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OPTIMIZING LOGISTICS NETWORKS WITH INTEGRATED SUSTAINABILITY AND CORPORATE SOCIAL RESPONSIBILITY (CSR)

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Abstract: *Optimizing logistics networks today presents increasing challenges for companies, particularly due to the need to integrate sustainability and corporate social responsibility (CSR). The aim of this research is to explore the strategies and methods through which the efficiency of logistics processes can be improved while reducing environmental and social burdens. Guided by the principles of sustainability, there is growing emphasis on green logistics solutions, such as low-emission transport modes, energy-efficient warehouse management systems, and intelligent route optimization. In addition, integrating CSR principles into logistics decision-making contributes to increased social responsibility, for example through ethical sourcing, ensuring employee well-being, and supporting community development programs. This study examines how sustainability considerations and CSR can be embedded into logistics network optimization processes without causing significant deterioration in costs or service levels. The analysis covers best practices applied by companies, as well as the challenges and limitations associated with implementing sustainable and responsible logistics strategies. The findings of the study can contribute to enhancing corporate competitiveness by demonstrating the successful integration of CSR and sustainability principles into logistics processes. Optimized and responsible logistics networks not only mitigate environmental and social impacts, but also offer long-term economic benefits for companies.*

Keywords: *sustainability, logistics, Corporate Social Responsibility.*

1. INTRODUCTION

The optimization of modern logistics systems is no longer solely focused on cost reduction and efficiency improvement, but increasingly requires the integration of sustainability and Corporate Social Responsibility (CSR) considerations [1]. As global supply chains become more complex, the growing environmental and social challenges are driving companies to develop new strategies aimed at sustainable operations [2]. CSR reflects corporate responsibility that extends beyond economic objectives, encompassing social and environmental goals such as reducing carbon emissions, ensuring ethical working conditions, and promoting a circular economy [3]. In the context of logistics network optimization, the integration of sustainability principles involves approaches such as green transportation, energy-efficient warehouse management systems, recyclable packaging solutions, and the adoption of alternative fuels [4]. Logistics and supply chain management are increasingly reliant on digital technologies—including Artificial Intelligence (AI), Big Data analytics, and blockchain solutions—that not only enhance operational efficiency but also improve supply chain transparency and sustainability [5]. One of the key elements of sustainable logistics is intermodal transportation, which reduces the ecological footprint by combining road, rail, and maritime modes of transport [6]. Integrating social responsibility and sustainability into logistics processes is not only beneficial from an ethical and environmental standpoint but also provides companies with long-term competitive advantage. Organizations that adopt

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CSR-based logistics strategies are not only compliant with regulatory requirements, but are also perceived as more trustworthy by consumers and business partners [7].

The aim of this study is to explore in detail how CSR and sustainability principles can be integrated into the optimization processes of logistics networks. The research analyses the sustainable logistics solutions adopted by companies, as well as the strategic role of CSR within the supply chain. The study offers not only a theoretical approach but also presents practical examples to demonstrate how sustainability goals can be achieved without compromising corporate efficiency or competitiveness.

2. Sustainable Logistics Networks

The issue of sustainability is playing an increasingly important role in the design and optimization of logistics networks as the global economy faces growing environmental and social challenges [2]. The rapid growth of industrial development and global trade has increased the ecological footprint of supply chains, reinforcing the demand for sustainable logistics solutions [4]. Fig. 1 illustrates the current practices of companies in the field of green transportation and environmentally friendly mobility across three key areas. The use of electric and alternative fuel vehicles shows a 35% adoption rate [8]. Intermodal transportation is currently utilized by approximately 45% of companies, primarily within larger supply chains [9]. Optimized route planning is the most widely applied solution, with around 70% of companies integrating it into their digital systems [10].

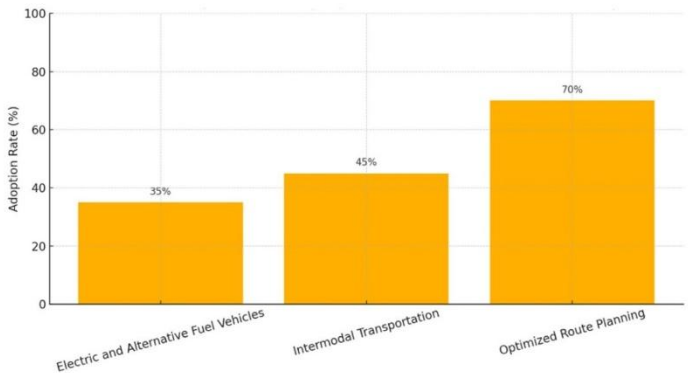

Figure 1. Adoption Rates of Green Transportation and Environmentally Friendly Mobility in 2019. Sources [8, 9, 10]

The principles of sustainable logistics can be examined along several dimensions, which are as follows.

2.1. Green Transportation and Environmentally Friendly Mobility

The logistics sector is one of the largest emitters of carbon dioxide and makes a significant contribution to climate change [17].

Electric and alternative fuel vehicles can play a key role in the sustainable transformation of logistics systems. Electric trucks developed by Tesla, Volvo, and Daimler can significantly reduce emissions during the transition process [18]. To enhance supply chain sustainability, the logistics sector increasingly relies on electric vehicles (EVs) and alternative fuel-powered trucks, including those running on hydrogen, biofuels, or compressed natural gas (CNG). The adoption of these vehicle technologies provides opportunities to reduce CO_2 emissions and dependence on fossil fuels, while also promoting environmental compliance and the development of ESG (Environmental, Social, Governance)-based logistics strategies. Electric-powered commercial vehicles are particularly suitable for urban and suburban distribution tasks, where short distances and frequent stops are not problematic in terms of battery capacity. In addition, reduced noise pollution and lower maintenance costs make EVs an increasingly attractive option for last-mile delivery solutions. Vehicles powered by alternative fuels, such as hydrogen fuel cell trucks, offer competitive advantages for long-haul, high-load transportation. These vehicles have shorter refuelling times and longer ranges compared to their electric counterparts, making them ideal for regional and cross-border freight transport. However, for logistics companies, the transition to these technologies requires not only vehicle-side investment but also substantial infrastructure transformation. This includes the establishment of charging networks, the integration of energy management systems, and the adaptation of operational planning tools such as route planning and fleet management systems, which are crucial for the efficient operation of new vehicle fleets. Thus, the implementation of electric and alternative drivetrains not only supports environmental sustainability but also provides long-term competitive advantages for logistics service providers by reducing operating costs, improving corporate image, and facilitating the spread of green logistics practices.

Intermodal transport is a fundamental component of global-scale supply chains. Combining rail and inland waterways reduces environmental impacts [13]. The integrated application of rail and water transport within combined freight systems significantly contributes to reducing the environmental footprint of logistics operations. Both transport modes offer outstanding energy efficiency: rail transport has considerably lower CO_2 emissions per ton-kilometre compared to road transport, while inland shipping – especially for bulk cargo – provides a low-emission and low-noise alternative. Combining the two modes – for instance, in containerized or bulk cargo transport – allows for the creation of “green corridor” type supply chains, where the road segment is minimized, thereby reducing congestion, pollutant emissions, and road infrastructure degradation. This form of intermodal logistics is not only advantageous from a sustainability perspective but also efficient in terms of cost and capacity utilization, especially when appropriate infrastructure, such as trimodal terminals, is available. Such combinations are therefore key to achieving green logistics objectives, particularly in alignment with the EU Fit for 55 directive and broader decarbonization strategies.

Optimized route planning is also a crucial element of sustainable logistics networks. Traffic models based on artificial intelligence support more efficient transportation processes [14]. AI-based traffic modelling plays an increasingly important role in the dynamic management and adaptive optimization of logistics systems. AI algorithms – especially those using machine learning and predictive analytics – can process real-time traffic data, historical patterns, and environmental factors (e.g., weather conditions, traffic density, accidents), enabling accurate forecasts for route and transit time optimization. Intelligent traffic models reduce delays caused by congestion, minimize empty mileage, and improve fleet utilization and fuel efficiency. These advanced systems allow for real-time rerouting, dynamic schedule adjustments, and contribute to sustainable logistics operations by reducing CO_2 emissions and environmental burden. The use of AI-based traffic simulations and decision-support systems is particularly beneficial in urban last-mile delivery and high-volume road freight operations, where reliability and predictability are critical. In this way, artificial intelligence becomes not only a tool for improving logistics efficiency but also an essential enabler of strategic decision-making.

2.2 Energy-Efficient Warehousing

The application of sustainable warehousing technologies can significantly reduce energy consumption. Improving the energy efficiency of warehousing systems is a key challenge in modern logistics, particularly in terms of meeting sustainability objectives and reducing operational costs. Intelligent, Internet of Things (IoT)-based energy optimization provides opportunities for real-time monitoring and adaptive control of warehouse infrastructure and operations, enabling significant energy savings without compromising logistics performance or service levels. IoT-based systems, through a network of sensors and data collection units, continuously provide information on temperature, humidity, lighting requirements, energy usage patterns, and the operational status of equipment such as forklifts, conveyors, and HVAC systems. This data enables predictive maintenance and the implementation of dynamic energy management, such as the automatic adjustment of lighting and ventilation according to warehouse occupancy.

Moreover, the integration of IoT devices with artificial intelligence supports peak energy load balancing, the incorporation of energy storage solutions (e.g., batteries combined with solar panels), and the forecasting of energy demands. This is particularly revolutionary in the field of cold chain warehousing, where optimizing energy-intensive operations is critical not only for cost efficiency but also for environmental impact. Intelligent energy management contributes to green logistics operations while also supporting ESG-compatible corporate objectives. Automated control systems, smart meter technologies, and cloud-based energy analytics platforms enable the objective assessment and continuous improvement of warehouse energy efficiency levels [15].

Ensuring the sustainable operation of logistics systems is one of today's key objectives, which also requires the implementation of new technological and energy solutions within the warehousing sector. The use of solar and geothermal energy can reduce the ecological footprint [16]. One of the most innovative directions in energy-efficient warehousing is the integration of renewable energy sources into warehouse energy supply systems, which serves both to reduce environmental impact and to optimize operational costs in the long term.

The most commonly used renewable energy source is solar energy, implemented via photovoltaic (PV) systems installed on or around warehouse rooftops. Solar power can partially or entirely cover the energy demand of lighting, automation systems, and heating and cooling equipment. Modern energy storage solutions – such as lithium-ion batteries – allow energy generated during the day to be used later during peak demand periods, increasing system autonomy. Wind and geothermal energy sources are also used in larger warehouse facilities, particularly in regions where these resources can be exploited economically. Geothermal heat pump systems are especially well-suited for energy-efficient heating and cooling of warehouses, particularly for temperature-sensitive goods. Warehousing based on renewable energy sources is closely connected to the smart grid concept, where the warehouse acts as an active energy node, not only consuming energy but also feeding it back into the grid. Advanced energy management systems can align renewable energy production with actual consumption needs, helping to balance peak loads and achieve carbon neutrality targets. Warehouses operating on such principles typically achieve higher ESG ratings, which is advantageous for market reputation, investment potential, and regulatory compliance. Furthermore, they support supply chain decarbonization and contribute to achieving the strategic objectives of green logistics.

3. THE ROLE OF CSR IN THE OPTIMIZATION OF LOGISTICS NETWORKS

CSR is increasingly being integrated into corporate logistics strategies, not only to enhance sustainability but also to strengthen brand loyalty and gain competitive market advantage. CSR plays an important role in logistics decision-making, as companies take responsibility for their environmental and social impacts [17]. Corporate Social Responsibility (CSR) and supply chain sustainability are closely interconnected concepts in modern logistics that define corporate operations at a strategic level. Logistics systems guided by CSR principles consider not only economic efficiency but also environmental and social responsibility across the entire supply chain—from raw material procurement to end-customer delivery.

Within the framework of sustainable supply chain management, logistics decisions increasingly prioritize emission reduction, the use of green transportation modes, energy-efficient warehousing, and transparency and ethical conduct throughout the supplier network. Integrating CSR principles not only reduces environmental burdens but also strengthens corporate reputation, trust among business partners, and consumer loyalty.

Tools such as sustainability audits, carbon footprint monitoring, and environmental performance indicators (KPIs) make it possible to measure CSR objectives and support continuous improvement. In this way, logistics is no longer merely a supporting function but becomes an active contributor to sustainable corporate operations and the creation of social value.

One of the most critical elements of environmental sustainability in logistics systems is emission reduction, particularly focusing on the total carbon footprint of the supply chain. Reducing this is essential to achieving long-term sustainability goals [18]. According to certain studies, optimizing fuel consumption alone can reduce CO_2 emissions by up to 15% [9], which can represent a significant step toward implementing green logistics practices. In addition, the increasing adoption of new technologies—such as energy-efficient warehousing systems and autonomous logistics devices, including drones and mobile robots—also contributes to reducing environmental impact and achieving sustainable operations [8].

In the logistics context, social responsibility primarily manifests in ensuring employee safety and supporting local communities. Ergonomically designed workplaces and regular occupational safety training can significantly reduce accident rates, thereby improving employee well-being [19]. Moreover, socially responsible companies often actively support the development of local communities—for example, by funding educational and healthcare improvements in regions where their logistics bases operate [20].

CSR practices are important not only from environmental and social perspectives but also in terms of direct economic benefits. Through long-term sustainable operations, companies not only minimize negative externalities but also enhance their competitiveness. Implementing green logistics solutions—including energy-efficient technologies and optimized waste management—can reduce operating costs and improve resource efficiency [21], while also strengthening market position and consumer trust [3].

Digitalization plays a major role in shaping sustainable and responsible logistics systems, as it enables complex data analysis, enhances transparency, and supports real-time decision-making [5]. Systems based on artificial intelligence and Big Data technologies help optimize resource management, reduce emissions, and improve operational efficiency [10]. Blockchain technology, in particular, contributes to increasing transparency and traceability within supplier networks, supporting the enforcement of ethical business practices [22]. Furthermore, the use of IoT devices and automated systems—such as intelligent sensors and predictive maintenance algorithms—enables energy-efficient operations while minimizing waste generation [23].

4. Integration of CSR and Sustainability into Logistics Networks

The integration of Corporate Social Responsibility (CSR) into logistics networks can be implemented at multiple levels, depending on whether the company aims to emphasize sustainability, ethical operations, or community engagement.

The objective of the model may therefore include:

- Optimization of sustainability across the entire supply chain.
- Balancing costs and environmental impacts.
- Supplier selection based on ethical and sustainability criteria.
- Determining optimal routes to support sustainable logistics.

One possible objective function, aimed at jointly minimizing total cost and emissions, is described by equation (1).

$$Z_{min} = min \sum_{i,j} (c_{i,j} \cdot x_{i,j} \cdot \omega \cdot e_{i,j} \cdot x_{i,j}) \quad (1)$$

where:

- Z: total objective function value (e.g. "weighted unit cost × transported quantity")
- $c_{i,j}$: the transportation cost from supplier *i* to warehouse *j* [tonne],
- $x_{i,j}$: the quantity of goods transported from supplier *i* to warehouse *j* [EUR/tonne],
- ω: a weighting factor that regulates the importance of sustainability considerations,
- $e_{i,j}$: the emission (e.g., in kg of CO_2) associated with a specific route and mode of transport [kg CO_2/tonnes].

Another possible solution is multi-objective optimization incorporating CSR, which is described by equation (2).

$$Z_{max} = max \sum_k s_k \cdot y_k - \lambda \sum_{i,j} e_{i,j} \cdot x_{i,j} \quad (2)$$

where:

- s_k: the supplier's sustainability score
- y_k: if the *k*-th sustainable supplier is selected, the value is 1; otherwise, it is 0 (binary variable),
- λ: a penalty weighting factor for emissions.

Constraints:

- Capacity constraint (maximum capacity of the supplier and the warehouse):

$$\sum_k x_{i,j} \leq \max cap_i \qquad \forall i \quad (3)$$

- Sustainability requirement (only suppliers that meet the CSR criteria can be selected):

$$s_k \cdot y_k \geq S_{min} \qquad \forall k \tag{4}$$

- Transport mode selection (e.g., regulation of intermodal transportation):

$$\sum_t t_{i,j} \leq 1 \qquad \forall (i,j) \tag{5}$$

- Compliance with total cost and emission thresholds:

$$\sum_{i,j} c_{i,j} \cdot x_{i,j} \leq C_{max} \tag{6}$$

$$\sum_{i,j} e_{i,j} \cdot x_{i,j} \leq E_{max} \tag{7}$$

The previously outlined optimization can be solved using linear programming or integer programming methods; however, heuristic algorithms are also commonly applied in addressing such complex and multifaceted challenges. The model is capable of integrating sustainability considerations into the logistics network while maintaining a balance between cost-efficiency and environmental protection.

5. CONCLUSION

The aim of this study is to explore how Corporate Social Responsibility (CSR) and sustainability principles can be integrated into the optimization of logistics networks without compromising cost-efficiency or service levels. The design of modern logistics systems increasingly goes beyond cost reduction, placing greater emphasis on green transportation, energy-efficient warehousing, and ethical supplier relationships. The solutions presented in the research include the use of electric and alternative fuel vehicles, the combination of intermodal transportation, and AI-based route planning. A key element of sustainable logistics is digitalization, which enhances transparency and operational efficiency through artificial intelligence, Big Data, blockchain, and IoT technologies. The study is complemented by mathematical models that support the simultaneous minimization of costs and environmental impacts across the entire supply chain. CSR-based logistics practices contribute to enhancing corporate competitiveness while reducing ecological footprints and supporting the achievement of green logistics objectives.

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