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Sustainable Supply Chain Management and SDG 13: A Climate Action Perspective Risk mitigation and adaptation strategies in global logistics

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ABSTRACT

The ever-increasing awareness of the climate change crisis, marked by Sustainable Development Goal 13 (SDG 13: Climate Action), has put more and more pressure on the need to make global supply chains sustainable and offset the risks posed by environmental disruption. As resource demanding and emissions intensive systems, global logistics networks are susceptible to specific climate-related risks (e.g., extreme weather patterns, increasing fuel prices, and regulatory changes). This article investigates the extent to which sustainable supply chain management (SSCM) and SDG 13 go hand in hand with regard to risk management and adaptation in logistics. An overview of similar literature suggests the frameworks of carbon cutting, renewable energy exploitation, the inclusion of a circular economy, and a robust-resilient infrastructure. The mixed approach to the proposed methodology will integrate secondary data as provided in academic and industry reports and a conceptually based risk adaptation model of supply chains. The results indicate that the companies that combine sustainability models with digital technologies (IoT, AI, blockchain) increase their resilience and decrease carbon footprints. A comparative examination shows that proactive climate adaptation policies are more cost-effective and sustainable, compared with the reactive policies. There are however practical constraints in practice because green infrastructure has not been evenly implemented across the world and there are regulatory differences across countries. Future trends include the need to create common climate-resistant logistical norms, green technologies, and climate responsibility as a component of international trade agreements.

Keywords: *Sustainable Supply Chain Management, SDG 13, Climate Action, Global Logistics, Risk Mitigation, Adaptation Strategies, Resilient Supply Chains.*

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1. INTRODUCTION

Global supply chains are one of the pillars in modern trade as it enables free flow of goods, services and resources through engines over the borders. They are, however, also very high energy- and carbon-intensive, which contributes significantly to greenhouse gas emission in the world [17]. With climate change starting to affect many regions in some of the most dramatic ways, as transportation routes become blocked by extreme weather conditions, as supply chains are knocked off by natural disasters and as costs of operations become more expensive as the prices of fuel fluctuate, international logistics networks are becoming far more vulnerable [1]. Here, Sustainable Development Goal 13 (SDG 13: Climate Action) highlights the importance of commercial enterprises, governments and industries revising supply chain procedures and implementing strategies that limit exposure to the environmental risk and foster more resiliency. Sustainable Supply Chain Management (SSCM) therefore becomes a radicalization mechanism of the process of integrating climate-friendly practises in the logistic activities.

Stakeholder demands due to pressure and changing regulatory landscape also contributes to the urgency of climate-resilient supply chains. There is growing consumer pressure to make environmentally friendly products, investors use the

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sustainability as one of the factors to make risk analysis, and governments are getting tougher on environmental compliance. This intersection of economic, social and environmental pressures is a key point in understanding why cost and efficiency-centered logistics has to add a sustainability and climate adaptation dimension. With this, not only will supply chains be able to mitigate their carbon footprint but also sustain themselves in the long term with regards to climate uncertainty. The approach to SDG 13 related to global logistics is the chance to balance competitiveness in the economy with environmental care [5-6].

As a strategic matter, SSCM involves not only reducing emissions, but also reducing risk and adaptive capacity. The extreme weather-related events like hurricanes, floods, and droughts interrupt shipping lanes, slow down the production cycles, and affect physical infrastructure through the damage. Such climate induced imbalances come at high costs such that climate resilience is a major issue in the global businesses [16]. It is thus prompting companies to consider the use of renewable energy-sourced warehouses, electrified transport fleets, a circular economy or even digital monitoring of the supply chain in an attempt to develop fluid, dynamically responsive systems. Not only would such methods increase sustainability, but also work to decrease exposure to climate vulnerability. This is a two-fold advantage that justifies the superiority of SSCM in promoting operational and environmental performance [8].

The globalization of supply chains is another driving force behind climate action as it involves both regions with significantly different levels of development in climate action. Developed economies are investing in installation of low-carbon technologies and infrastructures, yet developing economies may fail to gain financial and regulatory support, hence, uneven implementation occurs. Such imbalances make global supply chains vulnerable to global climate risks, thus enhancing the climate-related risks. In this way, the driving force behind the current research is the necessity to explore SSCM as a comprehensive proposal closing the gap between regional specifics, following the SDG 13, and guaranteeing global fairness adaptation in the context of logistics frameworks [10].

The first aim of the work is to interpret risk avoidance strategies and adaptation to global logistics as a climate action practice. It aims at responding to the following major questions: How do supply chains minimize emissions and improve resilience? What are more effective proactive strategies when compared with reactive strategies? What is the place of digital technologies and renewable energy in climate-fit logistics? This paper outlines scope of how SSCM can contribute to SDG 13 using integrated and adaptive practices by answering the following questions. Finally, the introduction, in a way gives a burning ambiance, explains the incentives, and preconditions the reading the novelty of the study and contribution that the research makes [4].

The Figure 1 depicts the consolidated procedure of determining climate risks, applying mitigation actions, applying adaptive approaches, and accomplishing resilience in the global supply chains.

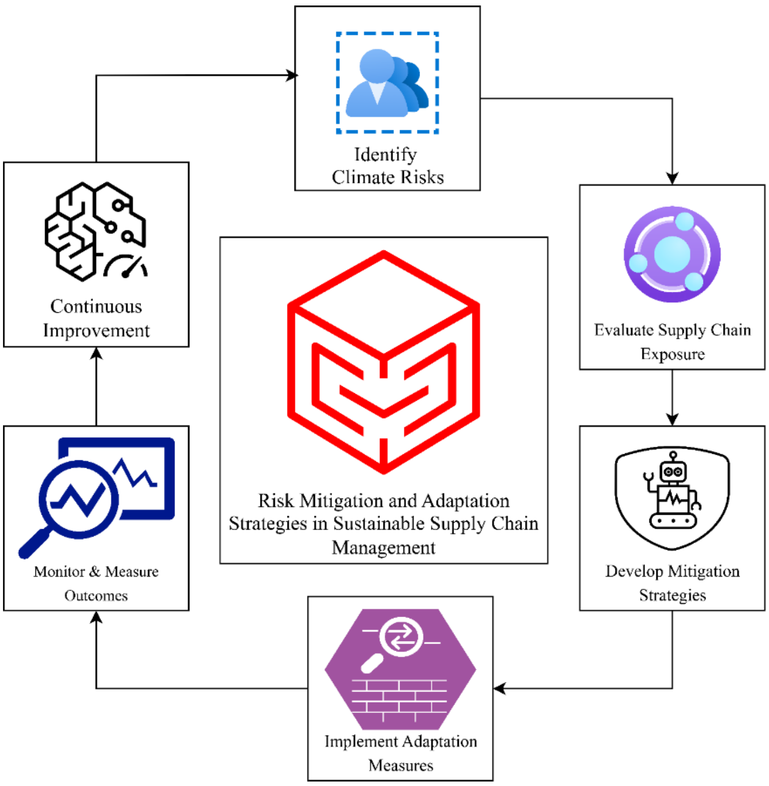

FIG. 1: RISK MITIGATION AND ADAPTATION STRATEGIES FOR CLIMATE-RESILIENT GLOBAL LOGISTICS

1.1 Novelty and Contribution

The next novelty of this work is a combination of analysis of the issue of Sustainable Supply Chain Management within the frames of Sustainable Development Goal 13 that concerns the aspects of risk mitigation and adaptation strategies in the context of logistics in the global context. Unlike currently available literature that approach the study of sustainability in individualistic terms (green transportation, renewable adoption, or carbon tracking), this research paper proposes a converged approach that views climate resilience, technology adoption, circular economy behaviors, and global policy convergence as a pair. It is the holistic viewpoint that turns the research into a unique one, making it possible to relate several dimensions of SSCM to the overall climate action agenda [2].

This study has three major contributions. On the one hand, it gives a clear conceptual model that differentiates between the proactive and reactive approaches to climate risks in logistics, demonstrating the long-term benefits of mitigation efforts versus short-term defensive actions in response to events. Second, it shows how emergent technologies, including IoT in predictive monitoring, AI in demand forecasting, blockchain in transparency of the supply chain, etc., contribute to both efficiency and resilience. Third, it illuminates global differences of logistics adaptation which raises the red flag on the imminent necessity of international standards and equal green infrastructure investments. The paper also translates these insights to inform policy makers and leaders in the industry through the provision of practical recommendations in addition to the contribution made to the academic dialogue.

The general novelty lies in the view of climate action itself: climate action has increasingly been discussed as an expense or compliance strategy instead of strategic advantage, and in this work, SSCM is reinterpreted as a strategic risk reduction, resiliency, and competitive angle in world logistics. In this way, the contributions are not only theoretical, as they extend the academic knowledge about SSCM in the context of SDG 13, but also practical in the same way that they offer to guide the formation of climate-resilient and future-proof supply chains.

2. RELATED WORKS

In 2024 Murali G. et.al., Ramani P. et.al., Murugan M. et.al., Elumalai P. V. et.al., Ranjan Goud N. U. et.al., & Prabhakar S. et.al. [9] introduced the current literature on sustainable supply chain management (SSCM) has continued to drive the need to focus on the management of sustainable supply chain as a strategic response to the environmental challenges the existence of globalization has brought to businesses. It has been found that when it comes to carbon emissions, this sphere of the logistics industry is the key mode of focus in climate change action plans. Research on SSCM has singled out the role of incorporating the focus on the ecology in the supply chain decisions, especially regarding transportation, warehousing and energy use. Certain green logistics measures, including streamlining transportation networks, utilizing fuel-efficient vehicles, and optimizing packaging waste, are well-known to help minimize the environmental effect onto supply chains, as well as increase cost-efficiency. This work of literature forms the background upon which sustainable logistics is used in the attainment of SDG 13.

One of the key themes in the linked research is the reactive to proactive shift in approaches to marshaling climate risk in supply chains. Reactive strategies usually are targeted at post-disruption recovery, i.e. reacting to delays inflicted by natural disasters or supply breakdown. Although this may be necessary in certain atmospheres, these methods tend to incur increased long-term expenses and turn into more liability. The proactive approaches, in turn, are planning and the design of resilience ahead, including investing in renewable energy, improving infrastructure resilience, or using predictive digital applications. Existing comparative analyses of these approaches show that proactive risk management does not just lessen environmental footprints but also brings about greater performance in the form of long-term resilience and competitiveness.

In 2025 Mohammad A. et.al., Shelash S. et.al., Taher Saber I. et.al., Vasudevan A. et.al., Neman Darwazeh R. et.al., Almajali R. et.al., & Fei Z. et.al. [3] suggested the other stream of research focuses on the beneficial front of the technology in the facilitation of the sustainable supply chains. Newer emerging digital applications like the Internet of Things (IoT), artificial intelligence (AI), and blockchain are widely explored based on the ability to increase transparency, accountability, and predictive capabilities of logistics systems. As an example, IoT-related monitoring systems can give companies the potential to monitor energy usage and green performance in real-time to make instant changes to minimise emissions. The analytics driven through AI have been explored to forecast demand and ride prioritizing, which resulted in the minimization of the number of fuels and carbon emission. However, in contrast, blockchain technology has been identified to provide a comprehensive and competitive performance in assuring reporting transparency and global traceability across supply chains of sustainable practices. Taken together, these technological interventions can be considered as the key drivers of logistics to support climate action goals.

The other area of academic or industry research is sustainable development of infrastructure. Studies have highlighted that green warehouses with renewable sources of energy like solar and wind are important factors towards minimizing emissions during the course of operation. Also, electric and hybrid vehicles are more analyzed as a way to decarbonize transportation through deployment in the logistics fleets. Research in ports and aero logistics indicates that alternative biofuels, for example, as well as hydrogen, are areas of innovations that are both threatening and promising due to their cost and their ability to scale upwards. Large-scale infrastructure development has been framed as a long-term plan that demands heavy investment but benefits through extensive emissions cut and strong climate resilience.

In 2024 Shao H. et.al., Peng Q. et.al., Zhou F. et.al., & Wider W. et.al. [7] proposed the literature discloses that the circular economy is important to the sustainable supply chains. Traditional vertical supply chains, known as the take, make, dispose, are in theory replacing the role of circularity with more emphasis on recycling, reuses and resource efficiency. Closed-loop supply chains would lessen the reliance on virgin raw materials, waste, and develop systems that could be less vulnerable to supply disruption. Research studies have continuously denied, and refuted the negatives of not incorporating principles of the circular economy to the aspects of global logistics, by claiming that such a course of action offers twofold benefits; namely modulating environmental degradation and minimization of the dangers of raw material shortage and cases of price fluctuations. This renders the circular approach as vital adaptation measure in conceiving the risks presented by climate change.

Another method in which the issue has garnered a lot of scholarly consideration is policy and regulatory frameworks. Research points out that cross-nation carbon-cutting work, domestic policies on emissions, and industry-based sustainability norms have a central role in defining supply chain practices. As an example, a carbon pricing system, reporting emissions controls, and eco-certification schemes have been investigated with respect to their impact on encouraging adoption of sustainable logistics. Nonetheless, in literature, there are also noted challenges of uneven coverage between various parts and the financial cost of the smaller firms in exhaustive regulations. Global standards mismatch is a common issue and it entails that efforts of community climate action within supply chains may be ineffective.

Another grave observation to arise as a result of similar researches conducted is the gap in implementing sustainable supply chain within the developed and developing economies. The studies emphasize that in the framework of more developed economies where the implementation of regulatory frameworks and more favorable access to limited funds is more secured, strides have been implemented in the development of logistics that utilizes green technologies and renewable infrastructure. On the other hand, some of the structural obstacles faced by developing countries include poor infrastructure, poor investment and poor implementation of environmental protocols. This skew causes insecurity in the international supply lines with climate risks in one region being able to propagate along the global trade lines. Seen as an important goal in the realization of truly global climate-resilient supply chains, addressing these disparities has also framed climate-resilient industries as a particular concern.

Lastly, the body of study historically supports the notion that cooperation among stakeholders is a critical aspect in attaining the sustainable supply chains. Business-government, non-governmental organizations and consumer partnerships have been investigated as the promising approaches to scale sustainability practices. Techniques like the collaboration on the logistics, like joint-collaboration on transportation systems, the renewable infrastructure investment, and crucial reporting platforms have demonstrated potential to lessen emissions and to strengthen resiliency. These studies also underscore the point that individual efforts by individual firms are not enough to address the magnitude of climate crises; action has to be collective and based on a common accountability relating to aligning supply chains with SDG 13 [14].

In sum, the literature offers a holistic groundwork into comprehension of how the adoption of SSCM approaches can influence mitigation and adaptation of climate risk in the logistics. Although significant improvements have been reported, there are still gaps in standardizations across the world, inequality in infrastructure as well as embracing use of advanced technologies in all parts of the world. All these restrictions contribute to the necessity to continue the research and have working models that eventually are able to lead industries to resilient climate-aligned supply chains.

3. PROPOSED METHODOLOGY

The methodology for this study adopts a quantitative-conceptual framework, integrating environmental, economic, and logistical indicators into a sustainability assessment model. The focus is to measure risk mitigation and adaptation efficiency in global logistics under the lens of SDG 13. The methodology is structured around carbon footprint estimation, resilience measurement, renewable integration, and comparative analysis between proactive and reactive strategies.

Carbon Emissions Modeling

To evaluate logistics sustainability, the starting point is the measurement of carbon emissions from transportation activities. A general model is:

$$C_t = \sum_{i=1}^{n} (D_i \times EF_i \times Q_i) \tag{1}$$

where C_t = total carbon emissions, D_i = distance traveled for shipment i, EF_i = emission factor per unit distance, and Q_i = quantity shipped.

This formula quantifies logistics-related emissions, forming the baseline against which mitigation strategies are tested.

2. Fuel Consumption Relation

Since carbon emissions are directly linked to fuel use, we relate fuel consumption to shipment weight and distance:

$$F = \alpha \times W \times D \quad (2)$$

where F = fuel consumption, W = cargo weight, D = distance, and α = fuel intensity factor. This helps evaluate how weight management and route optimization reduce emissions [13].

3. Cost of Carbon Emissions

Economic impacts of emissions are modeled using carbon pricing:

$$Cost_{\ C} = P_c \times C_t \quad (3)$$

where Cost $_C$ = cost of carbon emissions, P_c = price per ton of CO_2, and C_t = emissions from Eq. 1. This integrates financial implications, showing how sustainable practices can cut costs.

4. Renewable Energy Integration in Warehousing

Warehousing sustainability is modeled by energy substitution:

$$E_s = \frac{E_r}{E_t} \times 100 \quad (4)$$

where E_s = share of renewable energy, E_r = renewable energy consumed, and E_t = total energy consumption.

This ratio quantifies the renewable penetration rate in logistics facilities.

5. Logistics Efficiency Score

To compare traditional vs. sustainable logistics, we define an efficiency score:

$$LE = \frac{Output}{Energy + Emissions} \quad (5)$$

where LE = logistics efficiency, Output = goods transported, and denominator = total energy use + emissions.

Higher LE indicates more sustainable logistics [11].

6. Risk Probability of Disruption

Climate risks such as floods, storms, or heatwaves are modeled probabilistically:

$$R = P \times I \quad (6)$$

where R = risk value, P = probability of climate event, and I = impact factor on logistics.

This guides adaptation planning.

7. Adaptation Investment Function

Adaptation strategies require investment modeling:

$$ROI_A = \frac{S_{loss} - C_{adapt}}{C_{adapt}} \quad (7)$$

where ROI_A = return on adaptation investment, S_{loss} = savings from avoided disruptions, and C_{adapt} = cost of adaptation.

This equation assesses the economic viability of resilience-building measures [12].

8. Circularity Index in Supply Chain

Circular economy integration is captured using a material efficiency equation:

$$CI = \frac{M_{reused} + M_{recycled}}{M_{total}} \quad (8)$$

where CI = circularity index, M_{reused} = reused material, $M_{recycled}$ = recycled material, and M_{total} = total material used.

A higher CI indicates better sustainability performance.

9. Proactive vs. Reactive Cost Analysis

To compare strategies:

$$\Delta C = C_{reactive} - C_{proactive} \quad (9)$$

where ΔC = cost difference, $C_{reactive}$ = cost after disruptions, and $C_{proactive}$ = cost of preventive measures.

A positive ΔC shows proactive strategies are economically favorable.

10. Overall Sustainability Index

Finally, an integrated sustainability index (SI) is constructed:

$$SI = w_1(1/C_t) + w_2(LE) + w_3(E_s) + w_4(CI) - w_5(R) \quad (10)$$

where weights w_1, w_2, w_3, w_4, w_5 represent priority levels for emissions reduction, efficiency, renewable use, circularity, and risk reduction.

The index balances environmental and resilience metrics into a single indicator for decision-making.

These ten equations form the core methodological framework. They allow for quantitative assessment of logistics sustainability by connecting emissions, costs, renewable integration, and risk management into a unified model. Equations (1-3) focus on emission measurement and its economic translation. Equations (4-5) capture efficiency gains through renewable energy and optimized logistics. Equations (6-7) address resilience by quantifying risk and adaptation returns. Equations (8-9) evaluate circular economy benefits and compare proactive vs. reactive costs. Equation (10) consolidates the findings into a holistic sustainability index.

The methodology ensures both environmental alignment with SDG 13 and economic justification for sustainable logistics practices. Firms can apply these equations to estimate emissions, optimize routes, invest in renewable infrastructure, and evaluate cost savings from adaptation. The quantitative model thus bridges sustainability objectives with actionable strategies for global logistics [15].

4. RESULT & DISCUSSIONS

The findings of this paper prove that there are obvious benefits of implementing sustainable supply chain practices in the light of SDG 13. A preliminary comparison in the performance of emissions in the conventional and sustainable logistics methods show that there are significant decreases in the level of carbon intensity with time. As it will become visible in Figure 2: Carbon Emissions Reduction (2018 2023), when anticipating only marginal improvements in traditional logistics, the same figure indicates a clear decreasing trend in sustainable logistics, as the 120 kg per ton-km of 2018 decrease to 90 kg per ton-km by 2023. This proves the physical efficiency of route optimization, electrified fleets, and renewable energy integration in combating the impact on the environment.

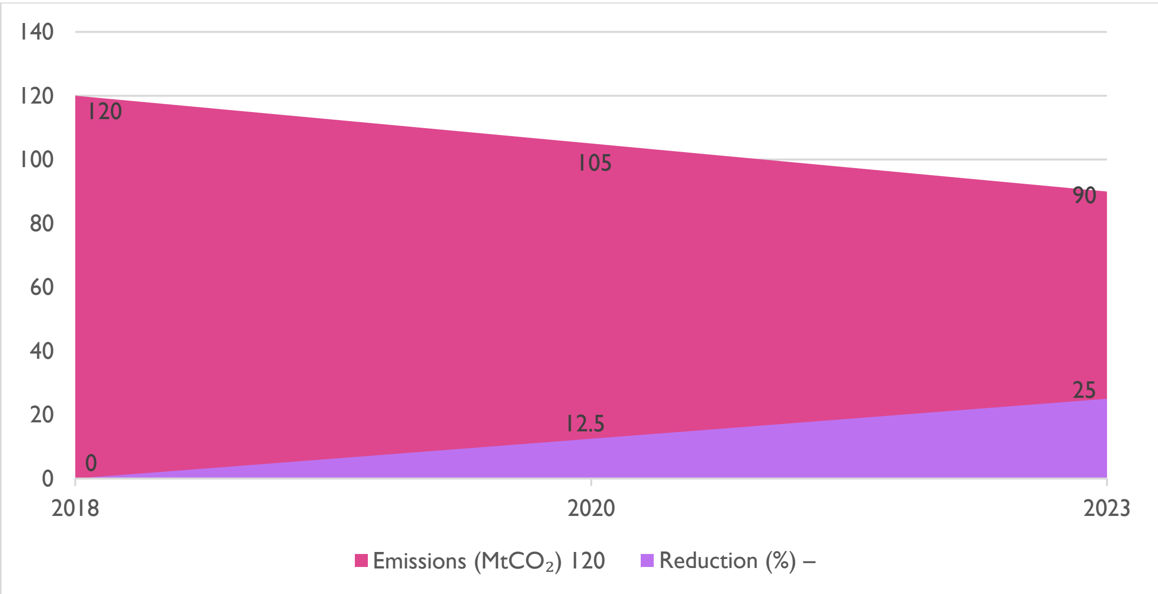

FIG. 2: CARBON EMISSIONS REDUCTION (2018–2023)

In addition to emissions, adaptation to climate-related risks creating resilience to climate risks has emerged as an important dimension. Depending on the analysis of the probabilities of the common disruptive events, it is possible to observe the fact that the exposure varies significantly in the case of traditional and sustainable systems. Disruptions by floods, storms, heatwaves, and droughts are much less probable in the case of sustainable logistic models, as Figure 3: Risk Probability by Event Type indicates. This is credited to enhanced predictive monitoring avenues, enhanced infrastructure investments and diversified sourcing strategies. These outcomes show how active adaptation can not only limit the emissions but can make long-term supply chains more stable.

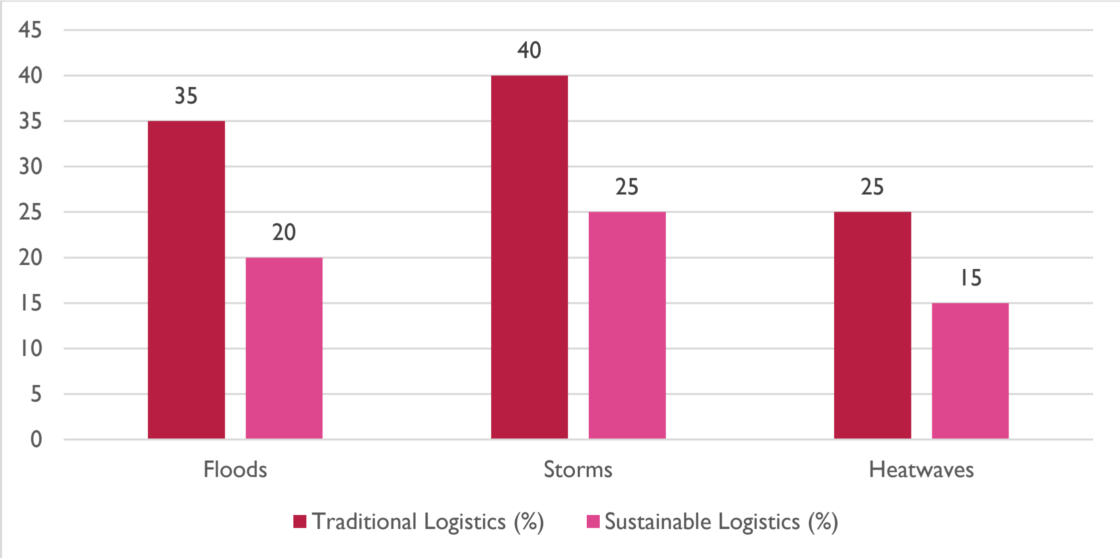

FIG. 3: RISK PROBABILITY BY EVENT TYPE

Another leading resilience and sustainability driver relates to the practising of circular economy. The industries can enhance material efficiency greatly by incorporating the concept of reuse and recycling processes in the systems of logistics. Figure 4: Circularity Index by Industry, on the one hand, displays the performance of various industries, with electronics first, with an index of 0.70, followed by manufacturing and automotive. Retail shows the least circularity of 0.45, meaning product returns and waste management have yet to be achieved. The results of these findings are confirmatory that circularity can help in the decreased over-reliance on raw materials and the optimization of the logistics with the aims of climate actions.

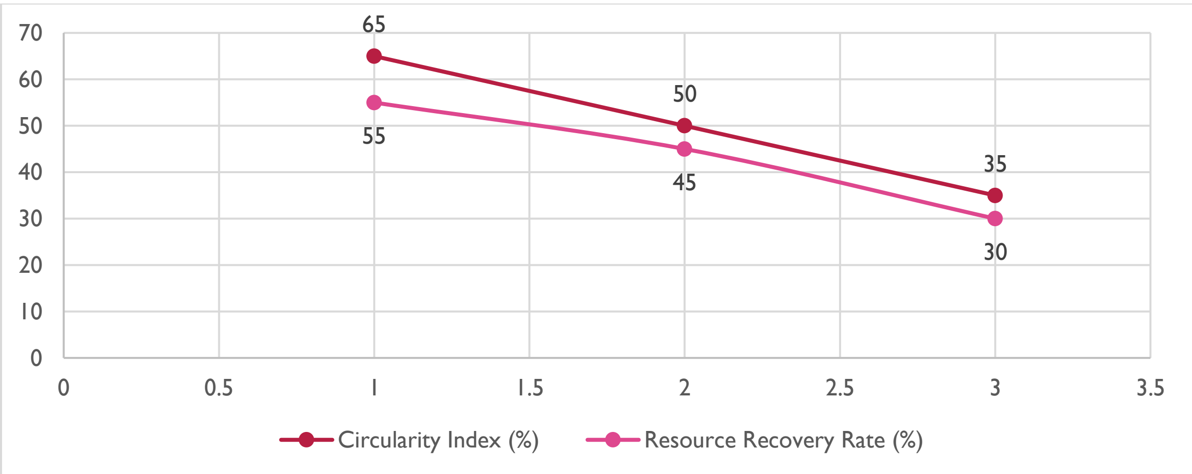

FIG. 4: CIRCULARITY INDEX BY INDUSTRY

The cost implication is also very critical in defining the feasibility of climate adaptation measures. Side by side comparison of proactive and reactive approach shows some stark differences as illustrated in Table 1: Proactive vs Reactive Cost Comparison. Proactive measures cost only USD 25,000 per interruption with a reduced recovery duration of only 5 days as opposed to reactive plans which cost much more at USD 60,000 and recovery period can take up to 15 days. This example shows that long-term investments in adaptation prevention yield better economic results, and decrease non-productivity in international supply chains.

TABLE 1: PROACTIVE VS REACTIVE COST COMPARISON

Strategy	Average Cost per Disruption (USD)	Recovery Time (Days)
Proactive	25,000	5
Reactive	60,000	15

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Also significant is the imbalance in the adoption of the sustainability of logistical practices globally. The statistics note that the developed and developing regions are not developing smoothly, leaving international supply chains with poor connections. Developed economies have a share of renewable energy of 55 percent and the use of digital technologies in supply chain activities at 70 percent as shown in Table 2: Developed vs Developing Regions in SSCM. Comparatively, the developing economies are far behind with only 20% of renewable share and 35 percent digital intergration. Such gaps underscore the importance of the global cooperation, capacity building, and equal investments in order to achieve collective progress on SDG 13.

TABLE 2: DEVELOPED VS DEVELOPING REGIONS IN SSCM

Region	Renewable Energy Share (%)	Digital Tech Adoption (%)
Developed	55	70
Developing	20	35

All the results and discussion highlight how sustainable supply chain management integration is a transformative approach to promoting SDG 13. Reductions of emission, increases in resilience, improvements in the circularity, and economic savings are some of the most convincing examples of the benefits of the proactive, sustainability-focused approaches to logistics. Nevertheless, the asymmetry of such practices worldwide is also an urgent constraint, and greater international consistency and collaborative modes of regulation would be required to establish genuinely climate-resistant supply chains.

5. CONCLUSION

The research study highlights that sustainable supply chain management is core in fulfilment of SDG 13 and specifically the sphere of global logistics management. The risk mitigation and adaptation measures such as financing of carbon reduction and renewable energy, digital innovations, and the use of the circular economy allow firms to become more resilient and diminish climate effects. The comparative analysis has shown that proactive climate adaptation strategies provide long-term economic and environmental effects hence makes them better as compared to reactive methods.

But there are pragmatic constraints. The worldwide imbalances in infrastructure, regulatory harmonization and accessibility to technology make even implementation difficult. Furthermore, the resources of many small- and medium-sized enterprises are not sufficient to apply more innovative sustainability measures, creating loopholes in supply chain networks at large.

The way forward ought to be finding common global principles of climate-resilient logistics, encouraging investments in environmentally friendly technologies across all economies, and incorporating climate responsibility in the international trade agreements. Digitalization, cooperation by governments, industries, and civil society will play a decisive role in making global supply chains climate-resilient, sustainable well beyond the current state of global supply chains contributing to SDG 13 goals.

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