$, and n is the

number of factors. Hence, matrices from each evaluator H are $X^1, X^2, X^3, \dots, X^H$, therefore average matrix $A = [a_{ij}]$ can be represented as in equation (1).

Step 2 Computing normalised initial direct-related matrix D . $D = A * S$, where D

represents the normalised initial direct-related matrix, and $S = \frac{1}{\max_{i \leq i \leq n} \sum_{j=1}^n a_{ij}}$.

Elements in matrix D fall between zero and one.

Step 3 Total relation matrix T .

$$T = D(I - D)^{-1}, \quad I : \text{is the identity matrix} \quad (2)$$

Defining c and r to be $1 \times n$ and $n \times 1$ vectors exemplifying the sum of columns and sum of rows of matrix T respectively. If r_i is the sum of the i^{th} row in matrix T , r_i summarises both the direct and indirect effects of factor i on the other factors. Similarly, if c_j is the sum of the j^{th} column in matrix T , then c_j represents both direct and indirect effects of factor j on the other factors. When $j = i$, the total effects given and received by factor i are shown by the sum $(r_i + c_i)$. That is, $(r_i + c_i)$ indicates the importance of factor i in the overall system. On the other hand, the difference $(r_i - c_i)$ represents the net effect that factor i has on the system. If $(r_i - c_i)$ is positive, factor i is a net cause, whereas if $(r_i - c_i)$ is negative, factor i is a net receiver or result.

Step 4 To obtain the digraph, set a threshold value. Because matrix T provides information on how one factor affects another, a decision maker must set a threshold value to filter out some insignificant effects. Only effects greater than the threshold value would be chosen and displayed in the digraph. The threshold value in this study is determined by taking the average of the elements in matrix T . By mapping the dataset of $(r + c, r - c)$ the digraph can be obtained.

4 Results

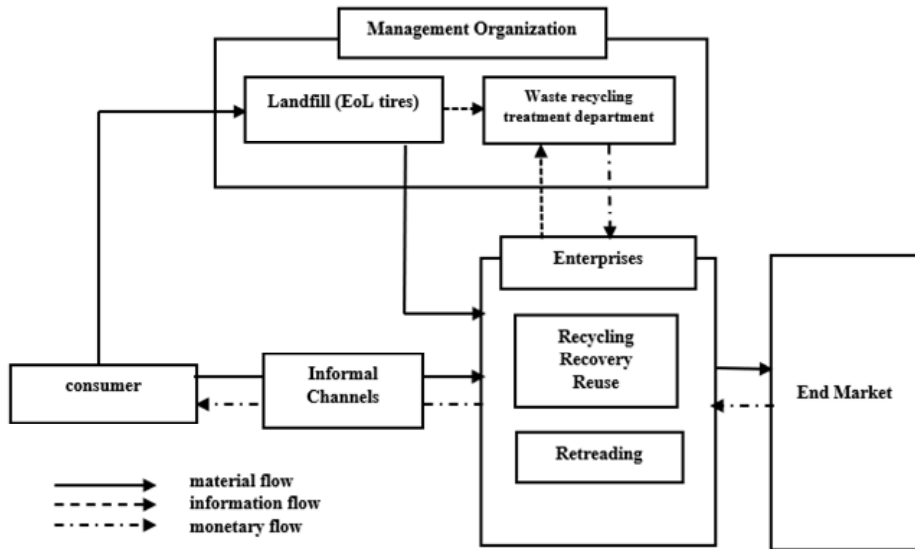
4.1 Supply chain in Qatar

Figure 2 illustrates the typical supply chain of scrap tires in Qatar, highlighting three critical flows that affect the supply chain: material, information, and monetary flows. This mapping is constructed based on the opinions of various stakeholders and, while it might differ slightly, it is similar to the mapping presented in Hu et al. (2021). A key common observation between the two mappings is the informal channel between consumers and the end market (or enterprises). The existence of illegal channels is a significant factor that has led to the collapse of the tire waste management system in China. However, despite the presence of illegal channels in Qatar, the supply chain depicted in Figure 2 has proven effective, successfully resulting in the evacuation of two main landfills.

Several factors contribute to this achievement. Firstly, the difference in geographical area between Qatar and China plays a role. Secondly, the significant disparity in population, which is proportional to car usage (Abdul Hassan et al., 2015), is another contributing factor. However, the primary reason for this success is the establishment of

specific criteria to facilitate the flow of tires from source to sink. These criteria, which include certain legislative measures, were developed as part of Qatar's Vision 2030. The detailed criteria are outlined in Table 4.

Figure 2 Actual supply chain system for EoL tires in Qatar



4.2 Criteria of success

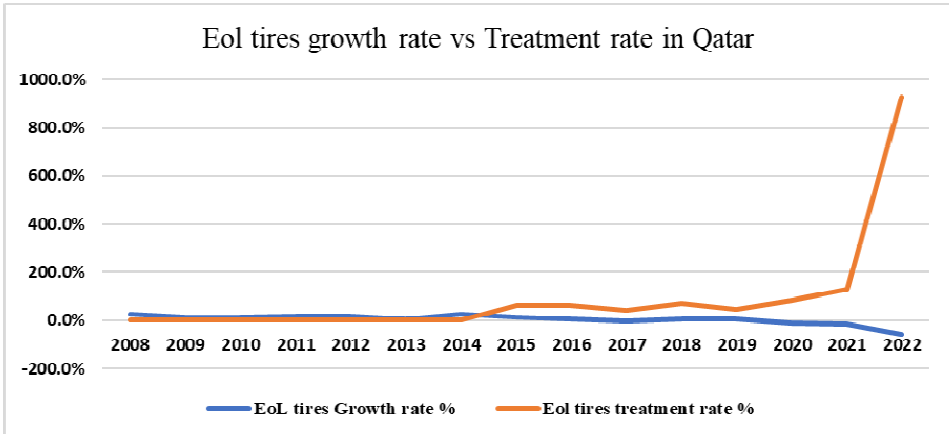
Based on contributors, the success of tire recycling initiatives is influenced by several key criteria, each playing a vital role in optimising the supply chain and ensuring sustainable operations. In this section, we will explore these criteria in detail.

4.2.1 Criteria 1 (C1): providing monthly subsidies and incentives

Providing incentives to factories for each ton of recycled material has proven to be an effective measure in increasing the number of recycled tires in landfills. This approach enabled enterprises to invest in transportation and heavy equipment, thereby streamlining the loading process. Additionally, timely subsidies positively impacted infrastructure development and significantly increased some end-products, such as reclaimed rubber as indicated by a representative of Bright Future Tyre Recycling Factory.

Ensuring timely incentives, preferably on a monthly basis, is crucial to avoid disruptions in the supply chain. This was evidenced when many qualified enterprises did not receive the 50% tax incentive refund promised by the Chinese government, adversely affecting treatment processes (Hu et al., 2021). In Qatar, the implementation of incentives in 2019 led to a notable increase in the treatment rate, with sustained progress since then, as shown in Figure 3.

Figure 3 Growth rate vs. treatment rate of EoL tires, in the period between 2008 and 2022
Environmental Statistics (2024) (see online version for colours)



4.2.2 Criteria 2 (C2): formal tire collection landfills closer to enterprises than end-users

Stakeholders have emphasised that this represents one of the most positive initiatives implemented by the Qatari government. The clustering of recycling enterprises in Qatar, forming a cohesive community of factories (CoF), has proven advantageous, given their proximity to landfills. This strategic move has enabled enterprises to invest in equipment and transportation at minimal costs, thanks to their close proximity to legal disposal sites. Furthermore, it has fostered enhanced communication among the private sector, government authorities, and landfill management.

Interestingly, this criterion has also placed increased responsibilities and costs on suppliers (end-users) to dispose of their scrap tires near these enterprises. It is noteworthy that criteria 2 (C2) along with criteria 3 (C3) have demonstrated significant effectiveness, compelling end-users to formally deliver tires to receive recycling certificates, either from landfills or factories. In essence, the implementation of C2 to reduce costs incurred by tire recycling enterprises should be considered globally, given the high production costs and low profit margins for some end-products.

4.2.3 Criteria 3 (C3): environmentally audited tire disposal system

Hsieh et al. (2024) underscored the criticality of implementing a robust traceability system, comprising audits and penalties. During the preparation phase for the FIFA World Cup Qatar 2022, the country embarked on extensive construction projects, including the construction of stadiums and residential buildings, in anticipation of hosting approximately 1.5 million tourists (as projected). Coinciding with this surge in development, the country witnessed a record-high tire importation of 40,895 metric tons in 2019, the highest recorded during the period from 2016 to 2021, according to the Environmental Statistics (2024).

The escalation in imported tires prompted enhancements in the managerial disposal system, leading to improved traceability in managing the disposal of EoL tires. Furthermore, the implementation of an audit system has been instrumental in curbing the incidence of tires leaking out of the formal supply chain, thereby minimising the impact on factories. This phenomenon, identified as one of the primary barriers by Hu et al. (2021), involves peddlers influencing the market by offering higher prices to collect tires. However, these peddlers lack the authority to issue recycling certificates, unlike certified factories, as they do not possess environmental permits.

4.2.4 Criteria 4 (C4): direct communication channels between 4R-enterprises and management organisations (e.g., waste recycling and treatment department)

According to a representative, direct communication channels are as important as having landfills near recycling factories. A positive connection between municipalities and factories keeps them up to date with recent issues. Additionally, it strengthens the relationship between the private and government sectors and helps the private sector develop comprehensive plans to efficiently dispose of waste tires.

4.2.5 Criteria 5 (C5): allowing each factory to operate at full capacity, considering the variations in production types (e.g., different tire-derived products), maximises efficiency and productivity

The Waste Recycling and Treatment Department consistently facilitates the establishment of recycling enterprises while recommending the production of diverse tire-derived products (TDPs). Consequently, the four main tire recycling factories in Qatar treat tires differently. The treatment options include devulcanised rubber, crumb rubber, rubber granules, shredded material or rubber blocks, buffing, and retreading. Table 3 summarises the factories and their associated products. This will help optimise the production processes. According to Hsieh et al. (2024), Prioritising factors such as optimising production processes and enhancing resource efficiency for remanufactured products will significantly improve the effectiveness of CESC's.

Table 3 Enterprises and their corresponding TDPs

<i>Factory</i>	<i>Establishment year</i>	<i>Products</i>
Bright Future Tyre Recycling Factory WLL	2016	Devulcanised rubber, crumb rubber
Modern Recycling Factory WLL	2014	Rubber tiles, cured rubber parts, rubber granules.
Golden Rubber WLL	2015	Rubber cuts, rubber shreds
Al Suwaidi Tyre Retreading WLL	2003	Retreaded tires, buffings

4.2.6 Criteria 6 (C6): exhibitions and conferences done by waste recycling and treatment department

Qatar is a small country and does not have the same variety in end-market demand as larger countries like India, Pakistan, China, or Saudi Arabia. Therefore, hosting conferences and exhibitions regularly creates opportunities for local factories to address

the unmet demand in neighbouring countries. Saudi Arabia, for instance, has a significant end-market demand for TDPs. Attending national or local exhibitions enhances trade exchange with minimal costs, allowing Qatari enterprises to expand their market reach and foster economic growth.

Table 4 Outlined criteria and legislation to optimise the flow of EOL tires through the supply chain

<i>n</i>	<i>Criteria/legislation</i>
1	Providing monthly subsidies and incentives
2	Formal tire collection landfills closer to enterprises than end-users
3	Environmentally audited tire disposal system
4	Direct communication channels between 4R-enterprises and management organisations (e.g., waste recycling and treatment department)
5	Allowing each factory to operate at full capacity, considering the variations in production types (e.g., different TDPs)
6	Exhibitions and conferences done by waste recycling and treatment department

Note: Criteria have been determined from both stakeholders and literature.

4.3 DEMATEL

The matrices of the evaluators can be observed in Appendix. As outlined in the methodology section, we acquired the total relationship matrix as shown in Table 5. The total relationship matrix is crucial for determining the threshold value (α), which is the average of the entire matrix. In this case, the value is $\alpha = 0.6314$. Any value greater than α is highlighted in bold in Furthermore, Table 5 indicates the impact of criterion *i* on another criterion *j*. For instance, in the first row, it is evident that C1 influences C2, C4, C5, and C6.

Table 5 Total Relationship Matrix (T)*

<i>i \ j</i>	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>
C1	0.688996	<i>0.783695</i>	0.516277	<i>0.894902</i>	<i>1.037351</i>	<i>0.745262</i>
C2	<i>0.774144</i>	0.473482	0.353426	<i>0.778608</i>	<i>0.907457</i>	<i>0.672464</i>
C3	0.568992	0.470015	0.263322	<i>0.703722</i>	0.594158	0.515814
C4	<i>0.850426</i>	0.627981	0.508668	0.709737	<i>0.929005</i>	<i>0.885416</i>
C5	0.574773	0.46357	0.279423	0.599549	0.563683	<i>0.706612</i>
C6	0.629379	0.421431	0.300299	<i>0.674751</i>	<i>0.763949</i>	0.500304

Notes: *The italics values are greater than the threshold value (α), which is the average of the entire matrix.

In the DEMATEL analysis, criteria with a positive Ri-Ci value are classified as causes, while those with a negative Ri-Ci value are categorised as effects. Table 6 shows this identification of causes and effects.

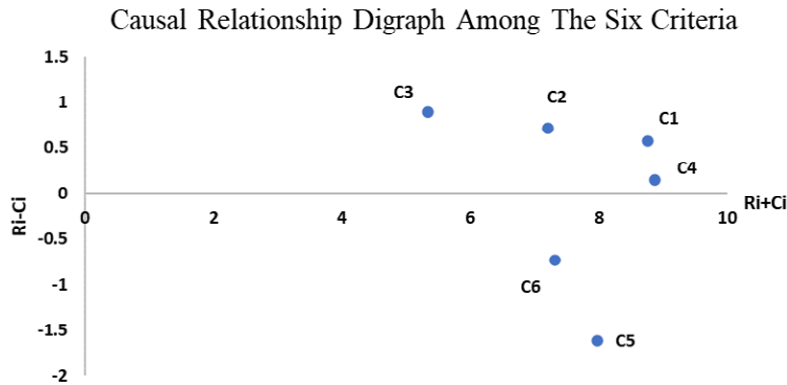
Following the determination of the total relationship matrix and degree of prominence (cause-effect values) the causal relationship diagram can be constructed, as illustrated in Figure 4Error! Reference source not found.. For example, C6 and C5 are positioned

below the x-axis, indicating that they are classified as effects. Conversely, a higher $Ri+Ci$ value signifies the criterion's importance to the supply chain.

Table 6 The degree of prominence as well as the net cause-effect values

Criteria	Ri	Ci	$Ri+Ci$	$Ri-Ci$	Identify
C1	4.666483	4.08671	8.753193	0.579773	Cause
C2	3.959581	3.240175	7.199756	0.719406	Cause
C3	3.116023	2.221415	5.337438	0.894608	Cause
C4	4.511232	4.36127	8.872502	0.149963	Cause
C5	3.18761	4.795603	7.983213	-1.60799	Effect
C6	3.290115	4.025872	7.315986	-0.73576	Effect

Figure 4 Diagram illustrating the causal relationships among the six criteria (see online version for colours)



5 Discussion

This study aimed to highlight and prioritise the primary success criteria for the effective treatment of tires stockpiled in landfills, as identified in Table 4. Initially, interviews were conducted to gather the criteria. Following this, a second round of interviews with the same stakeholders was held to obtain their perspectives, during which they filled out matrices, as detailed in Appendix. Additional criteria were incorporated from the literature review. Notably, all criteria identified by the stakeholders were included in the DEMATEL analysis, with none being excluded. There are some shared criteria between those extracted from stakeholders and those identified from the literature, such as C1, C3, and C5, which underscores their importance.

From Table 6 and Figure 4, six criteria can be prioritised. Surprisingly, C4 (direct communication channels between 4R-enterprises and management organisations) received the highest $Ri + Ci$ score, surpassing C1. This underscores the crucial importance of effective communication between waste recycling and treatment departments and stakeholders. These stakeholders are not limited to recycling enterprises, as shown in the mapping in Figure 2, but also include tire importers/exporters and the

chamber of commerce. Establishing robust communication channels with these entities is essential for increasing traceability and reducing the number of leaked tires.

Furthermore, providing incentives (C1) is the second most important criterion for facilitating the material flow of tires through the supply chain in Qatar. The impact of this criterion is evident: in 2019, Qatar approved incentives for each ton of tires treated, leading to a significant and sustained increase in tire treatment, as depicted in Figure 3. This chart shows a notable rise beginning in 2019 and continuing through 2021 (data for 2022 is not yet available on the Planning and Statistical Authority site). Additionally, Figure 3 highlights the first major increase in tire treatment around 2012, coinciding with the establishment of three main treatment factories during that period, as detailed in Table 2.

Participants also emphasised, with a strong consensus, that incentives must continue even after the complete treatment of EOL tires stockpiled in landfills to support recycling factories. These factories produce significant quantities of TDPs such as rubber crumb, rubber granules, shreds, buffing, and steel wires in a relatively short time compared to the quantity produced.

Maintaining continuous incentives will enable tire recycling factories to expand or upgrade their production lines beyond TDPs, allowing them to produce higher-margin products in smaller quantities. For instance, steel wire can be used to produce steel wire-cement mortar mixtures as a replacement for commercial steel (Oikonomou and Mavridou, 2009), or to manufacture steel products. Additionally, these incentives could facilitate the production of specialised rubber parts, such as gaskets and automotive rubber components. This strategic support is crucial for fostering innovation and diversification within the tire recycling industry.

DEMATEL has identified and prioritised criteria that have proven effective in Qatar, offering a valuable framework that could be implemented in developing countries facing significant accumulations of EoL tires in their landfills, such as Kuwait. Adopting these criteria could serve as a foundational step towards implementing an EPR system, either in the short or long term. This approach not only addresses immediate waste management challenges but also promotes sustainable practices and regulatory advancements in tire recycling and waste management.

6 Managerial insights

This study has divided the six criteria into two groups: cause and effect. Consequently, criteria identified as causes (C1, C2, C3, C4) are likely key drivers in the system. Stockholders should focus on these to understand the root causes and take proactive measures; however, criteria identified as effects (C5, C6) are outcomes influenced by the causes; therefore, managers should monitor these to assess the impact of changes in the causes.

Moreover, controlling and improving the criteria identified as causes. Since they have a significant impact on other factors, addressing these can lead to overall system improvement. In addition, monitoring the effects will help in understanding how well the changes in causes are impacting the outcomes.

6.1 *Balance act*

The sum of prominence and influence ($R_i + C_i$) can help in understanding the overall importance of each criterion in the system. For example, C1 and C4 have the highest ($R_i + C_i$) values, indicating they are crucial for the overall system dynamics.

Interventions should be balanced between improving the causes and monitoring the effects. For instance, while improving C1 (a cause) is vital, understanding its impact on C5 (an effect) is also essential to gauge the effectiveness of the interventions. This balanced approach ensures that resources are optimally utilised, leading to more effective and sustainable improvements in system performance. By addressing both the root causes and their resulting effects, organisations can achieve a comprehensive understanding of their operational dynamics and make more informed decisions.

6.2 *Resource allocation*

Allocate resources and efforts towards managing and improving the criteria with the highest prominence and influence values (C1, C4, C5). This strategic allocation can lead to better system performance and efficiency.

Resources (time, budget, personnel) should be allocated based on the importance of each criterion. High ($R_i + C_i$) values suggest that these criteria require more attention and resources. For example, C1 and C4 have the highest ($R_i + C_i$) values (8.753193 and 8.872502, respectively), indicating that they are pivotal to the system's overall performance and need adequate resources. By prioritising these criteria, organisations can optimise their resource utilisation and achieve more significant improvements in their operational outcomes.

6.3 *Enhanced stakeholder engagement*

Prioritising success criteria offers insights into the valuable inputs that can be generated from various stakeholders, including manufacturers, recyclers, government agencies, and the public. It also helps clarify how each stakeholder can contribute to meeting each criterion. This collaborative approach can foster greater cooperation and commitment, which are essential to developing targeted strategies that address the most pressing issues, such as collection efficiency, recycling capacity, and market demand for recycled materials.

Actively engaging community stakeholders, including local governments, NGOs, and civic groups, is crucial for promoting recycling initiatives and gaining community support. Managers should organise workshops, drives, and events to increase participation and awareness, strengthening the effectiveness and sustainability of recycling programs. Additionally, targeted education campaigns highlighting the environmental and economic benefits of recycling EoL tires can encourage responsible behaviour among consumers, businesses, and educational institutions.

6.4 *Paving the road to establish the EPR system*

Enhanced stakeholder engagement and EPR are closely linked. The process of prioritising success criteria helps clarify the roles and responsibilities of various stakeholders, particularly producers, in managing tire waste. This process establishes the

foundation for holding producers accountable for the EoL management of their products, which is a core principle of EPR. Additionally, prioritising success criteria often underscores the importance of stable markets for recycled materials. Developing these markets is essential for the sustainability of an EPR system, as it ensures that collected and recycled tires have viable end uses.

As criteria for success are prioritised, it becomes clear which regulatory and economic measures are necessary to support tire landfill evacuation. This alignment can help shape the legal and economic framework needed for an EPR system. Also, understanding the key success factors can lead to the development of incentives that encourage producers to participate in tire recycling efforts, aligning their economic interests with environmental goals.

6.5 Implementation of advanced data analytics and technology

Utilising data analytics offers valuable insights into the operational efficiency and market trends of the EoL tire recycling industry. Managers should invest in advanced data analytics tools to monitor performance, forecast demand, and optimise supply chain operations. Real-time data collection and analysis enable informed decision-making, identify areas for improvement, and boost productivity. Integrating internet of things (IoT) and smart technologies into the recycling process can enhance tracking, monitoring, and management of tire flows. Managers should consider adopting IoT-enabled sensors, radio frequency identification (RFID) tags, and smart waste management systems to improve traceability, reduce losses, and ensure regulatory compliance. These technologies also provide real-time alerts and actionable insights, facilitating proactive management of recycling operations.

7 Limitations and future research suggestions

In this study, the DEMATEL analysis involved recycling entities exclusively from the private sector. Although the private sector holds the majority of recycling experience and mechanisms, the analysis would have been more comprehensive if other entities, such as tire importers or waste treatment departments (governmental entities), had been included. Their input is believed to enhance the study by providing more rigorous prioritisation and involving additional success criteria. However, due to certain restrictions and confidentiality issues, we were unable to reach representatives who could contribute to this DEMATEL analysis.

This study serves as a crucial initial step in bridging the gap between strategic planning and operational or tactical planning. For instance, it addresses the impact of C2, where formal tire collection landfills are strategically positioned closer to enterprises rather than end-users, on transportation costs.

Consequently, this research lays the groundwork for extending into an optimisation problem. By exploring optimal landfill locations, it aims to minimise not only transportation costs but also gas emissions, thereby offering a comprehensive solution that aligns with both strategic objectives and operational efficiency. Furthermore, the utilisation of a stochastic optimisation model becomes imperative for delineating the range of tire supplies from each source (end-user) to landfills and subsequently from landfills to recycling enterprises.

Figure 2 and Hu et al. (2021) indicate that the leakage of EoL tires outside the formal supply chain is a prevalent issue. To address this problem, implementing reverse logistics models under various scenarios could be effective. One approach might involve municipal departments dispatching empty trucks to collect EoL tires from different companies and service centres, which would then be deposited in an official landfill. Recycling factories would subsequently manage the collection from these landfills, assuming the associated costs.

Different scenarios could involve integrating tire suppliers into the supply chain. For example, leveraging the existing truck fleets of tire suppliers for the collection of EoL tires. The emphasis is on dual-use opportunities, where these companies' fleets would be utilised for both distributing new tires and collecting EoL tires. These model scenarios can be simulated using a mixed-integer programming model to minimise tire leakage, overall costs, and carbon emissions.

8 Conclusions

After successfully evacuating two major tire landfills, we recognised the importance of highlighting the key factors that contributed to this achievement. This article begins by presenting the situation of EoL tires and the massive amounts accumulated in Qatar's dump areas. Following this, in line with Qatar's Vision 2030, the country decided to manage EoL tires in the most efficient ways, such as recycling.

Next, the article outlines the current supply chain network in Qatar based on interviews with representatives, which surprisingly similar to the network described by Hu et al. (2021). The core of this article is then focused on identifying the criteria for success, gathered from both literature and interviews. These criteria were used to conduct a DEMATEL analysis.

The results were analysed to prioritise six identified success criteria, categorised on two levels: distinguishing criteria as either cause or effect and identifying the most crucial ones. It was found that effective communication among municipal authorities, recycling enterprises, and chambers of commerce is vital ($R_i + C_i = 8.87$). Additionally, balancing interventions between improving causes like C1 and monitoring effects such as C5 ensures optimal resource utilisation and sustainable system improvements. Prioritising criteria with the highest prominence and influence values, such as C1 and C4, facilitates strategic resource allocation, enhancing overall system performance and efficiency.

Discussing the criteria for success has uncovered important managerial insights, especially the importance of the interaction and interrelationship between these criteria. Understanding how they influence each other, as seen with C1 and C5, allows organisations to allocate resources more efficiently, leading to more effective and sustainable system improvements. Furthermore, DEMATEL has showed the importance of C4 scoring the highest $R_i + C_i$, this gives us an insight that involving more stakeholders could make better interaction in EoL tire supply chain. Consequently, this could be involving tire importer as a crucial stakeholder which means paving the road to construct the EPR system.

This study makes several unique contributions to the literature on EoL tire recycling and sustainable supply chain management. First, it represents one of the earliest empirical studies to systematically identify and prioritise success criteria for EoL tire recycling supply chains specifically focused on landfill evacuation using the DEMATEL

methodology. Second, the study contributes practical managerial value by providing a structured framework that can support policymakers and practitioners in prioritising strategic interventions when developing tire recycling systems. Third, by using Qatar as a successful case study, the research offers transferable insights for developing and emerging economies facing similar environmental and logistical challenges related to stockpiled tire waste.

Despite these contributions, the study is subject to several limitations. The analysis is geographically limited to the State of Qatar, and therefore the findings may reflect country-specific regulatory, economic, and infrastructural conditions that may differ in other regions. In addition, the study primarily relies on expert opinions from private-sector stakeholders, excluding broader perspectives from public-sector regulators, consumers, and tire manufacturers, particularly since tire manufacturing does not exist locally in Qatar. Furthermore, the DEMATEL method, while effective in identifying causal relationships, remains dependent on expert judgment and subjective assessments, which may introduce potential bias in prioritisation outcomes.

The leakage of EoL tires from the supply chain remains a persistent issue. Future research should expand the scope of investigation by incorporating additional stakeholders such as governmental regulators, importers, and environmental agencies to establish a more comprehensive understanding of the tire recycling ecosystem. Comparative studies across multiple countries could also validate the applicability of the identified criteria under different legislative and market environments. Moreover, future studies may integrate quantitative optimisation and simulation techniques with DEMATEL to further assess operational efficiency and improve decision-making precision. As a future contribution, we suggest reshaping the supply chain to minimise costs and reduce the burden on factories while also decreasing carbon emissions. This can be achieved by implementing reverse logistics models across various scenarios. Subsequently, we recommend selecting the most suitable models based on criteria that align with both strategic and tactical planning objectives.

Declarations

All authors declare that they have no conflicts of interest.

References

- Abas, M.A. and Wee, S.T. (2014) 'Municipal solid waste management in Malaysia: an insight towards sustainability', *SSRN Electronic Journal*, <https://doi.org/10.2139/ssrn.2714755>.
- Abdul Hassan, N., Airey, G.D., Md. Yusoff, N., Hainin, M.R., Putrajaya, R., Abdullah, M.E. and Aziz, M.M.A. (2015) 'Microstructural characterisation of dry mixed rubberised asphalt mixtures', *Construction and Building Materials*, Vol. 82, pp.173–183, <https://doi.org/10.1016/j.conbuildmat.2015.02.015>.
- Aydin, R., Al-Shihabi, S.T., Alzarooni, S.I. and Jaber, H. (2024) 'Assessing the economic and environmental performance of a closed-loop supply chain for waste tires: an industrial case study', *Environmental Science and Pollution Research*, Vol. 31, No. 57, pp.65513–65532, <https://doi.org/10.1007/s11356-024-35618-3>.
- Castañeda-Rodríguez, I. and Espinoza Pérez, A.T. (2025) 'Multi-objective model for end-of-life tires reverse logistics: enhancing sustainability through a techno-political framework', *Expert Systems with Applications*, Vol. 291, p.128203, <https://doi.org/10.1016/j.eswa.2025.128203>.

- Dekker, E., Quik, J.T.K., Steenmeijer, M.A. and Lijzen, J.P.A. (2024) 'Stripping down sustainability assessments for easier comparison of innovative recycling options', *Cleaner Waste Systems*, Vol. 9, p.100178, <https://doi.org/10.1016/j.clwas.2024.100178>.
- DiCamillo, N. (2017) 'New eco-friendly, renewable tires stretch the boundaries of rubber production', *Newsweek*, 3 June [online] <https://www.newsweek.com/new-eco-friendly-renewable-tires-stretch-boundaries-rubber-production-564165> (accessed 12 November 2023).
- Dubey, R., Bag, S. and Ali, S.S. (2014) 'Green supply chain practices and its impact on organisational performance: an insight from Indian rubber industry', *International Journal of Logistics Systems and Management*, Vol. 19, No. 1, p.20, <https://doi.org/10.1504/IJLSM.2014.064029>.
- Environmental Statistics* (2024) 11 June [online] <https://www.psa.gov.qa/en/statistics1/pages/topicslisting.aspx?parent=Environmental&child=EnvironmentalStatistics> (accessed 11 June 2024).
- Feng, Y., Hong, Z., Tian, G., Li, Z., Tan, J. and Hu, H. (2018) 'Environmentally friendly MCDM of reliability-based product optimisation combining DEMATEL-based ANP, interval uncertainty and Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR)', *Information Sciences*, pp.442–443, pp.128–144, <https://doi.org/10.1016/j.ins.2018.02.038>.
- Ferrer, G. (1997) 'The economics of tire remanufacturing', *Resources, Conservation and Recycling*, Vol. 19, No. 4, pp.221–255, [https://doi.org/10.1016/S0921-3449\(96\)01181-0](https://doi.org/10.1016/S0921-3449(96)01181-0).
- Han, B., Kumar, D., Pei, Y., Norton, M., Adams, S.D., Khoo, S.Y. and Kouzani, A.Z. (2024) 'Sustainable transformation of end-of-life tyres into value-added products using thermochemical processes', *Carbon Research*, Vol. 3, No. 1, p.73, <https://doi.org/10.1007/s44246-024-00167-4>.
- Houbao, H., Qiang, C. and Junjun, L. (2022) 'Analysis of the driving factors of the extended producer responsibility system in China's tire industry', *Mathematical Problems in Engineering*, pp.1–13, <https://doi.org/10.1155/2022/4327074>.
- Hsieh, H-H., Yao, K-C., Wang, C-H., Chen, C-H. and Huang, S-H. (2024) 'Using a circular economy and supply chain as a framework for remanufactured products in the rubber recycling industry', *Sustainability*, Vol. 16, No. 7, p.2824, <https://doi.org/10.3390/su16072824>.
- Hu, H., Liu, J., Zhu, Q. and Chen, Q. (2021) 'An integrated supply chain management system for end-of-life tires in China and its promotion barriers: a stakeholder perspective', *Resources, Conservation and Recycling*, Vol. 164, p.105214, <https://doi.org/10.1016/j.resconrec.2020.105214>.
- Johnson, M.R. and Wang, M.H. (1998) 'Economical evaluation of disassembly operations for recycling, remanufacturing and reuse', *International Journal of Production Research*, Vol. 36, No. 12, pp.3227–3252, <https://doi.org/10.1080/002075498192049>.
- Karger-Kocsis, J., Mészáros, L. and Bárány, T. (2013) 'Ground tyre rubber (GTR) in thermoplastics, thermosets, and rubbers', *Journal of Materials Science*, Vol. 48, No. 1, pp.1–38, <https://doi.org/10.1007/s10853-012-6564-2>.
- Kole, P.J., Löhr, A.J., Van Bellegghem, F. and Ragas, A. (2017) 'Wear and tear of tyres: a stealthy source of microplastics in the environment', *International Journal of Environmental Research and Public Health*, Vol. 14, No. 10, p.1265, <https://doi.org/10.3390/ijerph14101265>.
- Leong, S-Y., Lee, S-Y., Koh, T-Y. and Ang, D.T-C. (2023) '4R of rubber waste management: current and outlook', *Journal of Material Cycles and Waste Management*, Vol. 25, No. 1, pp.37–51, <https://doi.org/10.1007/s10163-022-01554-y>.
- Manupati, V.K., Kulatunga, A.K., Ray, P. and Rofin, T.M. (2024) 'Sustainable management of EOL tyres: a remanufacturing supply chain network design', *Journal of Cleaner Production*, Vol. 434, p.140115, <https://doi.org/10.1016/j.jclepro.2023.140115>.

- Mashiri, M.S., Vinod, J.S., Sheikh, M.N. and Tsang, H-H. (2015) 'Shear strength and dilatancy behaviour of sand-tyre chip mixtures', *Soils and Foundations*, Vol. 55, No. 3, pp.517–528, <https://doi.org/10.1016/j.sandf.2015.04.004>.
- Narra, M-M., Agboka, K., Narra, S. and Nelles, M. (2025) 'Implementing extended producer responsibility for tyre waste in Togo: a circular economy perspective', *Frontiers in Sustainability*, p.6, <https://doi.org/10.3389/frsus.2025.1631139>.
- Niza, S., Santos, E., Costa, I., Ribeiro, P. and Ferrão, P. (2014) 'Extended producer responsibility policy in Portugal: a strategy towards improving waste management performance', *Journal of Cleaner Production*, Vol. 64, pp.277–287, <https://doi.org/10.1016/j.jclepro.2013.07.037>.
- Nowaczek, A., Kowalski, Z., Kulczycka, J. and Makara, A. (2025) 'Ecological innovations supporting sustainable development: the case of the Polish tire industry', *Sustainability*, Vol. 17, No. 16, p.7210, <https://doi.org/10.3390/su17167210>.
- Oikonomou, N. and Mavridou, S. (2009) 'The use of waste tyre rubber in civil engineering works', in *Sustainability of Construction Materials*, pp.213–238, Elsevier, <https://doi.org/10.1533/9781845695842.213>.
- Park, J., Díaz-Posada, N. and Mejía-Dugand, S. (2018) 'Challenges in implementing the extended producer responsibility in an emerging economy: the end-of-life tire management in Colombia', *Journal of Cleaner Production*, Vol. 189, pp.754–762, <https://doi.org/10.1016/j.jclepro.2018.04.058>.
- Ratsimandresy, A. and Miemczyk, J. (2024) 'Facilitating the circular economy: insights from novel supply network actors', *Supply Chain Management: An International Journal*, Vol. 29, No. 5, pp.852–870, <https://doi.org/10.1108/SCM-01-2024-0067>.
- Shieh, J-I., Wu, H-H. and Huang, K-K. (2010) 'A DEMATEL method in identifying key success factors of hospital service quality', *Knowledge-Based Systems*, Vol. 23, No. 3, pp.277–282, <https://doi.org/10.1016/j.knosys.2010.01.013>.
- Sienkiewicz, M., Kucinska-Lipka, J., Janik, H. and Balas, A. (2012) 'Progress in used tyres management in the European Union: a review', *Waste Management*, Vol. 32, No. 10, pp.1742–1751, <https://doi.org/10.1016/j.wasman.2012.05.010>.
- Sinkhonde, D. and Bezabih, T. (2024) 'On the computational evaluation of carbon dioxide emissions of concrete mixes incorporating waste materials: a strength-based approach', *Cleaner Waste Systems*, Vol. 8, p.100149, <https://doi.org/10.1016/j.clwas.2024.100149>.
- Sudan, N., Singh, A., Bhat, C.G. and Biligiri, K.P. (2025) 'Lifecycle assessment of end-of-life tire recycling through pathways of transitioning the recycling industry to renewable energy sources', *Resources, Conservation and Recycling*, Vol. 216, p.108169, <https://doi.org/10.1016/j.resconrec.2025.108169>.
- THE 17 GOALS (n.d.) [online] <https://www.globalgoals.org/goals/> (accessed 3 August 2024).
- Torretta, V., Rada, E.C., Ragazzi, M., Trulli, E., Istrate, I.A. and Cioca, L.I. (2015) 'Treatment and disposal of tyres: Two EU approaches. A review', *Waste Management*, Vol. 45, pp.152–160, <https://doi.org/10.1016/j.wasman.2015.04.018>.
- Zhu, Q., Chen, G. and Xu, X. (2026) 'Circular supply chain innovation in China's tire reutilisation: digital technological and social facilitators for enhancing resilience and efficiency', *Technovation*, Vol. 152, p.103489, <https://doi.org/10.1016/j.technovation.2026.103489>.

Appendix

Table A1 The direct-relation matrix of criteria by expert 1

<i>Criteria</i>	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>
C1	0	3	1	2	3	1
C2	3	0	0	2	3	0
C3	0	0	0	3	0	0
C4	2	1	1	0	0	3
C5	1	0	0	1	0	3
C6	3	0	0	0	3	0

Notes: '0 = no influence', '1 = low influence', '2 = medium influence' and '3 = high influence'

Table A2 The direct-relation matrix of criteria by expert 2

<i>Criteria</i>	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>
C1	0	3	0	1	1	1
C2	1	0	0	1	1	1
C3	1	0	0	3	1	1
C4	2	0	0	0	2	3
C5	1	0	0	0	0	2
C6	0	0	0	2	2	0

Notes: '0 = no influence', '1 = low influence', '2 = medium influence' and '3 = high influence'

Table A3 The direct-relation matrix of criteria by expert 3

<i>Criteria</i>	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>
C1	0	2	2	3	3	0
C2	3	0	1	2	2	0
C3	1	2	0	0	0	0
C4	2	2	2	0	3	2
C5	0	3	0	1	0	2
C6	0	0	0	2	1	0

Notes: '0 = no influence', '1 = low influence', '2 = medium influence' and '3 = high influence'

Table A4 The direct-relation matrix of criteria by expert 4

<i>Criteria</i>	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>
C1	0	2	3	1	3	0
C2	1	0	0	2	3	2
C3	2	2	0	3	1	1
C4	2	1	3	0	1	2
C5	2	1	1	2	0	3
C6	3	1	1	3	2	0

Notes: '0 = no influence', '1 = low influence', '2 = medium influence' and '3 = high influence'