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Advanced Optimization of Energy production Distribution System Integrated with Sustainable Supply Chain Networks

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Abstract

This study establishes a Mixed Integer Linear Programming (MILP) formulation that endeavors to streamline the integration of the supply chain with the master power network and, in particular, seeks to generate, manage, and disseminate products through the supply chain. The objective function will be to minimize the cost of the network, which comprises the fixed and variable expenses of the supply chain and its coordination with the main power network. Moreover, the model integrates occupational damage costs, the economic value of providing job opportunities, and emissions, considering the effects of carbon tax policies. The findings state that the selected carbon taxation policy has a direct effect on the overall cost structure and operational planning in the network, highlighting the role of policy issues in pursuing cost-effective and sustainable supply chain integration.

Keywords: Supply chain, Sustainable supply chain, Energy systems, Carbon emission, Optimization, Deterministic method, Mixed integer linear programming.

1 | Introduction

Supply chain networks have received significant attention over the last few years owing to their pivotal role in global operations. Meanwhile, the issue of global warming and climate change has become a priority for the international community. The lofty spike in energy demand, specifically during the Covid-19 pandemic, has reinforced energy expenses, making a steady energy supply a significant driver of effective supply chain management, more so during crisis periods. Accordingly, the design of supply chain networks that address power supply aspects has emerged as a critical but challenging task, as formulating optimal and feasible

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solutions by no means is an easy undertaking. To overcome this difficulty, optimization techniques have been instrumental in helping research in this field move forward. One of the main challenges in supply chain design relates to possible disruptions due to delays or supply shortages in providing energy, which can significantly influence operational effectiveness. Therefore, a supply chain should be designed with resilience and be able to withstand such disruptions.

Simultaneously, energy production and consumption continue to be the largest contributors to global carbon emissions, challenging sustainability greatly. Particularly, electricity is the second most used energy source in industry, with its consumption forecasted to increase steadily through 2040. This highlights the requirement to reconcile energy security with environmental and societal concerns while simultaneously managing economic limitations. This research aims to answer the inquiry as to how to combine supply chains and traditional grid electricity considering environmental, social, and economic concerns. The problem transcends developing and developed countries and presents itself as an international issue because the utilization of electricity needs to concurrently provide environmental gains and create energy security. To address this issue, we formulate a Mixed Integer Linear Programming (MILP) model with the aim of minimizing the overall system cost. The objective function includes costs associated with facility operation and establishment, material and product processing and transportation, occupational accidents, employment, and emissions. By addressing these complex issues, this study aims to contribute towards the development of sustainable and **2.**

2 | Literature Review

Sustainable supply chains are a topic that has attracted widespread attention among the researchers. Previous studies highlighted supply chain network design using several methodologies, including single-objective optimization [1], multi-objective frameworks [1], and multi-level decision-making models [2]. Effectiveness evaluation and comparative studies were also done to show how they are different from each other [3] Other studies include the formulations of deterministic MILP models to optimize performance in the supply chain by [4] and [5].

Sustainable supply chain design expands beyond cost and efficiency to major concerns like health and safety risks-both physical and psychological-incorporated with environmental impacts. The principles of sustainable supply chain management are about worker safety, human rights, and fair operations. According to [6], local employment providing housing and construction is sustainability, which further necessitates responsible practices benefiting society while reducing environmental harm. Through job creation as well as carbon emissions control and eco-friendly policies providing shapes to environmentally-responsible operations, sustainability strategies concern with supply chain networks [7].

Highlight resource maximization and waste reduction as very critical strategic initiatives in enhancing sustainability and competitiveness of closed-loop supply chain networks. For a complete appraisal of sustainability, the true definition demands careful assessment of environmental impact, economic profitability, and social responsibility[8]. explores hydrogen supply chains and their connection to the operation of renewable energy-powered electricity distribution networks.Regardless of the vast studies about environmental, economic, and social considerations of supply chain network design [9], to date, even less attention has been paid to energy supply and consumption. Existing literature has provided evidence on various connections linking economic development and growth with energy consumption and the corresponding rise in carbon dioxide emissions [10]. This nexus built the platform for the development of next-generation concepts that include energy efficiency production planning, driving economic advancement in balance with sustainable practices for energy consumption[11]. Develops a MILP model to integrate a supply chain with the main power grid, optimizing the production and distribution of the product throughout the supply chain. [12] Analyzed the impact of renewable energy on the power supply chain and compared the effectiveness of renewable generators versus power grid purchases from the spot market during energy shortages. In some fields, the energy considerations may be important enough to justify decisions on the use of closed-loop supply chains. Clearly, energy considerations deserve intertwined inclusion in supply chain management to stem voluminous greenhouse gas emissions from energy supply and consumption. These emissions have been appreciably labeled as prominent contributors to environmental degradation and climate change. Though power grids have been extensively studied and improved by researchers and professionals from the industry, we still find a significant gap in the literature about the integrating of such power grids into supply chain networks. The present study proposes to look at what can be considered for the optimal design of a supply chain that incorporates energy sourcing strategies while ensuring sustainability along with operational flexibility and economic viability with respect to carbon emissions.

3 | Problem Statement

The network structure analyzed in this study involves the coupling of two essential entities: the supply chain of the product and the primary power grid. The networks are interconnected, with the primary power grid supplying the power directly needed for the production and transportation processes that occur within the supply chain. As illustrated in *Fig. 1*, the principal power grid comprises a power generation facility that produces electricity, which is subsequently sent to each component of the product supply chain to satisfy manufacturing and logistics operations' energy requirements.

The supply chain framework is a standard logistics model with producers, wholesalers, and suppliers. The producer would arrange to have the raw materials brought in and transported to the factory for production. The manufacturer takes care of the creation of the product and then sends it to the distributor, who eventually supplies the final product to the consumer. Under this logistical system, various vital considerations are made, such as the total costs of the supply chain, the expenses involved in job creation, and the economic consequences related to work-related injuries.

In addition, the study has a carbon tax policy that seeks to maximize and reduce the carbon emissions generated in the process of manufacturing as well as transporting the product throughout the supply chain. The coupling of these networks is directed towards managing the issues of energy supply, cost reduction, and environmental sustainability, along with addressing social aspects like employment and occupational health. Through the application of optimization methods, this paper seeks to develop a model that is sustainable and balanced in nature, with minimum cost and emissions and maximum robustness and efficiency of the supply chain.

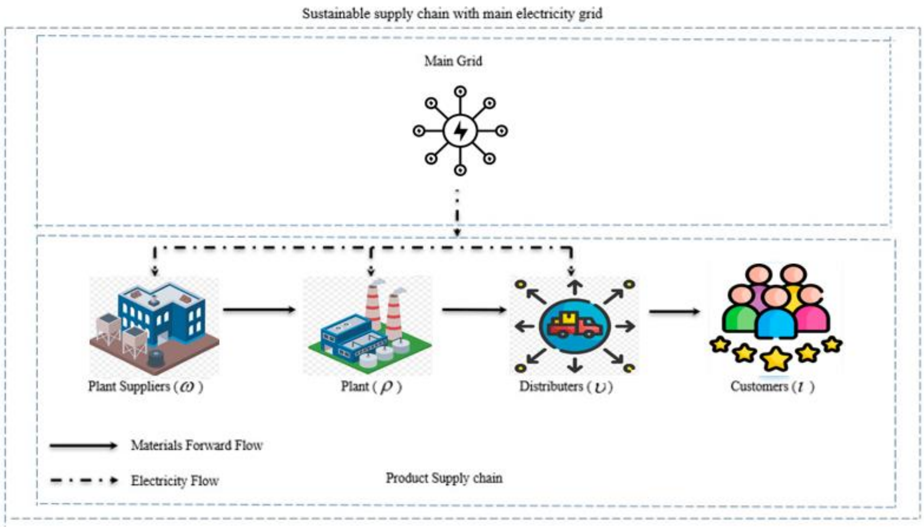

Fig. 1. The proposed network.

4| Problem Formulation

The model is then formulated through *Eqs.(1)-(22).*

$$Cost^{Total} = CostSC + JobOpportunity + WorkDamageSC. \tag{1}$$

Subject to:

$$\begin{aligned}CostSC = {} & C^{TAX}CO_2^{Emission} + \sum_{t} C^{MG} \sum_{i} MG_{it} + \sum_{\omega,t} Cost_{\omega t}^{Fix} J_{\omega} + \sum_{\rho,t} Cost_{\rho t}^{Fix} J_{\rho} + \sum_{\upsilon,t} Cost_{\upsilon t}^{Fix} J_{\upsilon} + \sum_{\omega,\rho,t} Cost_{\omega\rho t}^{Raw} \chi_{\omega\rho t} \\ & + \sum_{\rho,t} Cost_{\rho t}^{Prod} Pro_{\rho t} + \sum_{\omega,\rho,t} Cost_{\omega\rho t}^{Tra} \chi_{\omega\rho t} + \sum_{\rho,\upsilon,t} Cost_{\rho\upsilon t}^{Tra} \chi_{\rho\upsilon t} + \sum_{\upsilon,\iota,t} Cost_{\upsilon\iota t}^{CA} d_{\iota t}^{Product} J_{\upsilon\iota t}^{Market},\end{aligned} \tag{2}$$

$$JobOpportunitySC = Cost^{JobOpp} + \sum_{\omega,t} \zeta_{\omega t}^{Fix} J_{\omega} + \sum_{\rho,t} \zeta_{\rho o t}^{Fix} J_{\rho} + \sum_{\upsilon,t} \zeta_{\upsilon t}^{Fix} J_{\upsilon} + \zeta_{\rho t}^{Var} Pro_{\rho t} / C_{\rho t}^{Capacity} + \sum_{\upsilon,\rho,t} \zeta_{\upsilon t}^{Var} \chi_{\rho n t} / C_{\upsilon t}^{Capacity}, \tag{3}$$

$$WorkDamageSC = Cost^{WorkDam} + \sum_{\omega,t} cv_{vt}^{LD} J_{\omega} + \sum_{\rho,o,t} cv_{\rho t}^{LD} J_{\rho} + \sum_{\upsilon,t} cv_{\upsilon t}^{LD} J_{\upsilon t} + \sum_{\rho,o,t} v_{\rho t}^{LD} P_{\rho t} / C_{\rho t}^{Capacity} + \sum_{\rho,\upsilon,t} v_{\upsilon t}^{LD} \chi_{\rho\upsilon t} / C_{\upsilon t}^{Capacity}, \tag{4}$$

$$\sum_{it} MG_{it} = \sum_{\omega}\sum_{\rho} \chi_{\omega\rho t} E_{\omega t}^{Facility} + \sum_{\rho} Pro_{\rho t} E_{\rho t}^{Facility} + \sum_{\upsilon}\sum_{\rho} \chi_{\rho\upsilon t} E_{\upsilon t}^{Facility}, \quad \text{for all } t, \tag{5}$$

$$MG_{it} \geq E_{it}^{Facility} \vartheta, \quad \text{for all } i \in \{\omega, \rho, \upsilon\}, t, \tag{6}$$

$$MG_{it} \leq M\, \vartheta_i, \text{ for all } \; i \in \{\omega, \rho, \upsilon\}, t, \tag{7}$$

$$\sum_{\omega} \chi_{\omega\rho t} = \sum_{\upsilon} \chi_{\rho\upsilon t}, \quad \text{for all } \rho, t, \tag{8}$$

$$\sum_{\rho} \chi_{\rho\upsilon t} = \sum_{\iota} \chi_{\upsilon\iota t}, \text{ for all } \; \upsilon, t, \tag{9}$$

$$\sum_{\upsilon} \vartheta_{\upsilon\iota t}^{Market} = 1, \quad \text{for all } \iota, t, \tag{10}$$

$$\sum_{\omega} \chi_{\omega\rho t} = \sum_{t} Pro_{\rho t}, \quad \text{for all } \rho, t, \tag{11}$$

$$\sum_{\rho} \chi_{\omega\rho t} \leq C_{\omega t}^{Capacity} \vartheta_{\omega}, \quad \text{for all } \omega, t, \tag{12}$$

$$Pro_{\rho t} \leq C_{\rho t}^{Capacity} \vartheta_{\rho}, \quad \text{for all } \rho, t, \tag{13}$$

$$\sum_{\rho} \chi_{\rho\upsilon t} \leq C_{\upsilon t}^{Capacity} J_{\upsilon}, \quad \text{for all } \upsilon, t, \tag{14}$$

$$\sum_{\omega} \chi_{\omega\rho t} \geq \underline{C^{CapacityP}} \vartheta_{\rho}, \quad \text{for all } \rho, t, \tag{15}$$

$$\sum_{\rho} \vartheta_{\rho} \leq 1, \tag{16}$$

$$\sum_{\rho} \vartheta_{\rho} \leq A_{\rho}^{Available}, \tag{17}$$

$$\sum_{\omega} \vartheta_{\omega} + \sum_{\rho} \vartheta_{\rho} \leq A_{i}^{Available}, \tag{18}$$

$$\chi_{\upsilon\iota t} \geq \vartheta_{\upsilon\iota t}^{Market} d_{\iota t}^{Product}, \quad \text{for all } \upsilon, \iota, t, \tag{19}$$

$$CO_2^{\text{Emission}} = \sum_t \begin{pmatrix} \sum_{\omega} \varepsilon_{\omega t}^{\text{Facility}} \vartheta_{\omega} + \sum_{\rho} \varepsilon_{\rho t}^{\text{Facility}} \vartheta_{\rho} + \sum_{\upsilon} \varepsilon_{\upsilon t}^{\text{Facility}} \vartheta_{\upsilon} + \sum_{\omega,\rho} \varepsilon_{\omega\rho t}^{\text{Facility}} \chi_{\omega\rho t} \\ + \sum_{\rho} \varepsilon_{\rho t}^{\text{Facility}} Pro_{\rho t} + \sum_{\rho,\upsilon} \varepsilon_{\rho\upsilon t}^{\text{Facility}} \chi_{\rho\upsilon t} + \sum_{\upsilon,\tau} \varepsilon_{\upsilon\tau t}^{\text{Facility}} \chi_{\upsilon\tau t} \end{pmatrix}, \tag{20}$$

$$\chi_{ii't}, Pro_{\rho t}, MG_{it}, CO2_t^{Emission}, CO2^{\text{Tax}}, Cost^{Total} \geq 0, \quad \text{for all } i, i', t, , \upsilon, \rho, o, \omega, \tag{21}$$

$$\vartheta_i, \vartheta_{\upsilon\iota t}^{\text{Market}} \in \{0,1\}, \qquad \text{for all} \quad \omega, \rho, \upsilon, \iota, t, i. \tag{22}$$

The total cost function of the grid-connected product supply chain, illustrated in *Eq. (1)*, encompasses different varieties of costs, giving adequate weight to supply chain efficiency and economic viability of operation. Total cost structure comprises several operational and logistical costs, as clarified in *Eq. (2)*. *Eq. (3)* describes work damage costs inclusive of losses incurred through work injuries and lost productivity from interruptions to work flow in connection with equipment damage. On the other hand, the economic damages *Eq. (4)* quantifies lost production days that will be manufacturers and distributors due to damages on equipment and machinery. While *Eq. (5)* provides for an equilibrium in the supply and demand of electricity, the constraint goes a long way in ensuring that the quantity electricity supplied, mostly by the main grid, meets the total energy demand of the supply chain network. *Eq. (6)* protects an energy supply constraint in the network, so that there will be sufficient electricity distribution in all supply chain facilities, while *Eq. (7)* establishes a relationship with respect to resource consumption and the electricity consumption of the entities in the product supply chain.

Eq. (8) is used for the flow of materials, specifying input resources from suppliers to tenders and internalization to distributors from facilities. Demand versus production polynomial constraints for the given equations ensure periodic supply chain work without interruptions. In a sense, *Eq. (10)* actually governs particular distribution conditions whereby the demand of every market can be satisfied through just one direct distributive avenue. In *Eq. (11)*, so as to ensure congruence between the input of raw materials and output of production from the factory, factory production levels are balanced. Limitations for production capacity were given in the following *Eqs (12)-(14)*, there are thus defined capacity constraints related to plant production so that factory production occurs within the allowed capacity. *Eq. (15)* also sets a further stipulation that goods produced from every factory must be directly connected in one way or another to a single supplier for the quality of the goods produced and also for their operation in regard to the channeling of goods within the established chain of supply. The identification of a production facility is ruled then by *Constraint 16*, whereby there cannot be an identified factory producing a product other than one. Such constraints would allow for some additional flexibility in limiting the number of active production stations and help control the expansion of infrastructure and scalability of operations.

Constraint (16) mandates that at least one factory must be assigned for a single product. Additional constraints provided by *Constraints (17)* and *(18)* control further extension in the construction of new production locations and the scalability of their operations. *Eq. (19)* restricts the supply chain network design to the customer fulfillment time requirements; while *Eq. (20)* estimates the total carbon emissions produced in the supply chain network, which reflects environmental objectives in decision-making. Then *Eqs. (21)* and *(22)* provide definitions of the characteristics of the decision variables, differentuating between continuous and discrete variables typical in the optimization model. Taken together, these equations ensure that the mathematical model reflects real operational constraints, bringing an entire frame for the sustainable and cost-effective design of SCN.

5 | Numerical Example Representation and Results

5.1 | Numerical Example

In this section, the model of the proposed grid-connected sustainable supply chain network is confirmed, which includes $\varpi = 3$ plant suppliers, $\rho = 3$ production plants, $\upsilon = 2$ distribution centers, $\iota = 3$ customer zones, and the product will be sold to customers over four $t = 4$ periods.

Table 1. Summary of the input data.

Parameters	Unit	Parameters	Unit	Parameters	Unit
$C_{\varpi t}^{Capacity} = 800$	$1000kg$	$C^{WorkDam} = 100$	$	$10000 \le Cost_i^{Fix}\, i\{\omega, \upsilon\} \le 15000$	1000$
$C_{\rho t}^{Capacity} = 800$	$1000kg$	$0.3 \le Cost_{\upsilon\iota t}^{AS} \le 0.6$	1000kg/1000$	$25000 \le Cost_\rho^{Fix} \le 30000$	1000$
$C_{\upsilon t}^{Capacity} = 800$	$1000kg$	$0.10 \le c\varpi_{\rho t}^{LD} \le 0.15$	1000$	$0.5 \le Cost_{\omega\rho t}^{Raw} \le 0.8$	1000kg/1000$
$\underline{C^{CapacityP}} = 100$	-	$0.10 \le c\varpi_{it}^{LD}\, i \in \{\omega, \upsilon\} \le 0.15$	1000$	$0.5 \le Cost_{\rho t}^{Prod} \le 0.8$	1000kg/1000$
$C^{Tax} = 200$	$	$0.1 \le \varpi_{\rho t}^{LD} \le 0.3$	1000$	$0.1 \le Cost_{\omega\rho t}^{Tra} \le 0.5$	1000kg-km/1000$
$C^{MG} = 250$	$	$0.1 \le \varpi_{it}^{LD}\, i \in \{\omega, \upsilon\} \le 0.3$	1000$	$0.1 \le Cost_{\rho\upsilon t}^{Tra} \le 0.5$	1000kg-km/1000$
$C^{JobOpp} = 120$	$	$A_\rho^{Available} = 40$	-	$0.017 \le \varepsilon_{\upsilon t}^{Facility} \le 0.020$	1000kg
$0.10 \le \zeta_{it}^{Fix} \le 0.15\;\; i \in \{\omega, \upsilon\}$	-	$M = 1000000000$	-	$0.0014 \le \varepsilon_{\rho t}^{Facility} \le 0.0017$	1000kg
$0.15 \le \zeta_{\rho t}^{Fix} \le 0.20$	-	$0.001 \le E_{\rho t}^{Facility} \le 0.002$	kw-mile	$0.0030 \le \varepsilon_{\omega\rho t}^{Facility} \le 0.0034$	1000kg/mile
$0.2 \le \zeta_{it}^{Var} \le 0.4\;\; i \in \{\omega, \upsilon\}$	-	$0.002 \le E_{\omega t}^{Facility} \le 0.003$	kw-mile	$0.0027 \le \varepsilon_{\rho\upsilon t}^{Facility} \le 0.0030$	1000kg/mile
$0.5 \le \zeta_{\rho t}^{Var} \le 0.7$	-	$0.004 \le E_{\upsilon t}^{Facility} \le 0.005$	kw-mile	$0.0017 \le \varepsilon_{\upsilon t}^{Facility} \le 0.0020$	1000kg/mile
$A_i^{Available} = 100$	-	$0.012 \le \varepsilon_{\omega t}^{Facility} \le 0.016$	1000kg		

5.2 | Discussions

This section summarizes the results from solving the models using data shown in *Fig. 2* these findings provide insights into the supply chain network in operational efficiency and economics.

An important consideration in the analysis is the evaluation of the influence of the carbon tax policy as shown in *Fig. 3* the outcomes show that carbon tax implementation adjusts cost structure, as well as the decisions taken, in a supply chain. This corroborates the paramount significance that environmental regulations still demand to be integrated into supply chain planning. Apart from carbon, the interactions of product supply chain networks with the grid are another critical factor. This interaction defines the sustainability and resilience of the supply chain. Indeed, the fluctuations in power supply and electricity prices imply production efficiency, operational costs, and total carbon emissions. Applied optimization allows for proper balancing between economic performance, secured energy supply, and environmental cooperation.

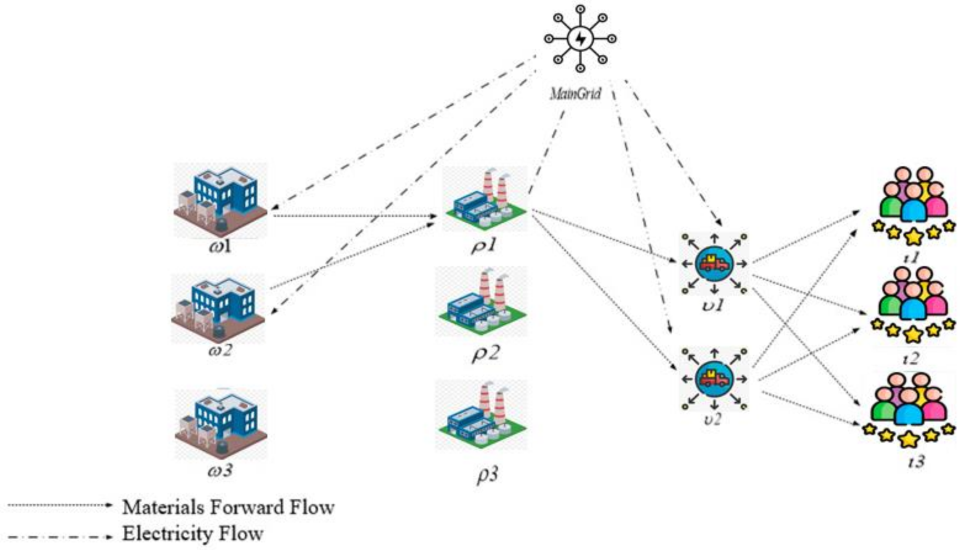

Fig. 2. The proposed network.

Fig. 3 shows how the supply chain network for product and the main power grid are intertwined and how the supply chain functions rely heavily on provision of electricity. As can be seen in *Fig. 3*, the carbon tax policy has a substantial influence on the overall cost of the supply chain network. The overall cost may be brought down if the implementation of the carbon tax is disregarded, but it would mean higher releases of carbon within that supply chain. On the contrary, when the policy of carbon taxation is employed in the total operational realization of the supply chain, it decreases carbon emissions while conforming to environmental sustainability beliefs. But in return for this environmental agenda, the operational costs go higher for the production, and the carbon tax promotes greener energy combats in the supply chain through the incentives for renewable energy use as well as energy-efficient practices.

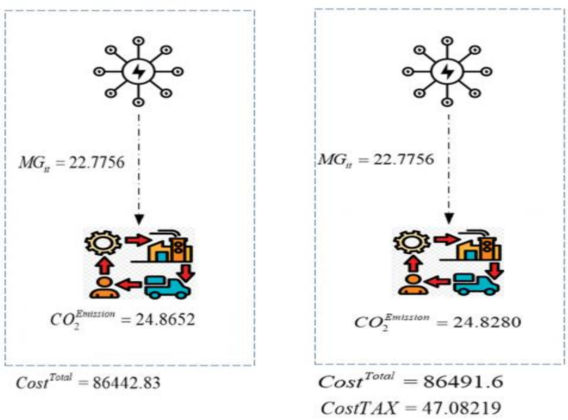

Fig. 3. The result of the network without/with carbon tax policy (a)/(b).

6 | Conclusion

This research presents a MILP model for developing a grid-connected supply chain integrating all main supply chain components with the major power grid. A carbon tax policy-based analysis provides an environmental-driven approach to the emissions produced by the entire system. The study does an analysis of the trade-offs among different cost components and provides consideration for economic, environmental, and operational factors together in their collective approach to the supply chain. The main theoretical contribution of this study is the development of a new mathematical framework that optimally addresses increasing electricity demand in traditional supply chains. In contrast to earlier models which strictly examined supply chain and energy systems separately, this model makes a specific approach for assuring their smooth interaction; that is, a combined interaction of supply chain networks and electricity grids. The analyses reveal that integration is plausible and the introduction of the carbon tax policy introduces additional cost elements and gives the supply chain an incentive to take into account cleaner energy sources. Though, in theory, it imposes further cost on the supply chain, it compels managers to consume cleaner energy resources while adopting this policy for sustainability. Conversely, the results show that if structured well, the supply chain energy plan can be directed toward economic efficiency and environmental sustainability. With the energy-responsive supply chain model design, businesses can not only minimize per-operation costs but also align themselves with global carbon reduction initiatives. This study further stresses the need to incorporate energy supply with environmental concerns in formulating respective strategic decisions about the supply chain owing to decision-making primarily in electricity-intensive industries.

Future research directions

Building upon the results obtained in this study, several key areas for future research emerge:

I. Incorporating uncertainty and risk management: Future models should account for uncertainty in energy supply, demand fluctuations, and disruptions. A stochastic optimization approach or robust MILP framework could be developed to enhance resilience in uncertain environments. Considering risk-averse and risk-bearing factors would allow for more flexible decision-making, ensuring supply chain stability in dynamic conditions.

II. Expanding sustainability considerations: This research primarily focuses on carbon emissions; however, future work could integrate other sustainability factors such as water consumption, resource depletion, and waste management. The model could be extended to include renewable energy sources such as solar and wind power, reducing dependence on fossil fuels and enhancing supply chain sustainability. Developing a multi-objective optimization model that balances economic, social, and environmental factors would provide a more comprehensive approach to sustainable supply chain management.

III. Integrating transportation modes and logistics: This study does not consider transportation logistics, which play a crucial role in supply chain emissions. Future research could analyze the impact of different transportation modes (e.g., road, rail, sea, and air) on carbon emissions and cost efficiency.

A multi-modal transportation strategy could be developed to optimize route planning, fuel consumption, and delivery scheduling while minimizing the environmental footprint.

I. Exploring the impact of policy and market dynamics: The research focuses on a fixed carbon tax policy; however, dynamic policies, carbon credits, and cap-and-trade systems could be explored in future studies.

The economic impact of fluctuating electricity prices, government incentives, and regulatory changes could be integrated into decision-making models.

Evaluating the influence of consumer demand for green products and Corporate Social Responsibility (CSR) policies on supply chain sustainability would provide valuable insights.

II. Developing real-world applications and case studies: While this study provides a theoretical framework, future research could apply the model to real-world industrial supply chains.

Conducting case studies on manufacturing, retail, or energy-intensive sectors would validate the model's practical applicability.

Collaboration with industries could lead to data-driven, AI-enhanced decision-support systems for real-time supply chain optimization.

Final thoughts

This research shows the great significance of coupling energy supply and environmental policies with supply chain design. Based on proposed model will help as a starting point for many future studies, providing access to cheap cost, sustainability as well as energy accounting when optimizing supply chain traits. If this future research embraces the areas for more work outlined above, this would contribute to building further contribution to establishing more resilient and sustainable supply chains that could assure long-term benefits both for companies and for the environment.

Nomenclature			
Indices		ζ_{it}^{Fix}	Fixed-job opportunities at facility i during time t
$\omega \in \{1,...,\omega\}$	Plant suppliers' index	ζ_{it}^{Var}	Variable job opportunities at facility i during time t
$\rho \in \{1,...,\rho\}$	Manufacturers' index	$E_{it}^{Facility}$	Amount of electricity needed for each facility $i \in \{\omega,\rho,\upsilon\}$
$\upsilon \in \{1,...,\upsilon\}$	Distributors index	$\varpi_{\rho t}^{CostLD}$	Cost of days lost due to injuries during the opening of plant ρ over period t
$\iota \in \{1,...,\iota\}$	Customer nodes' index	ϖ_{it}^{CostLD}	Cost of days lost due to injuries during the opening of facility $i \in \{\omega,\rho,\upsilon,\tau\}$ over period t
$t \in \{1,...,T\}$	Index of periods	$\varpi_{\upsilon t}^{LD}$	Cost of the days lost due to injuries during the handling of products at facility υ over period t
$i, i' \in \{\omega,\rho,\upsilon,\iota\}$	Index of facilities	$\varpi_{\rho t}^{LD}$	Cost of the days lost due to injuries happened in plant ρ over period t
Variables		M	A large positive number
$\chi_{ii't}$	Product flow from facility $i \in \{\omega,\rho,\upsilon,\iota\}$ to facility $i' \in \{\omega,\rho,\upsilon,\iota\}$ during time t		
$Pro_{\rho t}$	Manufactured product at plant ρ during time t	$A_{\rho}^{available}$ / $A_{i}^{available}$	Maximum available number of manufacturer ρ or facility $i \in \{\omega,\rho,\upsilon,\tau\}$
MG_{it}	The amount of electricity sent to centers i during time t		
$CO_2^{Emission}$	Total CO_2 emissions	$C_{it}^{Capacity}$	The capacity of facility $i \in \{\omega,\rho,\upsilon\}$ during time t
$Cost^{Total}$	Total cost of network	$Cost_{ii't}^{Tra}$	Cost of transference from facility $i \in \{\omega,\rho,\upsilon\}$ to $i' \in \{\omega,\rho,\upsilon\}$ during time t
		$Cost_{\upsilon\iota t}^{CA}$	Ordering cost of customer area ι from distributor υ at time t
Binary variables		$d_{\iota t}^{Product}$	Demand of product
ϑ_i	Binary variable that is set to 1 in case facility $i \in \{\omega,\rho,\upsilon\}$ is opened	$Cost^{JobOpp}$	Cost of job opportunity
$\vartheta_{\upsilon\iota t}^{Market}$	Binary variable to distribution center υ to market place τ over time t	$Cost_{\rho t}^{Prod}$	Cost of product at ρ manufacturer during time t
Parameters		$Cost^{WorkDam}$	Cost of work damage
		C^{Tax}	Cost for unit of carbon emission
$Cost_{it}^{Fix}$	Cost of facility i	C^{MG}	Cost of electricity plant
$Cost_{\rho}^{Fix}$	Cost of ρ manufacturer		
$Cost_{\omega\rho t}^{Raw}$	The cost of materials from ω supplier for manufacturing plant ρ during time t		

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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