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Enhancing Waste Management in Cold Supply Chains via Digital Transformation

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Abstract

The urgency of addressing the climate emergency has underscored the need for immediate action to mitigate its catastrophic effects, with cold chains identified as significant contributors to greenhouse gas emissions and environmental degradation. This paper explores the potential of digitalization to enhance sustainability within cold chains by leveraging technologies such as IoT, AI, and blockchain. Through a comprehensive investigation, the study aims to identify opportunities for optimizing processes, reducing waste, and minimizing environmental impact throughout the cold chain network. The research addresses urgent sustainability challenges, investigates the influence of digitalization on waste management, and provides practical insights aligned with global sustainability goals. Drawing on theoretical frameworks and empirical evidence, the study develops a framework integrating Industry 4.0 principles with Sustainable Corporate Theory to address waste efficiency in cold supply chains. The framework offers practical strategies for operationalizing waste efficiency and promoting sustainability within cold chain management. Implications of the findings include enhanced efficiency, improved product quality, sustainability compliance, and cost savings. However, the study acknowledges limitations and highlights avenues for future research, including technological challenges, behavioural factors, environmental impact assessment, and long-term sustainability considerations. Overall, this paper contributes to advancing our understanding of digital transformation in cold chain logistics and underscores the importance of addressing sustainability challenges in supply chain management.

Keywords: Cold chain management, digitalization, sustainability, waste efficiency, Industry 4.0

1. Introduction

The global community faces a "climate emergency" necessitating immediate action to mitigate its catastrophic effects [1]. With each passing year, scientific evidence further underscores the urgency, emphasizing the limited time available to implement effective solutions [2]. Among the critical contributors to greenhouse gas emissions and

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environmental degradation are cold chains, essential for preserving the integrity of perishable goods during transportation and storage.

Cold chains, while vital for food and pharmaceutical industries, exact a significant toll on the environment through their energy-intensive operations, substantial waste generation, and greenhouse gas emissions. The World Bank [3] and the International Energy Agency [4] have highlighted the immense impact of cold chains on energy consumption and waste production, emphasizing the pressing need for efficiency improvements.

This study seeks to address these challenges by exploring the potential of digitalization to enhance sustainability within cold chains. By leveraging digital technologies, such as Internet of Things (IoT), big data analytics, artificial intelligence (AI), and blockchain, it aims to identify opportunities for optimizing processes, reducing waste, and minimizing environmental impact throughout the cold chain network. Through this investigation, the study aims to contribute to the development of innovative solutions that align with global sustainability goals while meeting the evolving demands of modern supply chain management.

This research holds significance in addressing urgent sustainability challenges, such as waste efficiency and achieving net-zero emissions, with a specific focus on the cold supply chain (Fatorachian, 2023, 5). By investigating the influence of digitalization, it bridges existing knowledge gaps and informs stakeholders about the benefits and risks associated with technology adoption. Aligned with Sustainable Development Goals and national policies, the study provides practical insights into leveraging digital solutions for waste reduction in cold chains.

The primary objective is to investigate how Industry 4.0-enabled digital solutions influence waste efficiency in cold supply chains. Key research questions include the contribution of digitalization to waste management and the primary opportunities associated with digital solutions in cold chains. The study follows with a theoretical framework, methodology, findings, and implications for future research.

The next sections of the paper will outline the research background and research methodology employed in this study, detailing the approach and techniques used to gather and analyse data. Following this, the findings from the data analysis will be presented and discussed, providing insights into the key themes and implications for Supply Chain Disruption Management (SCDM).

2. Research Background

Efficient management of the cold chain is paramount to ensuring the integrity and safety of perishable goods throughout their journey from production to consumption. Cold chains encompass a series of interconnected processes and infrastructure designed to maintain specific temperature conditions essential for preserving the quality and freshness of temperature-sensitive products, such as food and pharmaceuticals. Any deviation from the required temperature range can result in product spoilage, loss of quality, and potential health hazards for consumers.

Temperature variations within the cold chain pose significant challenges, highlighting the critical need for optimization in both processes and infrastructure [6, 7]. Variability in temperature can accelerate the degradation of perishable items, leading to economic losses for businesses and contributing to food waste on a global scale. Therefore, ensuring consistent and controlled temperature conditions throughout the supply chain is imperative for mitigating these risks and maximizing product shelf life.

Waste within the cold chain arises from various sources, each presenting unique challenges to efficiency and sustainability. Inadequate storage facilities, improper handling practices, and logistical bottlenecks can all contribute to waste generation along the cold chain [8]. For example, insufficient refrigeration capacity or malfunctioning equipment can lead to temperature excursions, rendering products unfit for consumption and resulting in significant financial losses for businesses.

Addressing these challenges requires a multifaceted approach that integrates technological innovation, process optimization, and collaborative efforts across the supply chain (9). Ongoing research plays a crucial role in identifying emerging trends, evaluating existing practices, and developing novel solutions to enhance cold chain efficiency and sustainability. By investigating the root causes of waste and inefficiency, researchers can propose targeted interventions and best practices to improve the performance of cold chain networks and minimize their environmental footprint.

In summary, the effective management of the cold chain is essential for preserving the quality, safety, and integrity of perishable goods. Temperature control, waste reduction, and logistical optimization are key areas of focus for

enhancing cold chain efficiency and sustainability. Ongoing research efforts are vital for identifying challenges, exploring opportunities, and driving innovation within the cold chain industry to meet the evolving demands of global supply chain management.

2.1. Advanced digitalization

Advanced digitalization, particularly within the context of Industry 4.0, has revolutionized supply chain management, including cold chain logistics. This transformation is marked by the integration of various digital technologies that enhance operational efficiency and sustainability.

Firstly, the Internet of Things (IoT) plays a crucial role by enabling real-time monitoring of inventory and production processes in the cold chain (10;11) IoT sensors facilitate proactive identification of inefficiencies, allowing stakeholders to address issues promptly and prevent spoilage or loss of temperature-sensitive products [12].

Additionally, big data analytics and artificial intelligence (AI) are instrumental in optimizing supply chain processes. By analysing large datasets, these technologies provide insights that improve decision-making, leading to more efficient resource allocation, better inventory management, and enhanced overall performance [13].

Blockchain technology further enhances cold chain management by ensuring traceability and transparency. By securely recording transactions and product movements, blockchain enables stakeholders to track the entire journey of perishable goods, thereby reducing the risk of waste and enhancing trust and accountability within the supply chain [14].

Furthermore, Industry 4.0 facilitates the adoption of sustainable practices in cold chain logistics. For instance, predictive maintenance techniques leverage data analytics to anticipate equipment failures, reducing downtime and preventing disruptions in the supply chain [15;16]. Similarly, smart packaging solutions utilize sensors to monitor product quality and conditions, thereby minimizing spoilage risks and preserving the integrity of temperature-sensitive items [17].

Overall, the integration of digitalization and Industry 4.0 technologies in cold chain management leads to real-time monitoring, predictive analytics, and sustainable practices that contribute to waste reduction and product integrity. Continued innovation in this area is crucial to further enhance efficiency and sustainability in the cold chain industry, aligning with broader sustainability goals and initiatives.

2.2. Theoretical approaches

In In the realm of cold chain logistics, the imperative to efficiently reduce waste is underscored by a profound commitment to sustainability and environmental stewardship. This sentiment resonates with Sustainable Corporate Theory, which posits waste minimization not merely as an ethical obligation but also as a strategic imperative for businesses striving to curtail their ecological impact [18]. By aligning waste reduction efforts with broader sustainability goals, companies can enhance their environmental credentials while also optimizing operational efficiency.

Moreover, the fusion of digitalization and technology represents a pivotal aspect of sustainable corporate practices [19]. The advent of Industry 4.0 technologies introduces transformative prospects for waste reduction within cold chain logistics. By leveraging digital tools and technological innovations, such as IoT sensors, AI algorithms, and blockchain systems, companies can enhance transparency, visibility, and overall supply chain performance [120]. These advancements empower stakeholders to make informed decisions, optimize resource allocation, and streamline processes, thereby fostering a more sustainable and efficient cold chain ecosystem.

Academic discourse surrounding these theoretical frameworks provides valuable insights into the development and implementation of effective waste reduction strategies within the cold chain industry. By integrating principles from Sustainable Corporate Theory and harnessing the potential of Industry 4.0 technologies, businesses can navigate the complexities of modern supply chain management while simultaneously advancing sustainability objectives. Through scholarly research and practical application, stakeholders can collaboratively drive innovation and promote environmental responsibility across the cold chain landscape.

3. Research Methodology

To explore the impact of digitalization on waste efficiency within cold chains, this study employed a rigorous qualitative research methodology. The research was designed to capture the complex, multifaceted nature of digitalization's influence on cold chain operations, particularly focusing on waste management and sustainability. The chosen methodology provided a framework for deep, context-rich exploration of the participants' experiences and perceptions.

3.1 Data Collection Methods

The primary data collection methods consisted of four in-depth interviews and two focus group workshops. These methods were chosen for their ability to elicit rich, detailed information from a range of perspectives, both from academic stakeholders and industry practitioners engaged in cold chain operations and businesses.

In-Depth Interviews: Four semi-structured interviews were conducted with key informants from the cold chain sector, including managers, logistics coordinators, and digital technology specialists. The semi-structured format allowed for a balance between structured inquiry and open-ended discussion, enabling participants to provide comprehensive insights into their experiences and perceptions of digitalization and waste efficiency in cold chains. Each interview lasted approximately 60 to 90 minutes and was conducted either face-to-face or via a secure video conferencing platform to ensure confidentiality and comfort for the participants.

Focus Group Workshops: Two focus group workshops were organized, each comprising 6 to 8 participants representing a mix of academic researchers, policymakers, and industry experts. These workshops provided a collaborative environment where participants could engage in dialogue, share experiences, and discuss challenges and opportunities related to digitalization and waste management in cold chains. The workshops were facilitated using a semi-structured guide to ensure that all relevant topics were covered while allowing for dynamic discussion and interaction among participants. Each session lasted approximately 2 hours.

3.2 Justification for Qualitative Approach

The choice of a qualitative research methodology was deliberate and strategic. A qualitative approach allows for an in-depth exploration of complex phenomena, capturing the subjective experiences and nuanced understandings of participants. This is particularly valuable in the context of digitalization and waste efficiency in cold chains, where the interplay between technology adoption, operational practices, and sustainability outcomes is intricate and context-dependent. The semi-structured nature of the data collection methods provided the flexibility to probe deeper into specific areas of interest while maintaining a focus on the core research questions.

3.3 Ensuring Reliability and Validity

Several measures were taken to ensure the reliability and validity of the research findings:

- Triangulation: The use of multiple data sources (interviews and focus groups) enabled triangulation, enhancing the credibility of the findings. By comparing and contrasting data from different sources, the researchers could identify common themes and cross-validate the results.

- Pilot Testing: Before the main data collection, the interview and focus group guides were pilot tested with a small group of cold chain professionals to refine the questions and ensure clarity and relevance. This step helped minimize biases and enhance the reliability of the data collection instruments.

- Reflexivity and Peer Debriefing: Reflexivity was practiced throughout the research process, with the researchers maintaining a reflective journal to document their thoughts, biases, and decision-making processes. Regular peer debriefing sessions were also conducted, where the research team reviewed the data and discussed emerging themes to ensure an objective analysis.

3.4 Data Analysis

The data analysis was carried out using Braun and Clarke's [21] six-phase approach to thematic analysis, which provided a structured and systematic framework for identifying patterns and themes within the data:

- Familiarization with the Data: Researchers immersed themselves in the data by reading and re-reading the transcripts to gain a thorough understanding of the content.
- Generating Initial Codes: The data was systematically coded using NVivo 14 software, which facilitated the organization and retrieval of data segments related to specific themes.
- Searching for Themes: Codes were grouped into broader themes based on their relationships and meanings. This process involved examining how different codes interacted and contributed to overarching themes.
- Reviewing Themes: The identified themes were reviewed and refined to ensure they accurately represented the data. This step involved checking the themes against the coded data extracts and the entire data set.
- Defining and Naming Themes: Clear definitions and names were assigned to each theme to capture their essence and scope comprehensively.
- Producing the Report: The final step involved synthesizing the findings into a coherent narrative that articulated the relationships between the themes and the research questions.

3.5 Use of NVivo Software

NVivo 14 software was used to manage and analyze the qualitative data. The software provided a robust platform for coding, organizing, and analyzing large volumes of text data, enhancing the consistency and accuracy of the coding process. NVivo also enabled the researchers to perform complex queries and visualize relationships between different themes, further enriching the analysis.

3.6 Qualitative Network Analysis

In addition to thematic analysis, qualitative network analysis was employed to visualize and understand the policy networks related to cold chain management. This method provided a unique lens to examine how various stakeholders and policies interact and influence waste efficiency within cold chains. The network analysis complemented the thematic analysis by highlighting broader contextual factors and revealing the interconnectedness of different elements within the policy environment.

3.7 Comprehensive Understanding

By combining in-depth interviews, focus group workshops, thematic analysis, and network analysis, the study provided a comprehensive understanding of the interplay between digitalization, waste management, Industry 4.0 factors, and sustainability in cold chain operations. The rigorous research methods employed and the careful attention to reliability and validity throughout the process ensured that the study generated valuable insights that can inform both future research and practical applications in this critical area.

4. Discussion of Findings

The analysis utilized various NVivo functionalities, including triggers, queries, cluster analysis, and project mapping, all grounded in qualitative thematic analysis based on Braun and Clarke's framework. This approach provided a rigorous and contextually sensitive analysis, adhering to qualitative research standards [22]. The findings highlight a proactive shift among stakeholders toward leveraging digital solutions to enhance waste reduction in cold chains. Technologies such as AI, IoT, and Industry 4.0 show transformative potential in predicting and preventing waste, while initiatives like the WRAP-IGD Food Waste Roadmap offer valuable frameworks for optimizing waste management strategies. The study identifies several key constructs critical for enhancing waste efficiency in cold chains through digital transformation and innovative practices. A key finding is the importance of proactive stakeholder engagement. Stakeholders in the cold chain industry are increasingly adopting digital solutions and demonstrating a readiness to invest in advanced technologies. This proactive approach facilitates early identification of waste sources and the implementation of preventive measures through collaboration across the supply chain.

Another vital construct is the adoption and integration of advanced technologies. Technologies like Artificial Intelligence (AI), the Internet of Things (IoT), and Industry 4.0 have significant potential to predict and prevent waste. AI, for example, enables the analysis of large datasets to forecast disruptions, IoT provides real-time monitoring of conditions such as temperature, and Industry 4.0 tools enhance operational efficiency through automation and robotics.

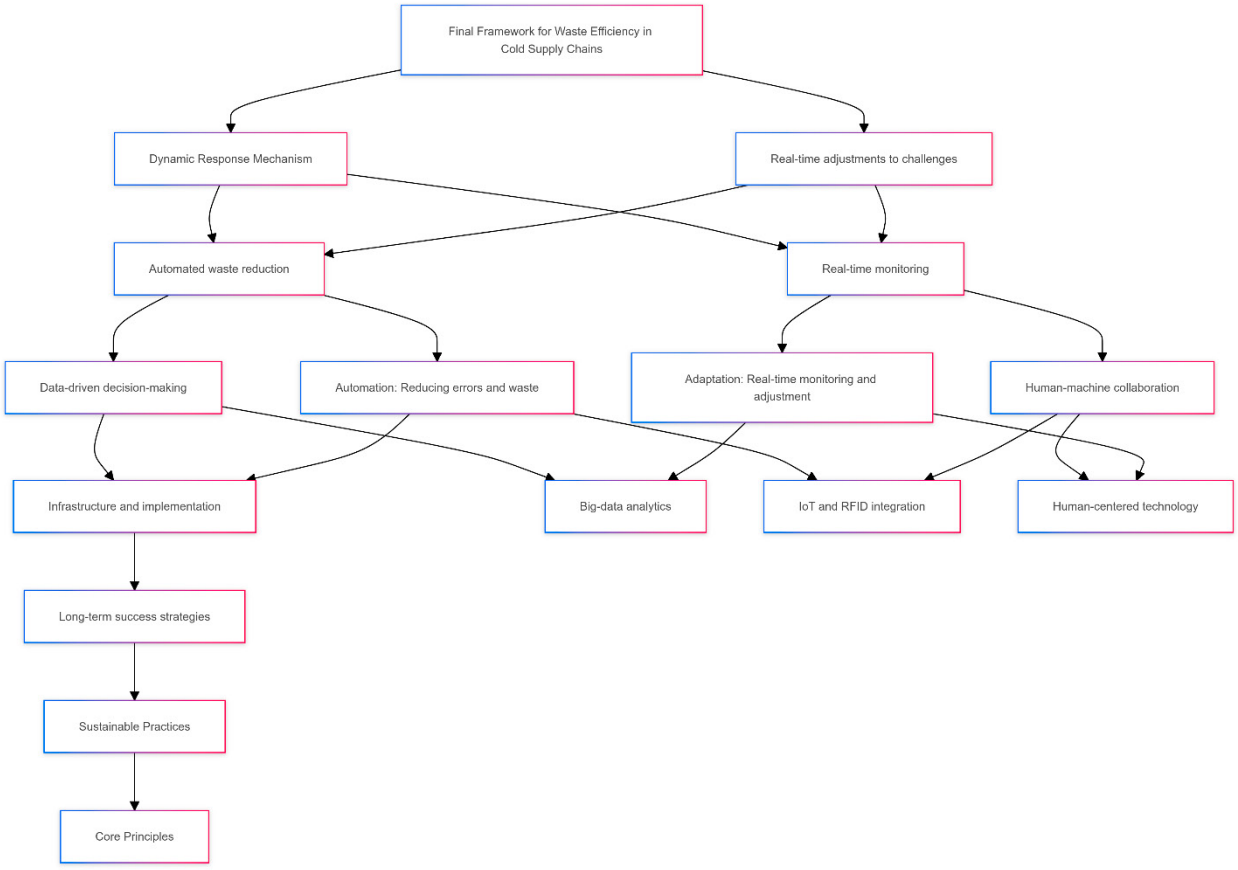
The study also underscores the importance of identifying and mitigating primary waste sources within cold chains, such as spoilage due to poor temperature control, inventory mismanagement, and operational inefficiencies. Addressing these issues through technological interventions and best practices is essential for reducing waste effectively. Improving waste management practices is further highlighted as a key area of focus, emphasizing the need for strategies that minimize waste generation and optimize disposal processes. This includes leveraging data analytics for informed decision-making, adopting circular economy principles, and providing comprehensive training for employees to enhance their understanding and management of waste. Frameworks like the WRAP-IGD Food Waste Roadmap are essential for guiding organizations in waste management. These frameworks provide structured guidelines, best practices, and benchmarks that facilitate collaboration among supply chain stakeholders to enhance waste reduction efforts.

Sustainability remains a central objective, with an emphasis on integrating waste reduction efforts into broader sustainability goals. This involves maintaining a balance between economic viability and environmental responsibility and fostering a long-term commitment to sustainable practices within the cold chain sector. The study also highlights the need for a dynamic response mechanism that allows real-time adjustments to waste management strategies. This mechanism is supported by real-time data analysis and the development of adaptive strategies to respond to changing conditions within the supply chain, ensuring flexibility and resilience. Human-centered technology integration is another important construct, focusing on balancing automation with human oversight. Designing technology solutions that complement human skills and decision-making processes, while ensuring accessibility and user-friendliness, is crucial for effective waste management.

Lastly, the study emphasizes the importance of robust infrastructure and strategic implementation to support digitalization efforts. Developing adequate digital infrastructure and strategic planning is necessary to ensure seamless data flow and connectivity across the supply chain, enabling a successful digital transformation for enhanced waste management. Together, these constructs form a comprehensive framework for improving waste efficiency in cold chains, emphasizing the pivotal roles of digital technologies, stakeholder engagement, and sustainable practices in achieving long-term sustainability objectives.

The final framework, depicted in Figure 1, integrates theoretical foundations and relevant concepts, combining Sustainable Corporate Theory with Industry 4.0 technologies. This framework offers a practical approach to implementing waste efficiency strategies within cold supply chains, providing a structured pathway to optimize sustainability practices.

Figure 1. Waste efficiency in cold chains framework



The Final Framework for Waste Efficiency in Cold Supply Chains represents a comprehensive approach aimed at addressing the pressing challenge of waste reduction within cold chain logistics. At its core, the framework integrates theoretical underpinnings from Industry 4.0 Principles and Sustainable Corporate Theory, laying the groundwork for practical strategies that promote sustainability and environmental stewardship.

Industry 4.0 Principles serve as a foundational element within the framework, encompassing key facets such as adaptation, automation, and human-centred technology. These principles underscore the transformative potential of

advanced digital solutions in optimizing waste management processes within cold supply chains. By emphasizing real-time monitoring and adjustment, as well as intelligent automation to reduce errors and waste, Industry 4.0 Principles provide a strategic framework for leveraging digitalization to enhance waste efficiency (Adaptation: Real-time monitoring and adjustment; Automation: Intelligent systems to reduce errors and waste).

Aligned with Sustainable Corporate Theory, the framework advocates for the integration of Industry 4.0 principles into corporate strategies to promote responsible environmental stewardship [18]. This integration emphasizes the long-term success achievable through sustainable practices, highlighting the importance of aligning waste reduction efforts with broader sustainability objectives (Sustainable Corporate Theory: Long-term success through sustainable practices).

A crucial aspect of the framework is the Dynamic Response Mechanism, which emphasizes the need for flexibility and adaptability in waste management to address evolving challenges. This mechanism underscores the importance of real-time adjustments to mitigate waste and align with sustainability objectives, ensuring that cold chain logistics remain responsive to changing environmental and operational conditions (Dynamic Response Mechanism: Real-time adjustments to evolving waste challenges).

Moreover, the framework prioritizes Human-centred Technology Integration, recognizing the significance of human decision-making alongside technological advancements. By fostering collaboration between humans and machines, the framework ensures that technology complements human efforts in waste management, enhancing efficiency and effectiveness (Human-centred Technology Integration: Complementary technology for efficient waste management).

Effective Infrastructure and Implementation are also emphasized within the framework, highlighting the importance of establishing necessary technological infrastructure and implementing strategies aligned with responsible corporate practices. This aspect ensures that digital solutions are deployed in a manner that maximizes their impact on waste reduction while minimizing potential adverse effects (Infrastructure and Implementation: Necessary infrastructure and effective strategies).

Finally, the Operationalization category outlines practical strategies for implementing waste efficiency in cold supply chains. These strategies include real-time waste monitoring, automated waste reduction processes, collaboration between humans and machines, data-driven decision-making, and strategic infrastructure development. By operationalizing these strategies, stakeholders can systematically address waste challenges and promote sustainability within cold chain logistics (Operationalization: Practical strategies for waste efficiency).

In summary, the framework addresses the research objectives by providing a structured approach to investigating the influence of Industry 4.0-enabled digital solutions on waste efficiency in cold supply chains. It integrates theoretical insights with practical strategies, emphasizing the contribution of digitalization to waste management and identifying primary opportunities associated with digital solutions in cold chains. Through this holistic approach, the framework offers valuable guidance for stakeholders seeking to enhance sustainability and environmental responsibility within the cold chain industry.

5. Conclusion

In conclusion, the integration of Industry 4.0 principles with Sustainable Corporate Theory offers a crucial framework for enhancing sustainability and waste efficiency in cold chains. The study's main findings highlight the transformative potential of digital technologies, such as AI and IoT, in predicting and preventing waste. This framework addresses the challenges of climate change and the need for net-zero emissions by providing a structured approach to reducing environmental impact.

The emphasis on digital solutions equips businesses with practical tools to optimize operations and reduce waste, aligning with global initiatives like the UN's Sustainable Development Goals. By adopting green digitization, industry stakeholders can promote a more sustainable future while complying with regulatory standards. This approach not only supports environmental goals but also improves economic efficiency, demonstrating that digital technologies and sustainable practices are vital for the future of cold chain operations.

Looking ahead, future research should delve deeper into the long-term implications of Industry 4.0 technologies on waste management within cold chains. Comparative studies across industries can provide valuable insights into best practices and lessons learned, facilitating knowledge sharing and continuous improvement. Additionally,

addressing regulatory and ethical considerations is paramount to ensure the responsible implementation of digital solutions. By exploring these avenues, researchers can contribute to the ongoing efforts to optimize cold chain operations while minimizing environmental impact and advancing sustainability goals.

5.1. Implications of findings and practical applications

The findings of this study have significant implications for both academia and industry. By identifying the role of digitalization in enhancing sustainability within cold chains, the study highlights the potential for technology-driven solutions to address pressing environmental challenges. Practical applications of the framework developed in this study include:

- Enhanced Efficiency: The integration of Industry 4.0 principles with Sustainable Corporate Theory offers a structured approach to waste reduction and efficiency improvement in cold supply chains. By leveraging digital technologies such as IoT, AI, and blockchain, businesses can optimize processes, minimize waste, and reduce environmental impact.
- Improved Product Quality: Real-time monitoring and predictive analytics enabled by digitalization can help maintain optimal temperature conditions throughout the cold chain, preserving the quality and safety of perishable goods. This not only reduces product losses but also enhances consumer satisfaction and brand reputation.
- Sustainability Compliance: The framework aligns with global sustainability initiatives such as the UN's Sustainable Development Goals, providing a roadmap for businesses to meet regulatory requirements and ethical standards. By adopting green digitization practices, companies can demonstrate their commitment to environmental responsibility.
- Cost Savings: By minimizing waste and improving operational efficiency, businesses can realize cost savings in terms of reduced energy consumption, lower product losses, and streamlined logistics. This can contribute to increased profitability and long-term sustainability.
- Limitations and Avenues for Future Research

While this study provides valuable insights into the potential of digitalization in cold chain management, several limitations and areas for future research should be acknowledged:

- Technological Challenges: The implementation of advanced digital technologies in cold chains may face technical barriers such as infrastructure limitations, data security concerns, and interoperability issues. Future research could explore strategies to overcome these challenges and ensure seamless integration of digital solutions.
- Behavioral Factors: The success of digitalization initiatives in cold chains depends not only on technological capabilities but also on human behavior and organizational culture. Research focusing on the human aspect of technology adoption, such as employee training, change management, and stakeholder engagement, could provide valuable insights.
- Environmental Impact Assessment: While digitalization has the potential to reduce waste and improve efficiency, its overall environmental impact, including factors such as energy consumption and electronic waste generation, should be thoroughly evaluated. Future research could conduct life cycle assessments to quantify the environmental benefits and trade-offs of digitalization in cold chains.
- Long-term Sustainability: The long-term sustainability of digitalization initiatives in cold chains requires continuous monitoring, evaluation, and adaptation. Research on the scalability, resilience, and socio-economic implications of digital transformation in cold supply chains can inform strategic decision-making and policy development.

In conclusion, while this study lays the groundwork for leveraging digitalization to enhance sustainability in cold chains, further research is needed to address technological, behavioral, and environmental challenges. By addressing these limitations and exploring new avenues for research, scholars and practitioners can advance our understanding of digital transformation in cold chain logistics and contribute to a more sustainable future.

References

[1] Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., Trisos, C., Romero, J., Aldunce, P., Barret, K. and Blanco, G., 2023. IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.

[2] Masson-Delmotte, V.P., Zhai, P., Pirani, S.L., Connors, C., Péan, S., Berger, N., Caud, Y., Chen, L., Goldfarb, M.I. and Scheel Monteiro, P.M., 2021. Ipcc, 2021: Summary for policymakers. in: Climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change.

[3] World Bank, 2013. The World Bank Annual Report 2013. The World Bank.

[4] Citaristi, I., 2022. International energy agency—iea. In The Europa directory of international organizations 2022 (pp. 701-702). Routledge.

[5] Fatorachian, H. (2023). The significance of Industry 5.0 in the globalization of supply chain management. European Economic Letters, 13(5), 843. https://doi.org/10.52783/eel.v13i5.843

[6] Lee, S. (2019). Blockchain in retail waste management: Improving waste tracking for sustainable practices. International Journal of Information Management, 46, 88-98.

[7] Smith, J. (2020). Leveraging IoT and Big Data in manufacturing for waste reduction: A case study of Lean Manufacturing implementation. Journal of Manufacturing Systems, 56, 218-231.

[8] Bai, L., Liu, M. and Sun, Y., 2023. Overview of food preservation and traceability technology in the smart cold chain system. Foods, 12(15), p.2881

[9] Smith, C., & Fatorachian, H. (2023). COVID-19 and supply chain disruption management: A behavioral economics perspective and future research direction. Journal of Theoretical Applications and Electronic Commerce Research, 18(4), 2163-2187. https://doi.org/10.3390/jtaer18040109

[10] Rajabzadeh, M., & Fatorachian, H. (2023). Modelling factors influencing IoT adoption: With a focus on agricultural logistics operations. Smart Cities, 6, 3266-3296. https://doi.org/10.3390/smartcities6060145

[11] Fatorachian, H. (2013). Role of Internet in supply chain integration; empirical evidence from manufacturing SMEs of the UK. Proceedings of the 9th European Conference on Management Leadership and Governance (ECMLG 2013), Austria.

[12] Yang, M., Fu, M., & Zhang, Z. (2021). The adoption of digital technologies in supply chains: Drivers, process and impact. Technological Forecasting and Social Change, 169, p.120795.

[13] Filieri, R., & Arreola-Risa, A. (2019). Business models for the digital economy: A systematic literature review and meta-analysis. Technological Forecasting and Social Change, 140, 24-35.

[14] Paul, T., Mondal, S., Islam, N. and Rakshit, S., 2021. The impact of blockchain technology on the tea supply chain and its sustainable performance. Technological Forecasting and Social Change, 173, p.121163.

[15] Meindl, B., Ayala, N.F., Mendonça, J., & Frank, A.G. (2021). The four smarts of Industry 4.0: Evolution of ten years of research and future perspectives. Technological Forecasting and Social Change, 168, p.120784.

[16] Fatorachian, H., & Smith, C. (2022). Impact of CPS on enhancing supply chain resilience, with a focus on solutions to pandemic challenges. In Semwal, T., & Faiz, I. (Eds.), Cyber-Physical Systems: Solutions to Pandemic Challenges (pp. 109-125). CRC Press.

[17] Latino, M.E., Menegoli, M., Lazoi, M., & Corallo, A. (2022). Voluntary traceability in food supply chain: a framework leading its implementation in Agriculture 4.0. Technological Forecasting and Social Change, 178, p.121564.

[18] Wang, Y., & Yue, L. (2017). Corporate sustainability, social responsibility and environmental management: An introduction to the special issue. Journal of Cleaner Production, 155, 1-3.

[19] Zhong, R.Y., Xu, X., Klotz, E. and Newman, S.T., 2017. Intelligent manufacturing in the context of industry 4.0: a review. Engineering, 3(5), pp.616-630.

[20] Verdouw, C.N., Wolfert, J., Beulens, A.J.M. and Rialland, A., 2016. Virtualization of food supply chains with the internet of things. Journal of Food Engineering, 176, pp.128-136

[21] Braun, V. & Clarke, V. (2013) Teaching thematic analysis: Over-coming challenges and developing strategies for effective learning. The Psychologist, 26 (2). pp. 120-123.

[22] Easterby-Smith, M., Thorpe, R. and Jackson, P.R. (2012). Management research. Sage.

[23] Fatorachian, H. (2024). Sustainable supply chain management and Industry 5.0. In Atiku, S.O., Jeremiah, A., Semente, E., & Boateng, F. (Eds.), Eco-Innovation and Sustainable Development in Industry 5.0. IGI Global. https://doi.org/10.4018/979-8-3693-2219-2