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OPTIMIZATION AND SUSTAINABILITY OF SUPPLY CHAINS IN THE FOOD AND BEVERAGE INDUSTRY

Abstract

This paper presents the strategies to improve and enhance the sustainability of food and beverage supply chain. It is a systematic literature review to address the increasing needs of efficiency and greenness in supply chain in food and beverage industry. The main emphasis is placed on the key strategies to enhance the inventory management and operational efficiency of the food and beverage supply chain with the implementation of the Internet of things (IoT) technology, blockchain and big data analytics. Other focus is on the sustainable strategies to reduce the waste, and use the renewable energy sources, waste reduction programs and the principles of circular economy to enhance the sustainability of the supply chain in food and beverage industry.

One of the main conclusions of this paper is that integration and optimization in supply chains can significantly improve all performance metrics (efficiency, cost reductions, brand, etc), and can generate a competitive advantage in the highly competitive food and beverage industry. Despite the trend of big businesses having their own supply chains, the study points out the importance of collaboration among all supply chain partners, e.g. suppliers, manufacturers, distributors and retailers, if the product maintains its quality and is produced in an efficient way. The paper presents practical implications on how implementing these strategies can indeed result in higher customer satisfaction, reduced waste, and a stronger competitive position in the food and beverage industry

Key words: Optimization, Sustainability, IoT, Big Data, Supply chain, Circular economy

JEL classification: L6

ОПТИМИЗАЦИЈА И ОДРЖИВОСТ ЛАНАЦА СНАБДЕВАЊА У ИНДУСТРИЈИ ХРАНЕ И ПИЋА

Апстракт

Овај рад представља стратегије за побољшање и унапређење одрживости ланца снабдевања у индустрији хране и пића. Овај рад представља систематски

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преглед литературе који адресира све веће потребе за ефикасношћу и еколошком прихватљивошћу у ланцима снабдевања индустрије хране и пића. Главни акценат је стављен на кључне стратегије за унапређење управљања залихама и оперативне ефикасности ланца снабдевања хране и пића путем имплементације технологије Интернета ствари (ИоТ), блокчејна и аналитике великих података. Други фокус је на одрживим стратегијама за смањење отпада и коришћење обновљивих извора енергије, програма за смањење отпада и принципа циркуларне економије како би се побољшала одрживост ланца снабдевања хране и пића.

Један од главних закључака овог рада је да интеграција и оптимизација у ланцима снабдевања могу значајно побољшати све перформансе (ефикасност, смањење трошкова, бренд, итд.) и генерисати конкурентску предност у високо конкурентној индустрији хране и пића. Упркос тренду да велике компаније имају сопствене ланце снабдевања, студија указује на важност сарадње између свих партнера у ланцу снабдевања, нпр. добављача, произвођача, дистрибутера и малопродаја, како би производ задржао свој квалитет и био произведен на ефикасан начин. Рад представља практичне импликације како примена ових стратегија може резултирати већим задовољством купаца, смањењем отпада и јачом конкурентском позицијом у индустрији хране и пића.

Кључне речи: Оптимизација, Одрживост, ИоТ, Биг Дата, Ланци Снабдевања, Циркуларна економија

Introduction

Food and beverage supply chains help to provide consumers with products on time and in the correct manner. It consists of a large number of complex processes and activities, ranging from raw material production to processing and distribution to the end consumer. These supply chains are very essential for the processing, packaging, and distributing of food and beverage products.

More and more important is the need to find sustainable and efficient methods for supply chain optimization, especially in the face of the rising demand for fresh and high-quality food products and the growing competition in the food market (Seuring and Müller 2008). Thanks to the development of new technologies like the Internet of Things (IoT) and blockchain, as well as the utilisation of big data analytics, companies gain more control over their stocks, can predict the demand much better and reduce the waste (Wong et al., 2024). Additionally, these technologies support food quality and safety by empowering the stakeholders to control the complete supply chain and monitor their products at every step (Brandenburg et al. 2014).

Along with this optimization, sustainability has emerged also as an important objective of the food and beverage supply chain (Ageron et al. 2012). Sustainability refers to the implementation of practices aimed at minimizing the consequences of the food production process on the environment and on society (Guang Shi et al. 2012); these include waste reduction, the use of renewable energy sources and environmentally-friendly production, the reduction of greenhouse gas emissions, animal welfare, fair working conditions and

responsible consumption (Ferreira et al. 2023). Over the years, many companies have started viewing sustainable practices as a crucial mission not only in response to regulatory requirements of consumer pressure, but also in order to reap long-term benefits in terms of reduction of costs and strengthening of the brand.

Combining optimization and sustainability processes for supply chains is a difficult challenge, but also an opportunity to improve the operation re-engineering process to improve the business in the food industry (Kamble et al. 2020). The objective of this paper is to delve into how we can combine optimization and sustainability to improve the performance and gain competitive advantage of food and beverage supply chains.

Supply chains can be quite complex, and as a result, numerous factors impact the effectiveness and productivity of the system. These include fluctuating prices of raw material, seasonal variations in production volume, and logistical imperatives such as storage and delivery of produce to the consumer (Bešić et al., 2021). Traditional supply chain management methods are often insufficient to address some of these challenges and so there is an increasing focus on the use of innovative tools to make better decisions and to do it more quickly (Quintana & León, 2021). Some of these advanced analytical tools can improve demand forecasts, optimise delivery routes and inventories, and all of this can be done in a way that reduces costs and improves service (Ahi and Searcy 2013).

Besides technological change, social and environmental factors are also important. Due to the growing awareness of environmental problems and protection, issues of sustainability in supply chains are gaining in importance (Bešić et al., 2022). Companies that implement ecological approaches such as reducing carbon emissions, recycling, and using sustainable materials are not only saving the environment but also benefit from an improved brand image due to consumers who increasingly prefer these products (Shin & Cho, 2022).

Implementing optimization alongside sustainability goals will pay off in the long run. More specific example: Using renewable energies will not only reduce the ecological footprint, but also lower electricity costs in the long run. A more efficient inventory management generates less losses, which will result in a reduction of waste, and as a result more profit, and also in less negative environmental impact (Cvetkovic et al., 2017). This paper will discuss the main approaches and strategies to implement these goals and analyze some concrete examples from practice.

The paper is organized as follows: after this introduction, the methodology chapter explains the search criteria and processes employed for selecting and coding the relevant literature, while the review results chapter undertakes a thematic analysis of the findings, putting forward key strategies, impacts and knowledge gaps. The discussion summarizes those findings while drawing implications for theory, practice and policy. The conclusion contextualises the main themes and reflects on the research implications for the debate on sustainable development of the food and beverage industry.

As guidelines for research, this paper addresses four main research questions:

1. Considering the food and beverage industry, what are the main strategies that can be adopted to optimise supply chains? What are their effects on business efficiency and cost?
2. How can food and beverage supply chains best engage with environmental and social sustainability, and what methods are the most effective for doing so?
3. What are the main challenges in implementing strategies for optimization and sustainability in food and beverage supply chains, and how do successful

companies overcome them?

4. What is the role of optimization alongside sustainability in food and beverage supply chains and how does it contribute to the long-term competitive position and profitability of firms?

Four main sections excluding the introduction and conclusion are included in this paper. First, more detailed explanations of the research methodology are provided. Then, the results of the literature review process will be presented.

Methodology

Literature Review and Selection Process

For conducting an adequate literature review, the research was conducted using two search engines: KoBSON and Google Scholar. The field of academic research that focuses on circular supply chain management model, the practices of supply chain, circular economy, sustainable innovation in the field of food and beverage supply chain were initially searched, and the articles were downloaded to conduct the review. Then, the articles with duplication were deleted. A strict selection process was carried out for publishing academic articles which mention relevant topics and information for the systematic literature review, so any other literature sources which are unwanted will be disregarded.

Eligibility Criteria for Literature

The interval for the search was between the year 2014 and 2024. All of the articles are written in scientific and peer-reviewed journals. The major topics discussed in the article are:

- Supply chain management in the food and beverage industry
- Management in circular supply chains
- Circular economy
- Food and beverage industry
- Sustainability and innovation

Articles not taken into consideration during the review were those published in predatory journals. Most scientific journals publish literature on supply chains, textile industry, innovation and circular economy, and sustainability. Source for the specific literature used can be found in the 'References' section.

Results and discussion

Literature Review and Categorization of Results

The results and discussion section delves into the critical findings from our review, focusing on the optimization and sustainability of supply chains in the food and beverage industry. This section is organized into key thematic areas, including collaboration among supply chain partners, technological innovations, and strategies for waste reduction, as well as addressing challenges and presenting actionable solutions. By exploring these aspects, we highlight the interconnection between supply chain efficiency, environmental sustainability, and long-term business competitiveness. Each subsection provides insights into specific

strategies, technologies, and practices that drive improvement, offering a comprehensive understanding of how companies can balance operational demands with sustainability goals.

1. Cooperation among supply chain partners, including suppliers, manufacturers, distributors and retailers, is essential for the success of SCM (Huang et al., 2020). The sharing of information freely enables improved planning and coordination, ultimately resulting in increased efficiency and lowered risks of supply chain disruptions.. For instance, in the food and drinks industry, cooperation among partners ensures product availability at the point of sale in the best possible condition and uncompromised quality and freshness (Gichuru et al., 2015).
COLLABORATION IN SUPPLY CHAINS

2. Supply chain optimization (SCM) refers to a range of strategies and methods that help companies manage their resources efficiently, reduce costs, minimize waste, improve the quality of services and products (Govindan et al., 2015). The basic concepts of SCM optimization are the management of stocks, efficient logistics, collaboration among supply chain members, and tracking and analyzing technologies. Food and beverage companies in particular heavily rely on efficient supply chains, due to the fact that products are perishable and have specific storage and transportation conditions. SCM plays a crucial role in making sure that products reach consumers fresh and safe to be consumed (Rahbari et al., 2023).
SUPPLY CHAIN OPTIMIZATION

3. In the food and beverage industry, sustainable supply chains encompass a natural resource utilization concept that aligns with economic, environmental, and social goals. The goal of sustainable supply chains is to minimise environmental damage and maximise economic and social responsibility. One of these is waste reduction due to more efficient inventory management, usage of recycled raw materials, and many others. In order to implement sustainable supply chains, the circular economy principles should be taken into considerations. Such an approach to the economy assumes reusing and recycling of resources instead of disposing them as garbage. As a result, new raw materials will not be produced and waste will not be generated (Haseli et al., 2024).
SUSTAINABLE SUPPLY CHAINS.

4. Incorporating sustainable energy sources at various points in the supply chain can improve the overall sustainability of the supply chain. Food storage and transport utilise a lot of energy, so shifting from energy production of fossil fuels to renewable energy resources, such as solar or wind energy, can to reduce the quantity of carbon dioxide emissions.(Palazzo & Vollero, 2022). Furthermore, shortening the distance of transporting food and using environmentally friendly vehicles can reduce the emission of various pollutant gases, and optimize the efficiency of supply chain transport, which is beneficial to improving the ecological sustainability of the supply chain (Adams et al., 2023).
SUSTAINABLE SUPPLY CHAIN.

5. Technological innovations such as IoT and blockchain can transform supply chains in the food, beverages and related industries (Sarkis et al., 2011). Real-time monitoring and information sharing among supply chain members are possible through the use of Internet of Things (IoT) and information and communication technologies (ICT), enabled by sensors, internal systems, computers, and mobile devices.(Rejeb et al., 2019). The Internet of Things (IoT) that relies on sensors,

along with these technologies, can track the whereabouts of perishable items throughout the entire supply chain, beginning from the point of production. (Ansari & Kant, 2017). Sensors, for instance, identify the temperature and humidity levels in warehouses and during transport, which is of vital importance for the quality and freshness of food. The data are collected automatically and can be quickly analyzed and acted upon, preventing, for instance, perishable commodities' deterioration caused by inappropriate storage conditions or delays in delivery (Jagtap et al., 2021). **TECHNOLOGICAL INNOVATIONS**

6. Blockchain reduces risk in the food and beverage supply chain by making processes more transparent and secure. Each transaction in the food supply chain can be recorded and verified through blockchain, making it easy to trace products, check certificates, and examine the authenticity of information. The consumer can scan a QR code on a particular product and trace the product's entire journey from farm to table, reassuring himself that it is safe and good. The traceability through blockchain helps curtail fraudulent activities in the food industry which can be detrimental to our health. Blockchain helps curb the issue of counterfeit products in the food supply chain as well (Subramanian et al., 2020). **SUPER TECHNOLOGY INNOVATIONS**
7. The application of big data analytics to improve supply. Using the information extracted from big data analytics, supply chains can optimise the supply and demand and minimize the number of required inventories. For instance, with the help of analytical tools, companies can establish patterns such as the seasonal trends of a certain product. By combining these patterns with sales data in previous years, the current situation of the market can be anticipated. By doing so, issues like insufficient inventory and the accumulation of excess materials can be prevented, thus improving production and storage efficiency (Irfan & Wang, 2019). **BIG DATA ANALYTICS**
8. An organisation can perform deep analysis of supply chain performance using Big Data analytics to help identify the bottlenecks and to reduce the cost and to improve the overall performance (Talwar et al., 2021). The company can make decisions regarding the delivery of their goods through transport data so that can optimise delivery routes thus reducing the time and cost of delivery (Kholaf et al., 2023). Big data analytics will help to find the best suppliers, to increase the efficiency of relationships with customers, and to the marketing strategy that can be designed according to the deep insights of consumer behaviour. **BIG DATA ANALYTICS**
9. Advancement of technology and digitalisation not only fails to increase efficiency and transparency of the supply chains, but also contributes to an overall agility and quicker response to market changes, as IoT, blockchain and the use of big data analytics can further reduce the costs for companies of the food sector, improve the quality of service and the products, and boost the global satisfaction of end consumers (Alkhatib, 2023). **BIG DATA ANALYTICS**
10. Since the manufacturing of food, beverage and their packagings require various resources, supply chain optimization (SCM) could help food and beverages companies to be more effective in using these resources. The application of Just-In-Time (JIT) methods reduces storage costs and the risk of product spoilage

by decreasing inventories and stocks. The food sector greatly benefits from this reduction, particularly because shelf lives are frequently restricted. (Stritto & Schiraldi, 2013). SUPPLY CHAIN OPTIMIZATION

11. Applying an optimised supply chains can directly decrease carbon footprint of a company. Reducing energy usage and gas emission are the result of more efficient production and distribution process (Stanković et al., 2022). Optimising delivery flows through transportation management software (TMS) will lead to a lower total distance of travel by vehicles which reducing fuel consumption and carbon dioxide discharge. Using vehicles with environmentally friendly fuel, like electric or hybrid vehicles, can also help to decrease the environmental impact (Thakur, 2021). SUSTAINABLE SUPPLY CHAINS
12. Renewable energy sources are also part of sustainable supply chains – for example, warehouses or production facilities can be powered by solar energy or other renewable sources. Energy efficiency is another important pillar for sustainability, for instance, LED lighting or energy-saving heating, ventilation and air conditioning (HVAC) systems can improve the ecological performance of a company (Schulman et al, 2021). SUSTAINABLE SUPPLY CHAINS
13. When applied to supply chains, circular economy principles can reduce the ecological footprint even more. Reducing the extraction of new raw materials and the amount of waste sent to landfills can be achieved by recycling and reusing products. For example, a company that offers programmes for the return of packaging and the recycling of used materials can extend the life cycle of the product and reduce waste (Read et al., 2020). RESOURCE AND WASTE MANAGEMENT
14. Moreover, next to enhancing the ecological performance of the company, implementing more sustainable supply chains can also improve the competitiveness of the company, because of the importance that consumers attribute to environmental issues, and the importance that both actors in B2B and B2C encounters attach to products produced sustainably (Beske et al., 2014) Implementing more sustainable supply chains can assist a company in enhancing its reputation, cultivating customer loyalty, and accessing new markets. (Frederick & Elting, 2013). SUSTAINABLE SUPPLY CHAINS
15. Optimizing the supply chain (SCM) in the food and beverages industry poses numerous challenges and hurdles that can impede the attainment of maximum efficiency. The first obvious barrier is high costs. Implementing new technologies requires huge initial investments, such as the expenditures of purchasing the equipment and needed software, as well as costs of training employees. For small and medium-sized enterprises that usually don't have enough resources, these investments can be a burden. The company's budget can come under significant pressure due to the high expenses associated with maintaining and updating these technologies. Some other challenges and obstacles in SCM implementation are the initial training costs, the distribution of proper equipment in every warehouse and plant, as well as the difficult task of replacing and updating the data. (Espinosa et al., 2021). CHALLENGES AND OBSTACLES IN SCM IMPLEMENTATION
16. Technical limitations are probably the next great barrier to the implementation of SCM. Introducing new technologies into current systems can be challenging,

primarily because the operation of the current processes must be adjusted to accommodate the new technologies. (Bayir et al., 2022). As an example, the introduction of IoT sensors for internal use within the enterprise (e.g. to track inventory and transport), requires the implementation of a network infrastructure that needs to be reliable. However, this in turn requires a language base that is not easily available in many rural and developing areas of our planet. Secondly, the lack of tech-savvy employees within the company means that the integration and utilisation of new technologies is more difficult (Ha et al., 2013). **CHALLENGES AND OBSTACLES IN SCM IMPLEMENTATION**

17. Regulations and standards can be a challenge too. Food and beverages are heavily regulated areas. For example, they have laws concerning food safety, packaging, and transport, which might require more resources and adaption of processes that are already established. Moreover, regulations and standards can vary across different markets, making the global coordination and compliance a more complex and costly task (Sindhu & Kumar, 2022). **CHALLENGES AND OBSTACLES TO THE IMPLEMENTATION OF SCM**
18. There are many different strategies companies can adopt to overcome the challenges and obstacles that exist to implementing SCM. One of the most important strategies is phased technology implementation, which is to say that firms can begin implementing new technological changes by focusing on the most critical areas first, such as warehouses, before expanding to transport operations, which allows the costs to be distributed over a longer period of time (Zain et al., 2023). **STRATEGIES FOR OVERCOMING OBSTACLES**
19. Companies can also promote sustainability by utilizing financial tools and offering incentives.. Governments, for instance, provide subsidies or tax incentives to the companies that implement sustainable, technology-oriented solutions. Availability of low cost debt and equity lends support to such funds procurement (Minj et al., 2020). **STRATEGIES FOR OVERCOMING OBSTACLES**
20. Education and training of employees is one of the most important factors for success of SCM. In this regard, companies must invest in employee training to develop internal technical competence and to ensure that workers can use new technologies and processes in a productive manner (Gupta et al., 2020). Training and skills development that occurs regularly can decrease alleged friction to change and enhance operational effectiveness (Sovacool et al., 2021). **STRATEGIES FOR WORKING AROUND BARRIERS**
21. The efficiency, costs, and reduced environmental impact are definitely influenced by waste within the food and beverage supply chain, particularly during transportation and mobility. In order reduce waste during transport, some specific waste reduction strategies for logistics and mobility exist (Haessner et al., 2024). Better load planning/consolidation. Improving the load planning and consolidation results in more pallets and packages being filled with goods. This helps to expand the truck's load range and increase the number of pallets per truck. Consequently, the transportation trips are reduced, therefore fuel consumption and emission are decreased. Moreover, the partial load is also likely to be spoiled during transportation. Combining multiple shipments into a single delivery route can increase vehicle utilisation and improve the overall efficiency

of the transportation process.(Parfitt et al., 2010). RESOURCE AND WASTE MANAGEMENT

22. Packaging solutions can also be improved to help reduce waste. Packaging with strong and eco-friendly materials can lower the chances of product damage or deterioration. Using packaging materials that can withstand extreme temperatures, or packaging that offers cushioning to sensitive or delicate items, can help to protect the quality of products throughout the supply chain (De Boni et al., 2022). More sustainable packaging materials that can be recycled or are biodegradable can increase the sustainability of processes through minimising environmental waste (Verghese et al., 2015). RESOURCE AND WASTE MANAGEMENT
23. A further smart zero-waste approach is collaborative logistics: companies can share and pool transport resources (trucks, warehouses, etc) to maximise load optimization, reducing the number of vehicles and prospective mileage to be run, thereby resulting in fewer kilometres driven and therefore lower fuel consumption and emissions. Shared logistics networks can also enhance the velocity and efficiency of the chain, reducing the time perishable goods are in transit and decreasing the risk of waste (Fiorello et al., 2021). COLLABORATION IN SUPPLY CHAINS
24. Reducing waste while transporting products requires maintaining and optimising transport vehicles. Vehicles that are properly maintained operate in optimal performance, thereby consuming less fuel and suffering mechanical failures such as overheating, which can lead to delaying the delivery and increasing the risk of the product spoiling.(Chintapalli & Vakharia, 2023) Telematics and predictive maintenance technologies for vehicles help companies to ensure that their vehicles are in good condition, thus reducing unplanned downtime and increasing the reliability of the dispatch (Samuel et al., 2019). RESOURCE AND WASTE MANAGEMENT

Literature Overview

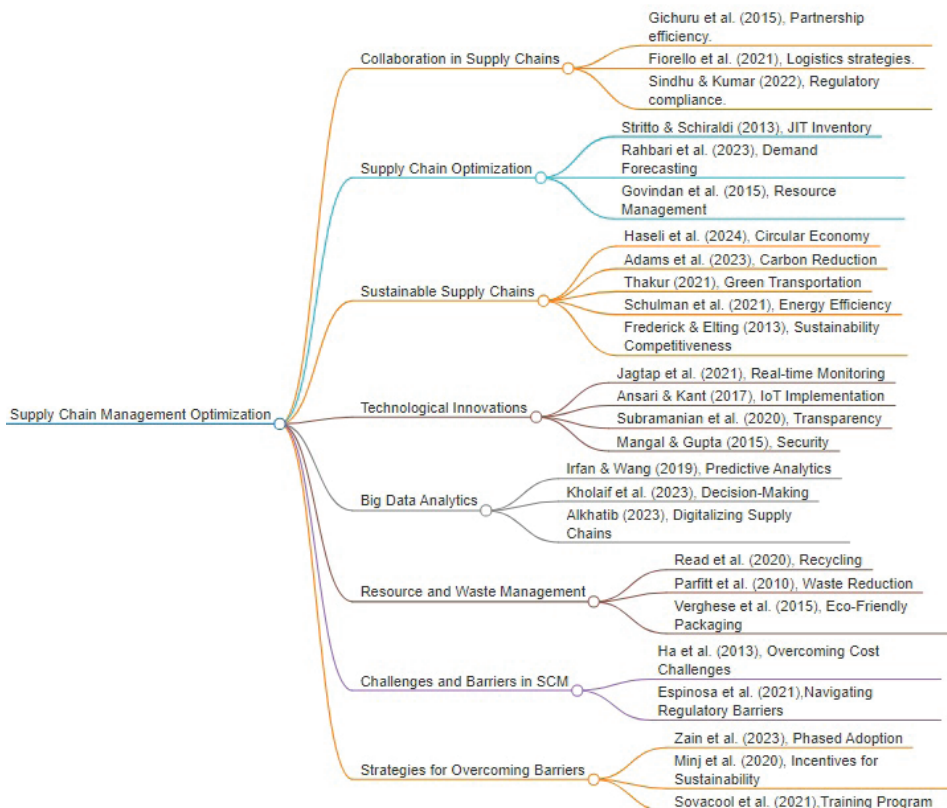
The figure below presents a detailed mind map focused on supply chain management in the food and beverage industry. At the center is the core concept, which branches into eight key themes, each representing a crucial aspect of supply chain management:

1. **Collaboration in Supply Chains** - This branch highlights the importance of partnership and logistics strategies, with references to authors like Gichuru et al. and Fiorello et al., emphasizing efficiency and compliance.
2. **Supply Chain Optimization** - Focused on improving inventory management, demand forecasting, and resource utilization, supported by studies from Stritto & Schiraldi and Rahbari et al.
3. **Sustainable Supply Chains** - Emphasizes practices like the circular economy and carbon reduction, referencing Haseli et al. and Adams et al. to illustrate sustainability efforts.
4. **Technological Innovations** - Covers the integration of IoT and blockchain technology for real-time monitoring and transparency, with insights from Jagtap et al. and Subramanian et al.

5. **Big Data Analytics** - Discusses the role of predictive analytics and decision-making in optimizing supply chains, as highlighted by Irfan & Wang and Kholiaif et al.
6. **Resource and Waste Management** - Concentrates on recycling and waste reduction strategies, with contributions from Read et al. and Parfitt et al.
7. **Challenges and Barriers in SCM** - Identifies regulatory and cost challenges, featuring authors like Ha et al. and Espinosa et al., focusing on overcoming these obstacles.
8. **Strategies for Overcoming Barriers** - Explores phased adoption, incentives, and training programs as solutions, with insights from Zain et al. and Sovacool et al.

Overall, the mind map provides a comprehensive overview of how various elements and innovations contribute to optimizing supply chains in the food and beverage sector, supported by academic literature.

Figure 1 Literature overview



Theoretical Model for Optimizing Supply Chain in Food and Beverage Industry

The optimized and sustainable supply chain model for a food and beverage industry can be understood as a framework for achieving goals of sustainability and effectiveness through the inter-relationship between its sub-elements and their main elements. The inventory management is a crucial sub-element which allows the production planning team to know the actual sales data and inventory information. As a result, it helps effectively reduce waste and minimise excessive usage of resources and time, especially food.

Figure 2 Developed model



On the other hand, demand forecasting can be considered as another important sub-element because it supports production planning and helps in achieving the goal of reducing food waste without losing market. Through data analysis and forecasting of customer demands, this allows more accurate allocation of existing resources for production, sales and logistics distribution. Three remaining sub-elements named process automation, logistics optimization and inventory management also enable production and distribution managers to maintain and enhance the effectiveness of food shopping distribution among the entire distribution network.

Firstly, process automation supports product circulation, manufacturing, packaging, and transportation through the Internet-of-Things (IoT) systems. For instance, algorithms can inform the working speed and guide human actions to allow the full usage of resources. This will significantly enhance the efficiency of ingredient transportation to the processing plant, which accelerates the order delivery process and reduces lead times for distribution. In addition, real-time adjustment based on big data plays a vital role in decision-making, especially in right time delivery.

Second, logistics optimization helps to decrease transportation costs and reduce carbon footprints of the production system. This optimization has the potential to impact operational choices, including the determination of the appropriate number of vehicles to deploy, the optimal locations for hubs, and the most efficient way to maximize vehicle capacity. Hence, it results in decreased CO₂ emissions by using fewer vehicles, traveling shorter distances, and accessing more distribution hubs in the supply chain. This type of policy is frequently put into action by numerous companies, offering a hopeful strategy for enhancing the sustainability of local supply chains on a large scale.

Sustainable supply chain practices intrinsically weave together these pillars into a single coordinated approach to sustainability. Tightly managing inventory and forecasting demand is beneficial for waste-reduction programs as it helps avoid over-ordering. Additionally, the lean characteristics of these programs also contribute to reducing food waste, which is a crucial area of focus for sustainability in the food sector. The integration of renewable energy lowers operational carbon emissions, especially in processes like cold chain management. Sustainable sourcing not only facilitates inventory management and automation efforts but also ensures materials are sourced responsibly. The circular economy complements programmes that minimise waste by focusing on used materials in a manner that keeps the supply chain resource-efficient.

Technology innovation drives the means to realise the twin goals of optimization and sustainability. Blockchain upgrades supply-chain transparency by increasing traceability of products, making them safer and satisfying consumer demands for information. Integration with IoT enables real-time monitoring and automation, optimising inventory, logistics and cold chain management. Big data analytics optimises demand forecasting and hence forward integration, better alignment with market trends.

Reduction of food waste in the value chain is closely associated with accurate forecasts and lean inventory management enabled by waste reduction and policies of the circular economy, energy-efficient cold chain enables product quality and reduces the environmental footprint guided by renewable energy and IoT, Sustainable packaging ensures a lower carbon footprints and aligned with consumer demands, Overall, market responsiveness informed by accurate forecasts and sustainable sourcing can enhance the competitiveness of the food and beverages industry, and its ability to meet market demand and sustainability targets.

Actions and Strategies Derived from the Model :

1. Conduct a comprehensive audit of the supply chain to identify areas for sustainability improvements. Source raw materials from suppliers who practice sustainable methods.
2. Utilize IoT and AI for real-time monitoring and optimization of the supply chain. Revise transportation routes to lower carbon emissions and minimize fuel usage.
3. Establish long-term partnerships with sustainable suppliers. Invest in sustainable packaging solutions to minimize waste.
4. Develop and implement a sustainability strategy aligned with business goals.
5. Integrate sustainability metrics into performance evaluations for continuous improvement.
6. Enterprises in the food and beverage industry can optimize their supply chains for sustainability, leading to cost savings, increased efficiency, a reduced ecological footprint, a stronger brand, and higher customer satisfaction by following these

actions and strategies. The theoretical model serves as a comprehensive guide for achieving these outcomes through strategic supply chain integration.

Discussion

Table 1 Key performance indicators (KPIs) for supply chain optimization

KPI	Definition	Importance in Food & Beverage Industry
Inventory Turnover	The rate at which inventory is used	Ensures freshness and reduces waste
Order Fulfillment	The percentage of orders delivered on time	Critical for customer satisfaction
Delivery Lead Time	Time taken from order to delivery	Impacts freshness and quality of products
Forecast Accuracy	Accuracy of demand forecasts	Reduces overstocking and stockouts
Cost per Order	Total cost of processing an order	Affects overall profitability
Carbon Footprint	Total greenhouse gas emissions	Measures environmental impact

Table above showcases us 6 most important KPIs , based on our research, regarding optimization and sustainability in food and beverages supply chain. One of the factors that greatly affect the freshness of a product delivered to the consumer is the Inventory Turnover ratio. This indicator measures how often inventory is replenished, which means that a higher inventory turnover ratio indicates more frequent and timely delivery of products to the end consumer. Another important aspect is Order Fulfillment, which evaluates the number of orders that are delivered on time, and thus, ensures the effectiveness of the process The time taken by the business to complete an order and deliver it to the customer is referred to as the Delivery Lead Time. A shorter lead time means that a process is faster and more efficient, which in turn increases customer satisfaction. Forecast Accuracy is a measure of predicting demand and providing the correct estimates of future commodity prices, while Cost per Order assesses whether the total cost of processing an order is reasonable or not. If the total cost is higher than the expected, it might indicate the presence of some ineffective processes. The final indicator is the Carbon Footprint, which assesses the business's environmental impact by measuring greenhouse gas emissions and assists in minimizing them.

Table 2 Technological innovations in supply chain

Technology	Application in Supply Chain	Benefits	Example in Food & Beverage Industry
IoT	Real-time monitoring and tracking	Improved transparency and traceability	Temperature monitoring in cold chains

Blockchain	Secure and transparent transactions	Enhanced security and trust	Tracking product origins
Big Data Analytics	Data-driven decision-making	Optimized inventory and demand forecasting	Predicting seasonal demand fluctuations
AI and Machine Learning	Automated processes and predictive analytics	Increased efficiency and accuracy	Optimizing delivery routes

Table 3 Sustainable practices in supply chain

Practice	Description	Environmental Impact	Example in Food & Beverage Industry
Renewable Energy Usage	Using solar, wind, or other renewable sources	Reduces carbon footprint	Solar-powered warehouses
Waste Reduction Programs	Minimizing waste through various strategies	Decreases landfill use and pollution	Recycling packaging materials
Efficient Transportation	Using eco-friendly vehicles and optimized routes	Lowers greenhouse gas emissions	Electric delivery trucks
Circular Economy Principles	Reusing and recycling resources	Promotes resource efficiency	Recyclable packaging

After providing these tables which summarized all the extensive literature review we are now going to answer 4 research questions we set earlier in this paper.

Research Question 1: What are the main strategies that can be adopted to optimize supply chains in the food and beverage industry, and what are their effects on business efficiency and cost? The principal ways of improving supply chain efficiency in the food and beverage industry are deploying the IoT and big data analytics, utilising Just-In-Time (JIT) inventory systems, and collaborating with supply chain partners. The use of IoT allows to predict consumer buying behaviour and to optimise inventory by ordering just enough food and beverage products. JIT inventory reduces ordering costs as it allows to order materials immediately before the need. Collaboration with supply chain partners increases the likelihood of better coordination among them, which in turn increases efficiency and reduces operational costs. Overall, these three strategies help food and beverage companies to achieve better business efficiency and reduced costs by reducing waste, optimising inventory management, and increasing flexibility in meeting consumer demand.

Research Question 2: How can food and beverage supply chains best engage with environmental and social sustainability, and what methods are the most effective for doing so? Sustainability in food and beverage supply chains can be achieved by adopting renewable energy sources in warehouses and production facilities, adopting waste reduction programmes, as well as following the principles of the circular economy. The use of renewable energies such as solar and wind in production facilities and warehouses helps to reduce carbon footprint and lower the use of non-renewable energies that are harmful to the environment. Waste reduction programmes such as the reuse of packaging materials and lowering the level of landfills

support sustainability efforts. Maximizing resource utilization and minimizing the use of new raw materials can contribute to sustainability through the adoption of circular economy principles. By following circular economy principles, unnecessary waste can be minimised and reused or recycled into new products, creating a more efficient use of resources and lowering waste levels. Overall, those efforts are a good way to support sustainability, improve the brand image, and increase the chances of success in a market that is becoming more concerned about sustainability while also leading to cost savings and a potential competitive advantage.

Research Question 3: What are the main challenges in implementing strategies for optimization and sustainability in food and beverage supply chains, and how do successful companies overcome them? Major challenges related to implementing strategies on optimization and sustainability in the food and beverage supply chain are the high initial costs, technical weaknesses and compliance to regulation. Implementing new technologies like IoT sensors and blockchain can be difficult for small and medium-sized enterprises due to the substantial investment required. The food industry is subject to strict regulations that come with various technical constraints. In many cases, there have been difficulties in integrating new systems with existing infrastructure, for example, the difficulty in getting building permission. Furthermore, the food sector must comply with different regulations in various markets, resulting in increased costs and complexity for companies. Companies that are thriving in these areas have found solutions by using a phased approach to technology implementation, starting with strategic areas and taking advantage of government incentives, such as subsidies and tax breaks to lower the costs of investment. Furthermore, investment in staff training and upskilling employees is a great way to ensure they have the necessary skills to use new technologies and processes, help with the transition and increase operational efficiency in the long run.

Research Question 4: What is the role of optimization alongside sustainability in food and beverage supply chains, and how does it contribute to the long-term competitive position and profitability of firms? optimization for sustainability is a key factor in improving firms' long-term competitive positioning and profitability. Firms in the food and beverage supply chain can become more efficient in production, distribution and sales when they effectively integrate advanced technologies (e.g., AI, machine learning and robotics) and sustainable practices. The reduction of carbon footprints, waste generation and water use during activities enables higher operational efficiency and lower costs, which can improve firms' profitability. When firms adopt corporate social responsibility practices such as reducing carbon footprints and waste generation, they may also improve their brand reputation and customer loyalty. For example, Starbucks pledged to reduce greenhouse gas emissions as a part of its strategic goals for the next decade. This commitment to sustainable practices contributed to Starbucks' enhanced competitive advantage in a challenging operating environment. Improving product quality and delivery speed can also be achieved by optimizing supply chains, resulting in increased customer satisfaction. The combination of optimization with the integration of emerging technologies and sustainable practices creates enhanced firm-level competitiveness. For instance, firms can take advantage of this competitiveness to differentiate their products or services from other firms and market to environmentally conscious customer segments. By doing all these things, firms can enhance their long-term competitive positioning and profitability.

Conclusion

The paper concludes that there is need for optimised supply chains in the food and beverage sector for improved operational efficiency, lesser costs and sustainability. Employing the use of technology in the food supply chain can benefit food and beverage companies. For instance, integrating the use of IoT and blockchain technologies, as well as big data analytics, can help improve real-time monitoring, forecasting, and inventory management. All these will help reduce food wastage and optimise the utilisation of available resources. On the sustainability front, green energy integration, waste programmes, and the adoption of the circular economy are equally important. Companies will gain a significant competitive advantage in an increasingly green marketplace by contributing to environmental good, as well as benefiting from positive brand reputation and consumer loyalty..

Overcoming barriers to the implementation of these strategies – such as high initial costs and technical hurdles – can be achieved through phased adoption of technology, government incentives and staff training. When these optimization efforts are integrated with sustainability goals, firms can achieve higher-quality products that are delivered faster, thereby improving customer satisfaction and long-term profitability. Integrating optimization and sustainability efforts into the supply chain serves to place firms in optimal position to satisfy the demands of consumers and other stakeholders. It is also a step toward achieving the public policy goals of sustainable development in the food and beverage industry.

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