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Enhancing Tire Recycling Supply Chains for Sustainable Waste Management: Insights from a Data-Driven Optimization Study

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Abstract

End-of-life (EoL) tires present significant environmental and economic challenges due to improper disposal and inefficient recycling networks. Additionally, stockpiling them in landfills results in lost economic and social opportunities. To address these issues, a data-driven operations research methodology was employed, focusing on the case of Qatar. This approach led to the development of a Mixed-Integer Linear Programming (MILP) model designed to optimize the EoL tire recycling supply chains. The model aims to achieve sustainable waste management by minimizing overall costs, reducing landfill overstock, and maintaining a consistent flow of materials to recycling enterprises. The results indicate that a buffer landfill may be necessary when the supply chain prioritizes recycling methods that produce high-return-value products. Furthermore, the findings suggest potential for either expanding demand at existing recycling factories or establishing new enterprises to create higher-value products from EoL tires. The study also provides managerial insights, including reshaping the supply chain network and encouraging factories to adopt advanced recycling technologies, to enhance overall efficiency and sustainability.

Keywords
End-of-Life Tire; Recycling Supply Chains; Mixed-Integer Linear Programming; Waste Management; Sustainability.

1. Introduction
End-of-life (EoL) tires, whether disposed of in legal or illegal dump sites, pose a significant threat due to the risk of uncontrollable fires that release harmful toxins like zinc and chlorine into the environment. Additionally, they contribute to the production of microplastics, which contaminate waterways and oceans, jeopardizing marine ecosystems. As highlighted by Kole et al. (2017), tires are responsible for approximately 10% of the total microplastic pollution in the world's oceans.

For over 150 years, rubber has been a mostly overlooked yet significant factor in shaping global political and environmental history (Charles C. Mann, 2015). Over 40 percent of the world's rubber comes from trees. Although synthetic rubber is typically less expensive to produce than natural rubber, it is also less durable. A lower-grade alternative is reclaimed rubber, obtained from scrap tires often found in landfills. This variation in quality is crucial for manufacturers, so to balance cost.

Recycling tires accumulated in landfills supports several United Nations Sustainable Development Goals (SDGs) (*THE 17 GOALS*, n.d.) by fostering economic growth, particularly in developing countries, through material repurposing and industry diversification (Target 9.3). It mitigates environmental and health risks, such as pollution and contamination, contributing to cleaner communities and more resilient infrastructure (Targets 9.6, 3.9, and 12.4). By emphasizing recycling and reuse, such as using recycled tires in civil engineering or as industrial fuel, a circular economy is promoted (Target 12.5). Additionally, innovations like rubberized asphalt improve infrastructure durability and climate resilience, addressing challenges like extreme weather and temperature fluctuations (Target 13.1).

Therefore, managing the stockpile of tires in landfills is anticipated to yield significant environmental and economic benefits. Despite advancements in tire recycling, some countries continue to struggle with managing or recycling the tires accumulated in their landfills. According to (Hu et al., 2021), China faces significant challenges with massive tire stockpiles, with approximately 14 million tons sitting in landfills, only half of which are utilized, while the volume grows at an annual rate of 8%. This issue is further exacerbated by the absence of a comprehensive management system and numerous logistical barriers.

The objective of this study is to investigate the flow of tires—from suppliers, through landfills, and ultimately to recycling factories—using a Mixed Integer Linear Programming (MILP) model. The study adopts the perspective of the municipality, aiming to streamline processes for recycling enterprises and enable them to produce end products at the lowest possible cost and emissions. The experimental study will rely on a case study conducted in Qatar, which serves as an exemplary reference due to its successful model for recycling and eliminating large stockpiles of tires from two major landfills. These efforts are implemented through various recycled materials, such as cutting EoL tires into three pieces for burning, shredding materials, producing chips, rubber granules, rubber powder, and reclaimed rubber, among others. These initiatives align with Qatar's Vision 2030, demonstrating the country's commitment to sustainable waste management. However, this study examines whether overstock may persist if the focus of recycling efforts shifts toward producing higher-value recycled materials (compared to simple shredding or cutting tires into three pieces). Specifically, the study considers how four factories with different demand profiles could produce higher-value products—such as retreaded tires, reclaimed rubber, rubber mats, rubber powder, or rubber granules—while minimizing reliance on simply cutting tires into shredded parts.

2. Literature Review

Each year, approximately one million tons of tire material are discarded globally. Conventional disposal methods such as burning, stockpiling, and landfilling have been shown to pose significant risks, causing adverse effects on human health, the environment, and ecological systems (Yadav & Tiwari, 2019).

The global challenge of managing used tires has spurred significant efforts in remanufacturing and recycling to reduce waste and maximize resource efficiency. For instance, producing new tires requires four times more material and consumes three times the energy compared to retreaded tires (Tanzadeh & Haghighat, 2012). Consequently, Recovery methods such as retreading, rubber reclamation, and energy recovery play a crucial role in addressing this issue (Dobrotă & Dobrotă, 2018; Ferrer, 1997). However, overcoming the associated challenges demands collaboration among stakeholders, advancements in technology, and the implementation of supportive policies.

Therefore, in another study aligned with this one, we explored the success criteria for establishing a sustainable and efficient EoL tire supply chain in Qatar using DEMATEL. This study drew upon literature, stakeholder insights, and expert opinions from the private sector. It emphasized legislative and operational parameters to enhance service quality and identified key criteria for managing stockpiled tires in landfills, using a successful case study from Qatar as a reference. Evacuating two main landfills and identifying criteria of success sparked the initiative to start the current study, which is essential to maintain, monitor and insure flow of EoL tires within a specific network starting from end-users to recycling enterprises.

Effectively managing EoL tire networks is considered crucial, particularly when approached through a MILP model. Several studies have explored this issue from various perspectives, offering insights into optimizing such networks.

Dehghanian & Mansour (2009) proposed a model to optimize recovery network configurations, aiming to maximize profits, minimize environmental impacts, and enhance social benefits, with a particular focus on addressing challenges in less developed regions. Subulan et al. (2015) developed a multi-configuration logistics network incorporating environmental considerations using the Eco-indicator 99 index. Similarly, Ghasemzadeh et al. (2021), simultaneously minimizes environmental impacts using the Eco-indicator 99 and maximizes profit while considering multi-echelon, multi-product, and multi-period scenarios. However, Demand and supplier quantities are treated as uncertain parameters, modeled through a two-stage stochastic programming approach

Pedram et al. (2017) optimize network design, considering uncertainties in demand and the quality of returned products. Its primary objectives are to maximize profit, minimize environmental impacts, and provide a decision-support tool for facility location, capacity determination, and material flow management. Fathollahi-Fard et al. (2018) proposed a tri-level programming model for designing a tire closed-loop supply chain (CLSC), integrating forward and reverse logistics. The model addresses location-allocation decisions for manufacturers, distributors, and collectors, aiming to optimize economic, environmental, and operational objectives. Moreover, a model by Ebrahimi (2018) integrated forward and reverse logistics while addressing supplier selection, location-allocation, and routing problems under uncertainty. It incorporates three key objectives: minimizing total costs, reducing environmental emissions, and maximizing network responsiveness. Both demand and supplier quantities are modeled as uncertain parameters, using a scenario-based stochastic programming approach.

Another model done by (Kiani Mavi et al., 2023), simultaneously considered economic, environmental, and operational objectives, such as minimizing costs, reducing emissions, and enhancing sustainability demand and supplier quantities, are treated as deterministic. The proposed framework aims to provide a comprehensive decision-making tool for facility location, material flow management, and overall network design, highlighting its potential for improving sustainability in tire supply chain systems.

In contrast to previous studies, this research introduces a multi-objective MILP model designed to manage the flow of EoL tires from suppliers (in this context, end-users) to recycling enterprises. The model's network closely mirrors a real-world case study in Qatar, where suppliers are responsible for covering transportation costs to landfills, while recycling factories bear the transportation costs from landfills to their facilities. However, the model does not determine the maximum hazardous risk quantities, as these may vary across countries. Developed from a management and organizational perspective, the model serves as a practical tool to assist decision-makers in identifying optimal landfill locations. By minimizing transportation costs, the model also helps reduce associated emissions, aligning economic and environmental objectives effectively (Table 1).

Table 1. List of previous studies considering supply chain network of Eol tires

Study	Cap.	Obj.	D/S Parameter	SCNT	Focus
Dehghanian & Mansour (2009)	ML	M	D: Deterministic	Reverse	Min. environmental impact + Max. economic and social benefits
Subulan et al. (2015)	ML	M	D: Deterministic	CLSC	Min. environnemental impact + Max. total profit
Pedram et al. (2017)	SL	S	D: Non-deterministic	CLSC	Max. total profit + strategic decision-making assistance
Ebrahimi (2018)	SL	M	D/S: Non-deterministic	CLSC	Min. overall cost and environmental impact + Max. Responsiveness
Fathollahi-Fard et al. (2018)	SL	M	D: Deterministic	CLSC	Optimizing location allocation + Hierarchical Decision Optimization
Ghasemzadeh et al. (2021)	SL	M	D/S: Non-deterministic	CLSC	Max. profit + Min. Environnemental impact
Kiani Mavi et al. (2023)	SL	M	D: Deterministic	CLSC	Min. overall cost and environmental impact
This study	SL	M	S: Non-deterministic	Forward	Minimize overall cost + determining landfill overstock

ML: Multi-Level; SL: Single-Level; M: Multi; S: Single D: Demanded quantities; S: Supplied quantities; SCNT: Supply Chain Network Type; CLSC: Closed-Loop Supply Chain; Cap: Capacity; Obj: Objective.

3. Problem Description

The supply chain network for EoL tires is illustrated in Figure 1. The configuration of the actual supply chain system for EoL tires in Qatar. It operates as a forward network where end-users (consumers), acting as suppliers, accumulate scrap tires in small quantities (truckloads). The municipalities are responsible for covering the transportation costs from the suppliers' locations to the designated landfills. These landfills are strategically planned for opening based on the model. The second segment of the network involves recycling enterprises, which collect EoL tires from the landfills and transport them to their facilities for processing. The model aims to determine the optimal locations for establishing large or medium-sized landfills, minimizing transportation costs, which are directly proportional to the distance traveled.

The model is considered to be open-loop at a high level, as it does not account for the recycling, reuse, or retreading processes that occur within the enterprises or recycling facilities. Instead, the model's scope ends at fulfilling a predetermined, real-life demand specified by each enterprise. This demand serves as the stopping point for the flow within the supply chain network, leaving downstream activities beyond the model's scope. Suppliers are located in diverse areas, resulting in varying transportation costs influenced by distances and logistical factors. The quantities supplied by each supplier also differ, introducing uncertainty into the supply chain. To address this uncertainty, the model accounts for multiple scenarios, each assigned a specific probability, to capture potential variations in supply quantities. Additionally, the model incorporates a constant parameter, min_utilization_ratio, set to 1 (default settings), this ensures that 100% of the supplier's capacity is utilized, promoting full commitment to available resources regardless of the uncertainties in supply.

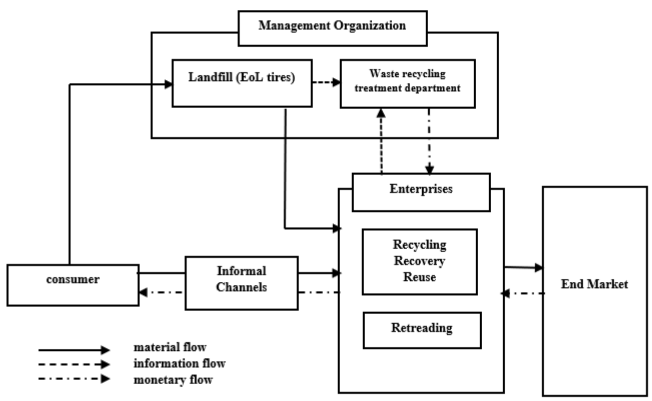

Figure 1. Management Pathways for End-of-Life Tires in Qatar

Demand, on the other hand, is treated as deterministic, as one of the primary objectives of this model is to evaluate whether the available scrap quantities (EoL) in the market can meet the required demand. Additionally, the model aims to strategically explore the feasibility of granting licenses to establish more recycling enterprises in the sector. This dual focus ensures a balance between optimizing current resources and planning for potential future expansions in recycling capacity. In the model, landfills function as cross-docking centers with no time delays Figure 2. The model does not account for specific time frames associated with transportation, processing, or demand fulfillment. Instead, all material flows are assumed to occur instantaneously or are aggregated over a predefined planning horizon, simplifying the temporal dynamics of the system.

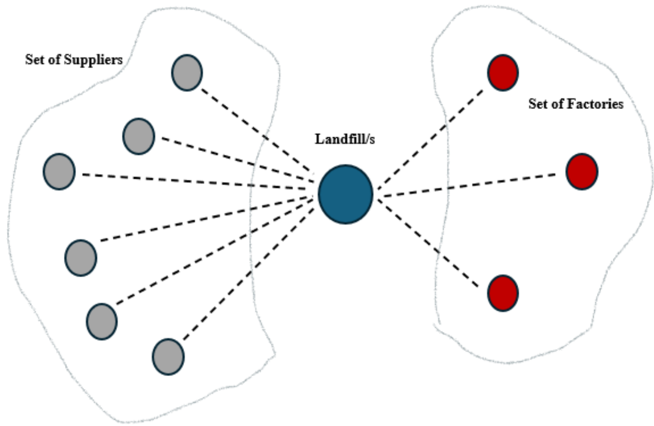

Figure 2. Linear Supply Chain Model for End-of-Life Tires in Qatar

The visual representation of the supply chain model can be seen in Figure 2. In Qatar, recycling factories are strategically centralized within a single district, commonly referred to as the Community of Factories (CoF). Consequently, the model will provide insights into the optimal location for landfills that align with the government's strategic needs. This centralized arrangement of recycling factories helps optimize the placement of landfills, reducing costs for suppliers delivering materials to the landfills and for recycling factories collecting materials from them.

Indexes and Sets

$i \in \{1, \ldots, n\}$	Index of suppliers;
$j \in \{1, \ldots, m\}$	Index of landfills;
$s \in \{1, \ldots, k\}$	Index of factories;
$\omega \in \{1, \ldots, \Omega\}$	Index of scenarios;

Parameters

p_ω	Probability of scenario ω;
min_demand_ratio	Minimum percentage of factory demand to be fulfilled (default = 1 or 100%);
min_utilization_ratio	Minimum percentage of supplier capacity to be utilized (default = 1 or 100%);
$SC_{\omega i}$	Capacity of supplier i in scenario ω;
$LFCl_j$	Capacity of a large landfill j;
$LFCm_j$	Capacity of a medium landfill j;
FLl_j	Fixed cost of opening a large landfill j;
FLm_j	Fixed cost of opening a medium landfill j;
$EFLl_j$	Equipment and traceability cost for a large landfill j;
$EFLm_j$	Equipment and traceability cost for a medium landfill j;
Tsl_{ij}	Transportation cost from supplier i to landfill j;
Tlf_{js}	Transportation cost from landfill j to factory s;
FD_s	Demand of factory s;

Variables

Xl_j	Binary variable, 1 if a large landfill j is opened;
Xm_j	Binary variable, 1 if a medium landfill j is opened;
$Qslf_{ij}$	Quantity transported from supplier i to landfill j;
$Qlff_{js}$	Quantity transported from landfill j to factory s;
$Overstock_j$	Overstock (unused tires) at landfill j;

3.1 Objective

The objective function (1), minimizes three priorities using weights α, β, and γ. The first term α minimizes total costs, including landfill fixed costs, equipment costs, and transportation costs from suppliers to landfills and landfills to factories. The second term β penalizes overstock at landfills, reducing inefficiency from unused resources. The third term γ minimizes the number of landfills opened, lowering infrastructure and operational complexity.

$$\alpha.\sum_{\omega}^{\Omega} p_{\omega}(\sum_{j=1}^{m} FLl_j.Xl_j + \sum_{j=1}^{m} FLm_j.Xm_j$$
$$+\sum_{j=1}^{m} EFLl_j.Xl_j + \sum_{j=1}^{m} EFLm_j.Xm_j$$
$$+\sum_{i=1}^{n}\sum_{j=1}^{m} Qslf_{ij}.Tsl_{ij}\sum_{j=1}^{m}\sum_{s=1}^{k} Qlff_{js}.Tlf_{js}) \quad (1)$$
$$+\beta.\sum_{j=1}^{m} Overstock_j + \gamma.(\sum_{j=1}^{m} Xl_j + \sum_{j=1}^{m} Xm_j)$$

3.2 Constraints

Supplier Capacity Constraints (for each scenario): constraint (2) ensures that each supplier's capacity is adequately utilized across all scenarios. For a given scenario ω, and supplier i, the total quantity of tires transported from that supplier to all landfills must be at least a certain percentage (min_utilization_ratio) of the supplier's capacity.

$$\sum_{j=1}^{m} Qslf_{ij} \geq min\_utilization\_ratio\ .SC_{\omega i}\ , \quad \forall\omega, \forall i \quad (2)$$

Landfill Capacity Constraints (for each scenario): constraint (3) ensures that the total quantity of tires delivered to each landfill does not exceed its capacity, based on the type of landfill built (large or medium) and the scenario being considered. For a given scenario ω, and landfill j, the total quantity transported from all suppliers to that landfill must be less than or equal to the landfill's capacity.

$$\sum_{i=1}^{n} Qslf_{ij} \leq LFCl_j.Xl_j + LFCm_j.Xm_j\ , \quad \forall\omega, \forall i \quad (3)$$

Factory Demand Constraints (partial fulfillment allowed): constraint (4) ensures that the factories receive at least the required proportion of their demand from all landfills. For each factory s, the total quantity of tires transported from all landfills to that factory must meet or exceed a specified percentage (min_demand_ratio) of the factory's demand.

$$\sum_{j=1}^{m} Qlff_{js} \geq min\_demand\_ratio\ .FD_s\ , \quad \forall s \quad (4)$$

Flow Balance Constraints (at each landfill): constraint (5) ensures that the total quantity of tires transported into each landfill equals or exceeds the total quantity transported out of that landfill to factories. For each landfill j, the inflow of tires from all suppliers must be greater than or equal to the outflow of tires to all factories.

$$\sum_{i=1}^{n} Qslf_{ij} \geq \sum_{s=1}^{k} Qlff_{js}\ , \quad \forall j \quad (5)$$

Minimum Number of Landfills: constraint (6) ensures that at least two landfills are opened in the solution, whether large or medium. The total number of landfills opened is determined by the binary decision variables Xl_j (for large landfills) and Xm_j (for medium landfills). The sum of these variables across all landfills must equal at least 2.

$$\sum_{j=1}^{m} Xl_j + \sum_{j=1}^{m} Xm_j = 2 \tag{6}$$

Overstock Definition: equation (7) to define the overstock at each landfill as the difference between the total inflow of tires from suppliers and the total outflow of tires to factories.

$$Overstock_j = \sum_{i=1}^{n} Qslf_{ij} - \sum_{s=1}^{k} Qlff_{js} , \quad \forall j \tag{7}$$

$$Xl_j, Xm_j \in \{0,1\} \tag{8}$$

$$Qslf_{ij}, Qlff_{js}, Overstock_j \in \mathbb{Z}_+ \tag{9}$$

4. Results and Discussions

As previously explained, the quantities supplied are stochastic, varying on a weekly basis from nine main supplier locations. To address these uncertainties, a scenario-based approach has been employed. Using weekly data, we generated a set of scenarios representing the quantities supplied to the landfills. Specifically, k-means clustering was applied to create 10 distinct scenarios, each assigned a corresponding probability. Four primary locations have been selected for consideration in the strategic-level study. These locations were determined by dividing Qatar's map into four quadrants. Location 4 is the closest to the CoF, therefore, the positioning of the factories creates a center of gravity that favors selecting location 4, which explains the considerable amount of quantities passing through location 4 as shown in Table 2 and Table 3. However, Landfill 2 is opened as a medium landfill to strike a balance between cost minimization, system requirements, and handling overstock. The quantities supplied to this landfill suggest that it is more cost-effective for nearby suppliers to transport their waste here compared to other locations. Additionally, under certain scenarios, Landfill 2 plays a crucial role in meeting capacity requirements and ensuring the system's adaptability to potential supply variations.

Table 2. Material flow (MT) from suppliers through medium- or large-size landfills at four different geographic locations

Landfill operation status (active=1/inactive=0)				
	1	**2**	**3**	**4**
Xl_j **(large)**	0	0	0	1
Xm_j **(medium)**	0	1	0	0
Quantities supplied from different nine supplier locations through previously activated landfills in metric ton (MT)				
S1	0	11213	0	0
S2	0	0	0	5649
S3	0	0	0	188925
S4	0	0	0	33553
S5	0	0	0	13995
S6	0	18379	0	0
S7	0	0	0	7251
S8	0	0	0	1096
S9	0	7841	0	0

Table 3. Flow of material from landfills to factories (MT)

Landfills	Factories**			
	1	**2**	**3**	**4**
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	7441*	7441	146165	4872

*Material flow through large landfill Xl_4 in location 4 to factory in other location 1.
**Factories' locations (1,2,3,4) are different from landfills' locations (1,2,3,4).

Table 4. Overstock quantity at each active landfill (MT)

	Landfill location			
	1	**2**	**3**	**4**
Overstock	0	37433*	0	84550**

*Amount of excess quantity in medium landfill Xm_2.
**Amount of excess quantity in large landfill Xl_4.

Table 3 and Table 4, providing valuable insights. no material is transported from Landfill 2 to factories, indicating that Landfill 2 functions exclusively as a buffer or temporary storage facility. Landfill 2 serves as a strategic buffer to enhance system resilience, ensuring capacity for future demand fluctuations, regulatory changes, or disruptions. While current material flow does not utilize it, maintaining this spare capacity aligns with real-world waste management practices that prioritize redundancy and long-term planning. Its inclusion strengthens the model's adaptability to uncertainty, supporting Qatar's sustainability goals without immediate operational inefficiency.

As discussed, Qatar has previously cleared two major landfills by implementing various tire recycling strategies. These strategies included cutting tires and shredding them into pieces ranging from 10 mm to over 300 mm. However, when recycling efforts shifted to focus on entities producing higher-value, sustainable products with greater return value—such as retreading—it became evident that tire accumulation could occur. This highlights the potential challenge of balancing high-value product production with efficient tire recycling to avoid stockpiling.

5. Managerial Implications

5.1 Balancing High-Value Production and Waste Reduction

Focusing on high-value products, such as retreading, reclaimed rubber, rubber mats, rubber products, and rubber powder, aligns with sustainability goals and offers higher return value. However, this approach may result in tire accumulation if production capacity or market demand for these products is insufficient. To address this, diversifying recycling strategies—by maintaining a balance between shredding for rapid waste reduction and high-value production for long-term sustainability—can help prevent bottlenecks in waste processing and ensure a more efficient and adaptable recycling system. Another solution could involve government support for new recycling projects, ensuring they are sustained as long as raw materials remain available.

5.2 Supporting Recycling Factories

Facilitating access to advanced technologies involves enabling the adoption of state-of-the-art recycling solutions such as automated sorting, pyrolysis, and chemical recycling. These technologies can significantly enhance the processing capacities of factories by improving operational efficiency, optimizing material recovery, and supporting the production of high-value recycled products. Also, by offering subsidies or tax incentives to factories that invest in advanced recycling technologies and higher-capacity production systems.

5.3 Reshaping the Supply Chain

Reshaping the supply chain by introducing smaller collection stations before landfills can help address EoL tire management challenges. Municipalities, instead of suppliers, would bear transportation costs from these stations to landfills, increasing supplier satisfaction. These stations would also act as buffers, slowing the flow to landfills and giving recycling factories more time to process materials, reducing overstock and improving efficiency.

6. Limitations And Future Research

The model did not account for variability in demand. Developing a dynamic waste management network that adapts to changing demand conditions will help giving insights about how overstock will be affected. Also, Including closed-loop supply chain will give better understanding of the situation in Qatar. By including CLSC, the analysis could track products and materials throughout their lifecycle, considering: Collection of EoL products from consumers, Processing and reintroducing recycled materials back into production, and reduction of waste through material reuse. Moreover, while the model penalizes overstock, it does not directly incorporate environmental impacts, such as emissions from transportation or the ecological footprint of landfills. This could limit its alignment with sustainability goals.

The model is static and does not account for specific time frames or the delays associated with waste processing, such as those occurring at landfills. These delays may arise from activities like unloading, sorting, processing, or temporary storage. The lack of time-based considerations can result in overly optimistic assumptions about landfill capacity utilization and the efficiency of waste flow management. Moreover, the model assumes a 100% utilization rate of the materials supplied. While this simplifies analysis, conducting a sensitivity analysis on varying utilization rates could provide valuable insights into the model's flexibility and robustness under different supply conditions.

As illustrated in Figure 1, the current supply chain for EoL tires in Qatar includes certain informal channels that enable tires to bypass formal landfills, which match findings done by Hu et al. (2021). This results in a lack of traceability and imposes additional costs on factories, as these informal entities often monopolize the supply, driving up prices. To enhance the accuracy and practicality of the mathematical model, future iterations should incorporate these costs and explore strategies to mitigate this phenomenon, such as introducing stricter regulations, incentivizing formal channels, or integrating penalties for using informal networks.

6. Conclusion

This study introduces a MILP model to optimize EoL tire supply chain, focusing on sustainability and economic efficiency. By strategically locating landfills, the model minimizes overstock and enhances material flow. Using Qatar as a case study, the research emphasizes the need to balance high-value recycling processes with rapid waste reduction strategies or the establishment of factories capable of producing higher-value tire-derived products to prevent landfill accumulation. Future research should explore dynamic demand conditions, environmental impact assessments, and closed-loop supply chain frameworks to improve the model's applicability and alignment with sustainability goals.

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Biographies

Abdullah Riad is a PMP-certified and a PhD student at Hamad Bin Khalifa University (HBKU), where he also earned his master’s degree. His academic and professional pursuits are centered around two key areas: robotic surgery and sustainable supply chain management for scrap materials. Alongside his PhD studies, Abdullah serves as the Deputy Manager at Bright Future Tyre Recycling Factory, where he oversees logistics systems and production operations.

Majed Hadid is a researcher and instructor in Engineering Management and Decision Science. He holds a Ph.D. in Logistics and Supply Chain Management from the Engineering Management and Decision Science Division at Hamad Bin Khalifa University, Doha, Qatar, and an M.Sc. degree in Engineering Management from Qatar University. Majed's research focuses on improving service operations and supply chain networks using simulation and optimization as well as data analytics approaches. His work has been published in leading international journals and conferences in the fields of operations research and supply chain management. He is also a postdoctoral fellow actively involved in teaching and mentoring students for various courses and projects in the Division of Engineering Management and Decision Science at Hamad Bin Khalifa University.

Regina Padmanabhan is a researcher specializing in the intersection of artificial intelligence, mathematical modeling, and its application in healthcare, logistics, and supply chain management. With a Ph.D. in Electrical Engineering, her expertise lies in developing innovative solutions for real-time problems using cutting-edge methods such as reinforcement learning and machine learning. With over 10 years of research experience, she has demonstrated exceptional proficiency in study design, data interpretation, and evidence-based decision-making, resulting in numerous international publications. Additionally, she has 5 years of teaching and mentoring experience. Currently, Dr. Padmanabhan serves as a postdoctoral fellow in the Division of Engineering Management and Decision Science at Hamad Bin Khalifa University.

Mohammed Matar holds a Master’s degree from Qatar University, with a primary focus on sustainability. During his graduate studies, he conducted research to investigate the impact of varying sawdust content on the mechanical properties of whole tire reclaimed rubber. His work aimed to determine whether this innovative reclaimed rubber composite could meet the stringent requirements of industry standards. Through his research, Mr. Mohammed sought to contribute to sustainable material development by exploring eco-friendly alternatives within the rubber industry. In parallel he is the general manager of Bright Future Tyre Recycling Factory.

Adel Elomri is an Associate Professor of Logistics and Supply Chain Management at Hamad Bin Khalifa University's College of Science and Engineering. He holds a Ph.D. and MSc in Operations Management from CentraleSupélec Paris and a BSc in Industrial Engineering from the National Engineering School of Tunisia. With over 15 years of international experience in lecturing and research, Elomri specializes in modeling and analyzing supply chain networks, including healthcare operations management, sustainable supply chain management, smart logistics, and production and operations management.

Laoucine Kerbache is full Professor of Logistics and Supply Chain Management and a founding member of the Engineering Management and Decisions Science (EMDS) Division within the College of Sciences and Engineering (CSE, HBKU) since 2018. In addition, over the last 35 years, Dr. Kerbache has been in academia (teaching and research) with 24 years at HEC Paris where he was full Professor of Operations management, Logistics, and Supply Chain Management. While at HEC Paris, he held various academic and managerial positions including Associate Dean in charge of the HEC Paris PhD Program (during 5 years), Dean and CEO of HEC Paris in Qatar, in addition to other academic positions. He holds a Ph.D., an MSc. and a BSc. degrees in Industrial Engineering and Operations Research from the University of Massachusetts at Amherst (USA). His research areas span interfaces of industrial engineering, operations research, operations management, logistics and supply chain management with a special focus on modelling and optimization of problems relative to industrial facilities and service organizations. He is active member of numerous professional organizations such as INFORMS, POMS, EUROMA, IEOM, etc.