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Resilience and sustainability of supply chains in the face of natural disasters and climate change

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Abstract

In the fast-paced global business, characterised by increasing competition and the necessity of being sustainable, the agility of supply chains (abbreviated as SCR) with their capability to withstand natural hazards and climate change have emerged as critical factors. This paper analyses the strategies and methods that are used to overcome the problems connected to SCR and sustainability in detail. A review of literature shows a wide variety of strategies of which some are comprehensive development plans, innovative risk management techniques, infrastructure adaptation measures, data analytics integration, adherence to quality management principles, strategic management approaches, collaborative efforts, stakeholder engagement initiatives, compliance with regulatory frameworks, and adoption of advanced technologies. With the use of a mixed method research approach, applying both quantitative surveys and qualitative interviews, this study evaluates the strategies' effectiveness and their contribution towards SCR and sustainability. The results show the importance of the immediate implementation of the necessary measures and the joint work to reduce the risks and to guarantee operational resilience. Additionally, the paper examines the interdependency across sectors, which demonstrates the significance of collaborative governance, stakeholder involvement and the linkage with regulatory frameworks in building resilient and sustainable supply chains.

Keywords: Resilience; chains; Natural disasters; Climate change

1. Introduction

The global business environment intensifies its competition, with sustainability and supply chain resilience being critical issues (Saidi et al., 2024). Climate change and natural disaster stand as significant barriers affecting businesses and supply chain making them vulnerable. They also disrupt operations and the global flow of goods and services (Wang et al., 2023). In this light, it is important to proffer solutions to this issue. These solutions cover how businesses should strategically plan, manage risks, adapt infrastructure, and implement quality management systems (Katsaliaki et al., 2021; Ali et al., 2023). Moreover, businesses need to align their strategies with national security and sustainable development goals to foster collaboration and engage stakeholders, adapt big data, embrace technology, and adhere to established regulatory policies (Fritz, 2022; Adewusi et al., 2024).

1.1. Study Background

Natural disaster and climate change have debated for decades as leading causes of supply chain disruption (Katsaliaki et al., 2021). These disruptions have lay off businesses and endangered societies hence putting sustainability and supply chain resilience at the forefront of the global agenda (Scaini et al., 2021; Wang et al., 2023). Supply chain is key in every business as it helps connect different department/sector to achieve a particular business goal. These include farmers, suppliers, marketers, procurements managers, companies, and other relevant stakeholders. Protecting the movement of products and services between these personals is paramount (Zutsara, 2022). As natural disaster and climate change-

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related risks keep increasing, businesses are forced to revise their supply chain strategy and re-strategies how to tackle inherent risks, enhance resilience and align their operations with national sustainability development goals (Wang et al., 2023).

Notably, studies by Ali et al. (2023) and Leitold et al. (2021) highlight social capital, risk management, and infrastructure adaptation as the crucial elements of SCR. Furthermore, some scholars have recently developed and adopted methods to enhance SCR programs. These include predictive analysis, quality management principles, and stakeholder engagement (Katsaliaki et al., 2021; Fritz, 2022; Adewusi et al., 2024). Nevertheless, this review relies on varied sources from different aspects of supply chain resilient strategy, risk management, infrastructure adaptation, planning for strategic operations management, data analytics for predictive modelling, quality management principles, the strategic management of national security and the sustainable management strategies, stakeholder engagements and collaboration, regulatory and policy frameworks, and technology adoption and innovation.

1.2. Purpose of the Study

The purpose of this paper is to investigate the resilient approaches and strategies applicable to supply chain vulnerabilities given the impacts caused by climate change and the risks posed by natural disasters. Thus, it will investigate the literature and the research to identify the disruptions, factors, and possibilities for stability and continuity in the supply chain. In addition, mixed method research consisting of qualitative and quantitative data collection and analysis will be integrated to gain understanding related to SCR and sustainability in natural disasters and climate change.

1.3. Research Question

What are the most effective supply chain and sustainability strategies businesses can adopt in the face of natural disasters and climate change?

Research Objectives

- To review existing literature on SCR and sustainability related to climate change and natural disasters.
- To examine the effectiveness of various strategies in supply chains and sustainability including strategic planning, risk management, infrastructure adaptation, sustainability integration, quality management, stakeholder engagement and collaboration, regulatory frameworks, and technology adoption.
- To identify challenges and opportunities in resilience and sustainability measures and within supply chains.
- To recommend how to enhance the resilience and sustainability of supply chains in the face of natural disasters and climate change.

2. Literature Review

2.1. Strategies for Building Resilient Supply Chains

In the face of rising climate change and natural disasters (Wang et al., 2023), SCR has become an important factor in modern trade. The interconnections of supply chains between industries and regions intensify the impacts of such disruptions, demanding the development of plans and strategies for resilience building. Spikes in extreme climate events like China's heatwave impending food shortages, Italy's drought-driven supply chain disruptions, and Pakistan's hard-hit floods are evidence of the dire and urgent need for resilient mitigation strategies (Ali et al., 2023). Ali et al. (2023) examine how the extent of exposure to climate change affects SCR among agricultural producers and the role of social capital and network complexity in this process. However, the research following the standard protocol with data from 260 firms in Australian food supply chains reveals that social capital, both intra and inter-firm, is a crucial mediating factor between climate change exposure and SCR.

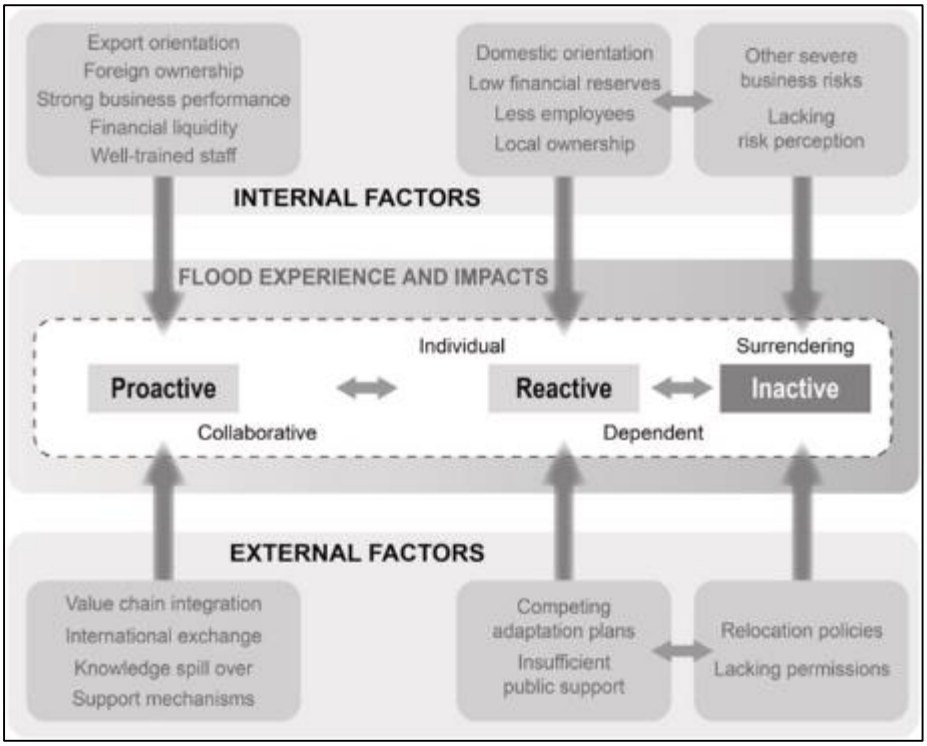

Figure 1 Firm adaptation framework: factors determining adaptive responses (Leitold et al., 2021)

Furthermore, Leitold et al. (2021) illuminate a firm adaptation framework where the proactive strategies for floods in Ho Chi Minh City (HCMC) are influenced by internal and external factors. The external risk management systems, especially the systems that are linked to international value chains, significantly affect firms' adaptation strategies to floods. Consequently, this results in proactive actions such as site elevation and drainage system installation. The expected action of the government towards flood risk management or industrial park administrations often does not get implemented, and firms are left to collaboratively manage risks (Scaini et al., 2021).

2.2. Innovative Risk Management Approaches

Innovative risk management approaches have become crucial in modern supply chain management because of the increasing incidence and severity of natural disasters and climate change-related disasters. With the changing nature of global trade and instability in supply chain dynamics, businesses face diverse risks including geopolitical tensions, shifting in demand and delays in transportation (Bednarski et al., 2023). John et al. (2021) highlight that risk evaluation and management should be considered as an integral part of supply chain management. They point out recent risk management strategies which imply not only risk identification but also possible future risks and vulnerability forecasting. In addition, they incorporate the utilisation of IoT, blockchain as well as AI to heighten SCR (John et al., 2023).

On the other hand, Jegede et al. (2020) opine that insurance models provide a platform that mitigates the supply chain from disaster and climate change risks. They study various insurance products and risk-sharing methods which represent companies as the proper alternative for minimising financial losses resulting from disruption of the supply chain. Their article describes the position of insurance as an adaptive tool to mitigate the risk exposure in the conventional banking system and, this reflects more insurance involvement in the risk management activities of SCR.

2.3. Infrastructure Adaptation for Supply Chain Resilience

Lewin et al. (2023) emphasise climate change-related risks and natural disasters as the most urgent problem for SCR and operations management. Their report concludes by providing a detailed framework strategy, which identifies all possible impacted areas and measures to be taken to minimise the negative influence of disasters on infrastructural performance. In line with the views of Lewin et al. (2023) on infrastructure resilience, Adger et al. (2018) propose some strategies to guide climate adaptation and resilience planning. They illustrate how relevant risk-based policies for climate adaptation can be implemented by identifying the trigger points and acting immediately to maintain much-needed resilience.

Furthermore, incorporating climate scientists and risk management techniques into the infrastructural planning process helps planners develop quick response strategies that are flexible in dealing with any environmental changes (Adger et al., 2018). Shahzad et al. (2022) suggest implementing modular construction technology to simultaneously enhance infrastructure adaptability and resilience. In their findings, modular construction is flexible with multiple choices and can be modified as needed, to adapt to the changing situation.

2.4. Strategic Planning for Continuity in Operations Management

Strategic planning for continuity in operation management has become so significant in organisations due to the high level of competition, business condition uncertainty, natural disasters, and climate (Khaw, 2022). Hubbart (2023) notes that businesses that face challenges of uncertainties and changing consumer expectations and respond fast have improved performance and competitive edge over their competitors. As a result, the ability of an organisation to handle and resist disruption becomes a major determinant for such organisations which not only want to survive in such an environment but also to succeed. Thus, having a well-structured business continuity plan is essential for operation management.

Table 1 Strategic Plan for Continuity in Operations Management

Strategic Planning Component	Description
Risk Assessment and Mitigation	Conduct comprehensive risk assessments to identify risks associated with natural disasters and climate change. Subsequently, implement measures to reduce the impact of identified risks (Stringer et al., 2020).
Diversification of Supply Sources	Design supply systems to reduce dependence on a single supplier. Strive for geographical diversification to prevent regional disruptions (Bednarski et al., 2023).
Agile Logistics Networks	Build agile logistics networks for swift and flexible response. Implement real-time monitoring systems that can track supply chain activities and detect disruptions in time (Zamani et al., 2022).
Resilient Infrastructure Investment	Invest in resilient infrastructure that can stand against the effects of natural disasters and climate change. This includes incorporating advanced technologies, and reinforcing critical infrastructure against possible threats (Stringer et al., 2020).
Cross-Functional Collaboration	Promote collaboration and communication between all departments and stakeholders (Siems et al, 2022).
Data Analytics for Predictive Modeling	Adapt data analytics for predictive Models to foresee possible risks and take countermeasures (Adewusi et al., 2024).

Table 1 outlines the conceptual framework for strategic planning to ensure operational continuity in businesses in the face of natural disasters and climate change. These strategic planning elements establish a robust framework that allows uninterrupted operations management despite risks posed by climate change and natural disasters.

2.5. Data Analytics for Predictive Modeling and Risk Assessment

A key aspect of supply chain resilience involves integrating data analytics and predictive modeling into supply chain management operations. Adewusi et al. (2024) highlight that predictive analytics is a managerial tool used within the supply chain to transform data into actionable information for improved decision-making and consequentially, improved outcomes (Adewusi et al., 2024). Utilising historical data in predictive analytics designs enables businesses to foresee/predict various disruptions and picture the evolution from various scenarios. They can also use the data to design the most appropriate framework to tackle future risks (Adewusi et al., 2024). This is in line with the continuity operations management's conceptualised strategic plan.

Additionally, predictive analysis is a crucial element of SCR, this is accentuated in case studies presented by Adewusi et al. (2024). The data analysis shows that predictive analytics method is highly accurate and is applicable in real life for swift monitoring and preventive risks. In supply chain, however, predictive analysis may be problematic due to it technicality. Most businesses often ignore predictive analysis due to lack of skills and manpower, and as a result, endangers their business to natural disasters and climate change-related risks. Notwithstanding businesses that would want to thrive in the face of natural disasters and climate change must ensure to be equipped with technological

capabilities such as the IoT and machine to detect risks and dictate patterns and other potential anomalies before they occur (Zamani et al., 2022).

2.6. Application of Quality Management Principles

Total Quality Management (TQM) is crucial in supply chain processes for sustainable business operations. Quality issue is one of the pitfalls of many businesses. Thus, applying TQM implies taking account of the entire circle of the business including its supply chain, operations, management, and administration (Katsaliaki et al., 2021). In the case of climate change, natural disasters, TQM requires thorough check on the inventory, suppliers, materials and the technology adopted. However, it may fail to account for employee performances. Karamouz et al. (2020) explain the importance of performance measurement and how TQM helps organisations in their quality assurance measures. According to them, the TQM translates strategy into behaviour, monitors progress, and motivates employees.

Nonetheless, performance indicators selected inappropriately may not portray the real situation in the company, hence the need to develop both financial and non-financial measures to efficiently evaluate quality management performance (Rasit et al., 2018). To address those gap areas, Karamouz et al. (2020) identify quality management performance indicators at different levels including supplier, customer, or enterprise among others. They also note that most companies lack quality management strategies due to a lack of knowledge and resources.

2.7. Strategic Management for National Security and Sustainability Goals

The incorporation of sustainability and resilience into supply chain management has become an inseparable part of the global market as supply chains have become lifelines of economies. Saidi et al. (2024) point out that supply chain operations should be coordinated with broader national security and sustainability objectives, which should be aimed at economic stability, environmental protection, and social welfare. The research acknowledges the leading role that supply chains play in ensuring lasting profitability of economies without hindrances and environmental and social compliance. This resonate with broader sustainability goals of achieving business sustainability in the face of natural disasters and climate change. However, their study fails to capture the challenges involved when implementing national security and sustainability goals as this could help businesses and society corporate with relevant authorities and stakeholders in the process of implementation.

Notwithstanding, Shekarian et al. (2022) shed light on the integration of sustainability into supply chain management through their research. They suggest that sustainable supply chain management entails taking into account environmental, social and economic factors throughout the whole supply chain lifecycle. While businesses struggle to align the overall business goals with national policies and sustainability goals, they become vulnerable to disasters, and sanctions from the government. As such, businesses need to be aware that these policies and sustainablity goals are meant to protect them from threatening forces such as natural disasters and climate change related risks. In this way, they can not only reduce their footprint on the environment and social sector but also create a stronger resilience and become a part of the national sustainable dynamics.

2.8. Collaboration and Stakeholder Engagement

Collaboration and stakeholder engagement are identified as basic building blocks of resilient and sustainable supply chains in the face of natural disasters and climate change (Fritz, 2022). Effective collaboration is necessary among businesses, governments, non-governmental organisations (NGOs), and international organisations, as supply chains are very interdependent and there are various stakeholders involved. As mentioned by Siems et al. (2022), the role of non-traditional supply chain stakeholders, including NGOs and competitors, could not be understated in sustainability goal achievement. Organisations must therefore bring these stakeholders into supply chain practices for them to benefit from shared knowledge and resources to combat environmental and social challenges.

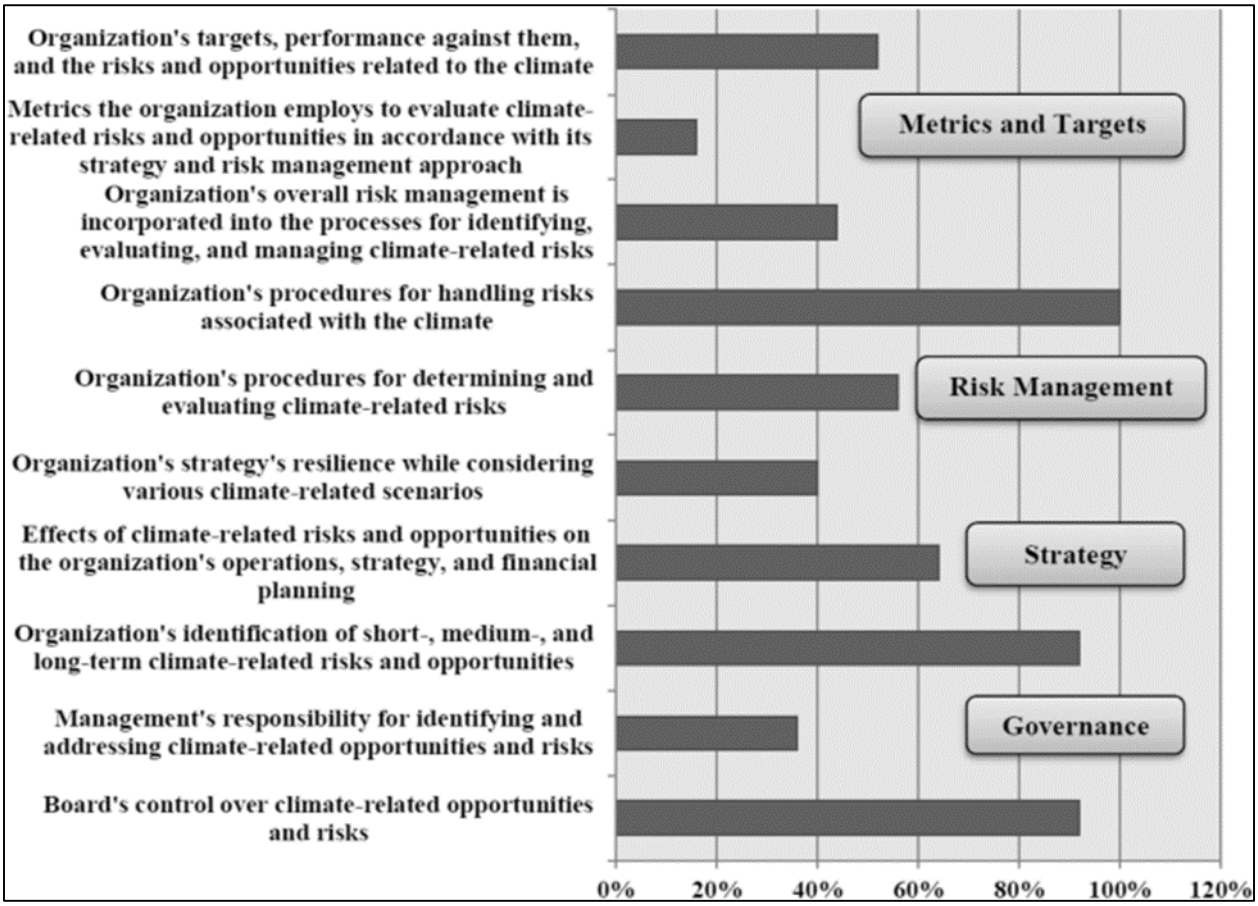

Figure 2 Climate Change-Related Risk Management (Megeid, 2024)

However, Megeid (2024) evaluates the contribution of stakeholders in risk management. The researcher notes that stakeholders are essential for creating widespread industry awareness, adoption and consequent integration of sustainable supply chain management (SSCM) practices. He also emphasises the role of the Task Force on Climate-related Financial Disclosures (TCFD) to guide their climate-related financial disclosures and strategic planning for investors.

2.9. Regulatory and Policy Framework Analysis

The regulatory and policy landscape plays a key role in determining the resilience and sustainability of supply chains since governments and international organisations usually create regulatory frameworks to define issues and support responsible practices (Truant et al., 2024). The global uncertainties and social-environmental problems have drawn attention to the need for stable regulations and policies aimed at coping with supply chain disruptions as well as comprehensive recovery. Manurung et al. (2023) emphasise SCR and its necessity to improve the supply chain. They propose a service-dominant logic (SDL) approach which through value co-creation recognizes it as the key feature of SCR towards sustainability.

The SDL has been considered an effective mechanism for increasing both public awareness and sustainability. However, continuous research must be conducted on how SDL principles can be strategically utilised for developing policy and regulatory framework. SDL increases stakeholder transaction benefits; however, the ideas should be realisable by assessing mechanisms of regulation and governance structures (Manurung et al., 2023). Therefore, policymakers must incorporate SDL principles into regulatory institutions to ensure the adoption of an inclusive and sustainable approach.

2.10. Technology Adoption and Innovation

Technology is a key player in solving complex emerging challenges like disruptions in the supply chain and sustainability issues. Yousefi and Tosarkani (2024) examine how blockchain technology (BT) can help enhance the efficiency of sustainable supply chains (SSC) in terms of social and environmental aspects. Adopting the systemic approach, their research attempts to reveal how SSC results are linked to BT implementation. The study uses the fuzzy

cognitive map to model the relationship between the objectives of SSC performance and BT adoption (Yousefi and Tosarkani, 2024). The outcomes show that blockchain is the basis of sustainable development of several dimensions, including but not limited to environmental balance, smart contract development, and product traceability. However, the study pinpoints some of the organisational challenges such as financial barriers which might slow down the wide use of this technology (Yousefi and Tosarkani, 2024).

Further, Mohamed et al. (2023) focuses on the smart IoT-driven real-time monitoring system, which is a tool to access supply chain visibility and responsiveness. Thus, businesses can keep track of their production sites in real-time through the Internet of Things sensors and smart data analysis, which will enable them to implement countermeasures before the actual occurrence of the problems and make intelligent decisions (Mohamed et al., 2023).

3. Research Methodology

3.1. Research Design

The study design involves mixed methods, comprised of both quantitative and qualitative approaches. This method will help to come up with different strategies for improving the SCR and sustainability in the face of natural disasters and climate change. Quantitatively, data collection via surveys and statistical analysis will allow us to measure the effectiveness of the different strategies. Meanwhile, qualitative interviews with the supply chain professionals and major stakeholders would offer in-depth information on the challenges, advantages, and customary practices associated with this area (Kuehn and Rohlfing, 2022). The research is both exploratory and descriptive, which means that it investigates the current sustainability and resilience practices within the supply chain and identifies the underlying reasons for them.

3.2. Data Analysis

This study will adopt descriptive statistics to analyse the survey data to validate the variables and check the impact of different approaches on SCR and sustainability (Kuehn and Rohlfing, 2022). Additionally, it will employ a thematic analysis to analyse the interview transcripts in so as to determine the dominant themes, patterns and insights about supply chain management practices, challenges and opportunities.

3.3. Ethical Considerations

All participants will be fully provided with information about the research purpose and thee importance of their contribution, while assuring them of confidentiality of their responses (Arellano et al., 2023). They will also be informed to provide unbiased responses. An informed consent form will be provided to each survey respondent and interviewee before commencing the research process. Participants' responses will be stored in confidentiality and measures will be taken to maintain the anonymity of the respondents. Measures will also be taken to avoid unauthorised access, data breaches and misuse of research data.

4. Result

This study reveals the complex nature of the risk management of the supply chains in the context of natural disasters and climate change effects focusing on the global business environment. Wang et al. (2023) emphasise the alarming upsurge in the CO2 concentrations in the atmosphere in 2022 which reached a level of 417. 2 ppm, representing a 51% increase from the pre-industrial levels. Human activities, such as the burning of fossil energy, have taken the majority of the blame. Despite a 5. 4% decrease in emissions during the COVID-19 pandemic of 2020, the world emission of 36. 1 ± 0. 3 GTCO2 was still beyond expectation, which implied the dominance of the pre-pandemic growth. The major contributors to global emissions including China, the US, The EU, India, and Russia comprise 65% of the collective emissions, while emerging economies generating the biggest increase in emissions are the ones that require tailored mitigation strategies to keep within 1. 5 °C (Wang et al., 2023).

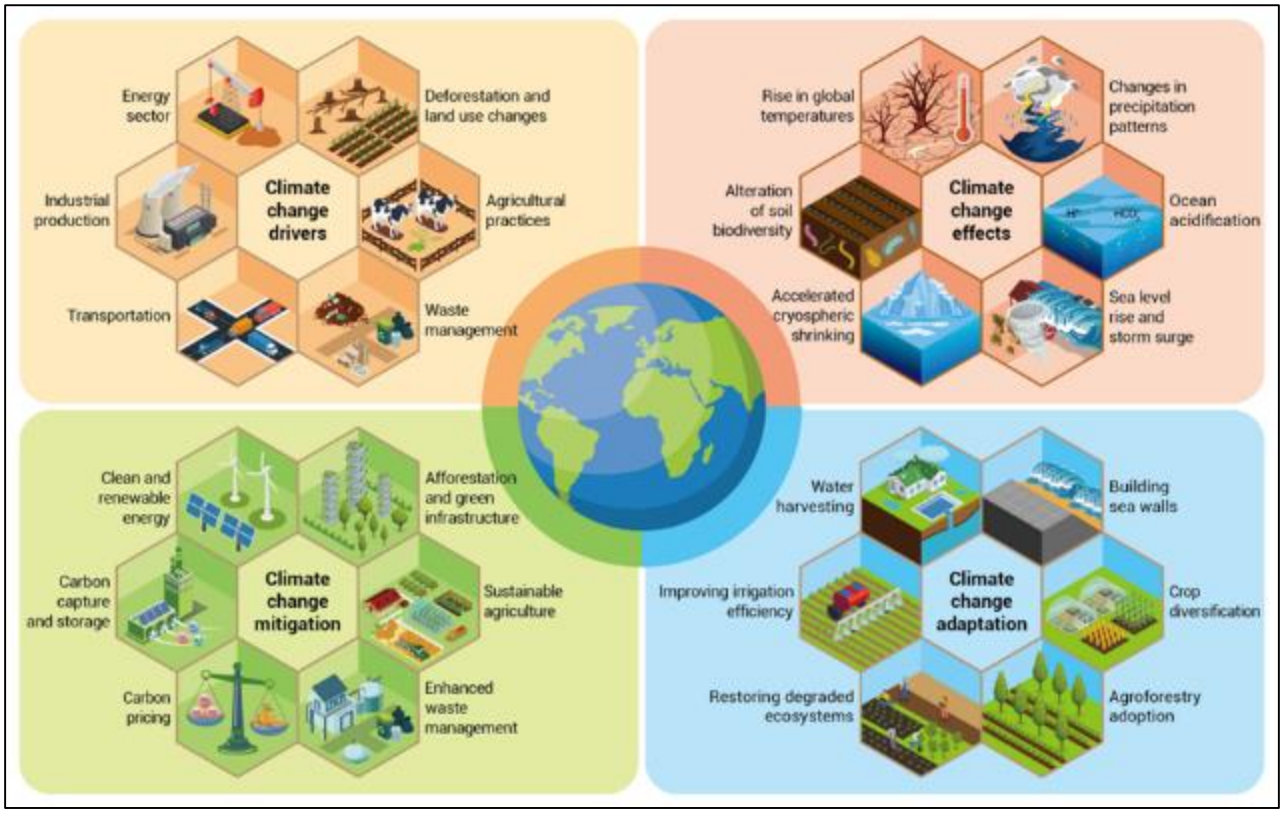

Figure 3 Climate Change Drivers, Effects, Mitigation, and Adoption (Wang et al., 2023)

On the other hand, in a survey on flood risk and river management by Scaini et al. (2021), respondents had different opinions on flood issues, with about 33% agreeing, 35% disagreeing, and 30% neither agreeing nor disagreeing about current river management. On the other hand, there was agreement (88%) that mitigation of the flood risk is a possible investment into the preservation of the river. Most citizens note that they are either not satisfied or not sure if flood risk management takes into account their sentiments. This finding implies that community interest in natural disaster risk management is high.

On a broader scale, the results about flood risks and river management align with the discussion on the sustainability of the supply chain that highlights the importance of stakeholders' involvement and policy framework. Just like stakeholders' involvement makes a supply chain visible and reliable, community engagement should be centric on flood risk management. The literature review findings highlighted the role of policy and regulation in enhancing SCR and sustainability. Hence, policymakers can create an environment conducive to resilient infrastructure and community involvement both in the supply chains and natural disaster-related risk management if they encourage organisations to promote eco-friendly practices and guidelines that will help to achieve the goals of sustainability. These findings thus propose a holistic approach which allocates strategies, innovations, collaborations and policy backing to come up with strong and sustainable systems that can deal with challenges related to natural disasters and climate change globally.

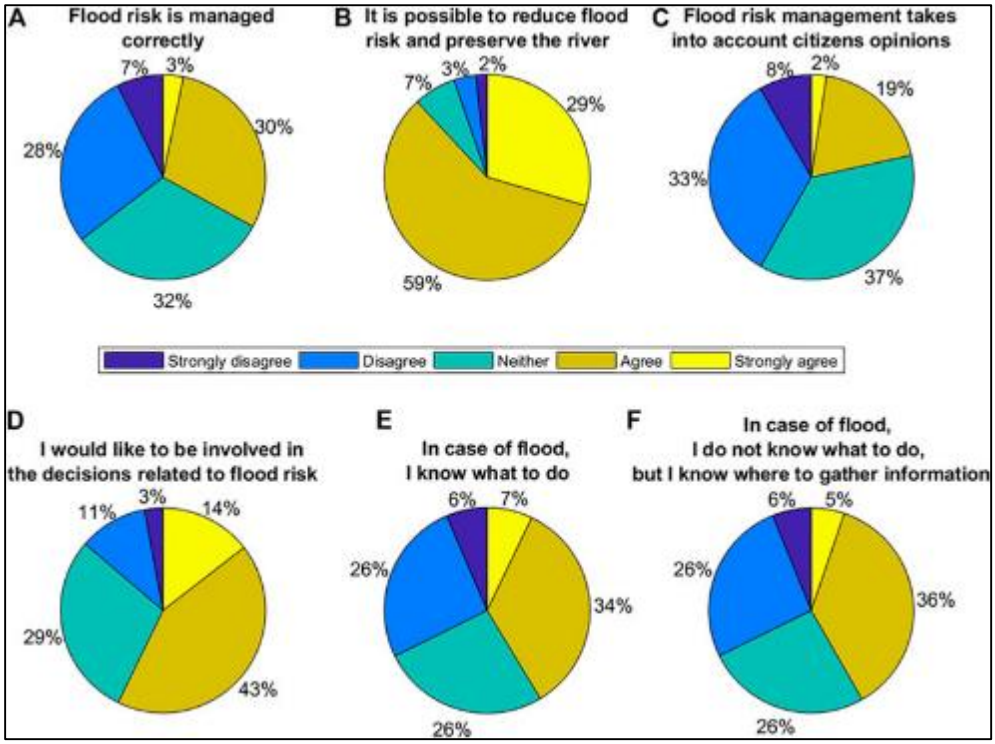

Figure 4 Flood Risk and River Management Survey Response (Scaini et al., 2021)

5. Discussion

This discussion covers the diverse issues of SCR and sustainability in the context of natural disasters and climate change, considering diverse perspectives from the literature review. The results indicate the need for overall strategies to minimise risks and build resilience in different areas. The study, carried out by Wang et al. (2023), highlights the disturbing rise in levels of CO2 and the effects on climate. As a result, there is a need for innovative mitigation strategies to curb emissions on the global level. Moreover, Scaini et al. (2021) point out divergent perceptions in their survey concerning the management of flood risks that motivate immediate community engagement and involvement of stakeholders to provide societies and organisations with stronger resilience.

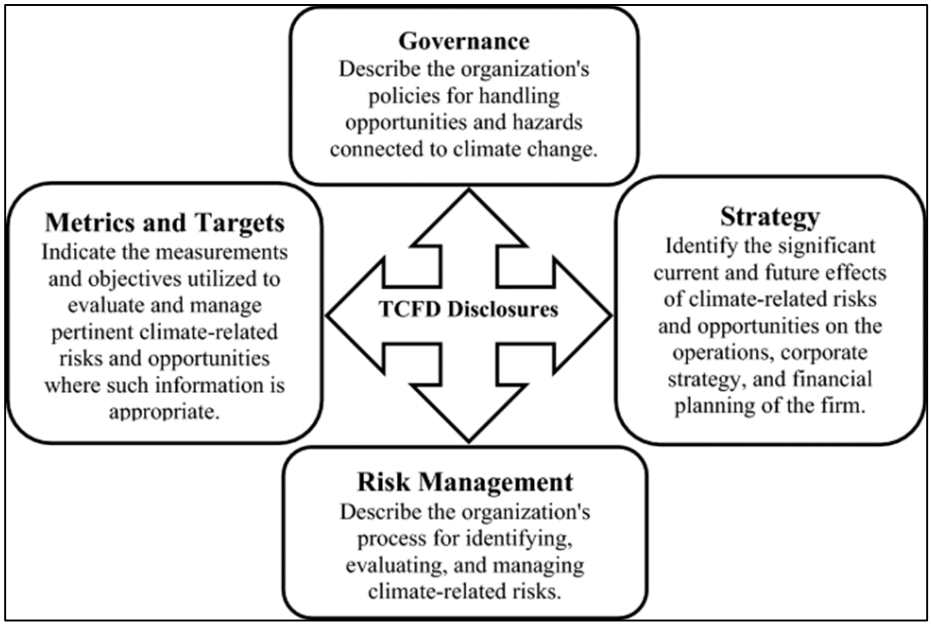

Figure 5 TCFD Framework (Megeid, 2024)

In addition, organisations can adopt the TCFD framework based on the recommendations of the Financial Stability Board for climate-related financial disclosure and resilient strategies. Moreover, this framework identifies governance, strategy, risk management and metrics/targets to be the four core dimensions of an effective strategy informing the stakeholders on the organisation's stance on climate change. The implementation of sustainability principles in supply chain management by Saidi et al. (2024) and Shekarian et al. (2022) also reinforces the need to match business operations with national goals towards sustainability and security.

Additionally, regulatory and policy frameworks also play a critical part as indicated by Manurung et al. (2023) in creating the right ecosystem that enables companies to manage climate-related risks seamlessly. In addition, technology application and innovation act as the driving force for enforcing supply chain resiliency. The works of Yousefi and Tosarkani (2024), as well as Mohamed et al. (2023), show the opportunities for deploying the technologies of blockchain and IoT in improving supply chain visibility, traceability, and responsiveness respectively. Nevertheless, financial problems and regulatory matters must be dealt with for the progress of such technologies into widespread use.

5.1. Cross-Sectoral Findings and Policy Implications

The cross-sector findings illustrate the necessity of holistic strategies in handling the impacts of natural disasters and climate change globally. The integration of SCR literature with climate science and risk management helps to prove how governance, strategy, the fight against risks, stakeholders' involvement and innovation technologies are tightly linked with each other in the process of designing strong sustainable systems. Policy implications stress the importance of joint activities of government, organisations, NGOs and international organisations to create regulatory systems supporting climate change adaptation and sustainable growth.

6. Conclusion

This study provides insights into the essential strategies and approaches for improving SCR and sustainability during natural disasters and climate change. The exhaustive literature review and the analysis of different factors affecting supply chains underline the beneficial role of prompt measures in eliminating risks and maintaining the normalcy of operations. As a result, the study presents a wide range of strategic actions that include risk management innovations, infrastructure adaptation, strategic planning as well as technology adoption. The results also pinpoint collective action, engagement, and regulations as the key success factors in creating a suitable atmosphere for sound infrastructure and community development. Through this holistic approach, different stakeholders like organisations and policymakers will be able to counter challenges associated with climate change and natural disasters and put in place systems that will withstand the complexities involved.

Recommendations

- **Conduct Scenario Analysis:** Businesses need to conduct scenario analysis to enable them to uncover their climate risks as well as potential natural disasters. This will help them make informed decisions/strategies.
- **Implement Robust Risk Management Processes:** Businesses should incorporate efficient risk management processes that adequately identify, assess and control climate risks to ensure that different risks are properly managed.
- **Set Metrics and Targets:** Set up monitoring indicators that are aligned with the sustainability and climate change objectives for the assessment of performance and strategic planning.
- **Enhance Stakeholder Engagement:** Partner with key players including communities, governments, NGOs, and international organisations.
- **Align with Regulatory Frameworks:** Comply with regulatory frameworks as well as policies that support sustainability initiatives and improve SCR.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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