Sustainable Operations of End-to-End Closed-loop Supply Chain - Taking Nestlé Nespresso Aluminum Coffee Capsules as an Example

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Abstract. In recent years, the frequency of extreme weather events around the world has significantly increased. This is due to the traditional "acquisition - manufacture - disposal" linear economic model, which has caused severe environmental pollution on the planet and consumed a large amount of its natural resources, ultimately leading to a global temperature rise. Consequently, businesses are under growing pressure to transform their supply chains towards more sustainable models. This article will analyze the aluminum coffee capsules of Nestlé, introduce its current supply network, and analyze the sustainability issues faced by coffee capsules in operation and the supply chain. As a leading company in the food industry, Nestlé has set a target to achieve net-zero greenhouse gas emissions by 2050, making such an analysis both timely and relevant. Based on the identified problems, targeted solutions will be formulated to optimize its supply chain and improve its operational efficiency. The proposed solutions aim to address these challenges through circular economy principles, such as product recycling and closed-loop supply chain design.

Keywords: Circular economy, Closed-loop supply chain, Sustainable supply chain.

1. Introduction

As people's awareness of environmental protection and morality has increased, consumers are more capable of recognizing unethical issues in the supply chain of enterprises, such as child labor and gender discrimination, and are more concerned about the environmental impact of the supply chain. Therefore, when consumers purchase goods, they tend to prefer products from enterprises with higher sustainability. Moreover, when investors invest in enterprises, they also consider the sustainability of the enterprises. Because enterprises with high pollution have reputational risks, which can lead to financial problems, and if enterprises have high sustainable supply chains, they can not only help the enterprises save costs but also enhance their reputation and increase market share.

Against this backdrop, various countries have begun to implement corresponding measures to improve carbon emissions and strengthen environmental governance. The CBAM regulation mechanism of the European Union and China's carbon peak and carbon neutrality strategic goals have promoted the green manufacturing and circular economic development of enterprises. As a major source of global carbon emissions, the food industry plays a critical role in addressing climate change.

Nestlé, as a leading company in the fast-moving consumer goods (FMCG) and food manufacturing industries, has also set a goal of achieving net zero greenhouse gas emissions by 2050. In addition, as people's awareness of environmental protection and morality has increased, consumers are more capable of recognizing unethical issues in the supply chain of enterprises, such as child labor and gender discrimination, and are more concerned about the environmental impact of the supply chain. Therefore, when consumers purchase goods, they tend to prefer products from enterprises with higher sustainability. When investors invest in enterprises, they also consider the sustainability of the enterprises. Sustainable supply chain management has therefore become a core element for companies to gain competitive advantage. Because enterprises with high pollution have reputational risks, which can lead to financial problems, and if enterprises have high sustainable supply chains, they can not only help the enterprises save costs but also enhance their reputation and increase market share.

To achieve better environmental and economic benefits, the concept of the circular economy has also been integrated into the supply chain of enterprises. Through product recycling, remanufacturing, and reverse logistics, enterprises can build a closed-loop supply chain, thereby improving operational efficiency, reducing long-term costs, and protecting the natural environment. In this transition process, case studies of specific products have become particularly important. This article will analyze Nestlé's aluminum coffee capsules, introduce its current supply chain network, and discuss the sustainability issues faced by coffee capsules in operations and supply chains. Based on the identified problems, targeted solutions will be proposed to optimize the supply chain and improve operational efficiency.

2. Sustainability Challenges in Operations and Supply Chain

2.1. Upstream Sustainability Issues

Moreover, in the entire upstream, midstream and downstream industrial supply chain, this product also faces different risks and sustainability issues. From the upstream perspective, Nestlé's coffee bean planting areas are relatively scattered. As mentioned earlier, they mainly come from Latin America, Africa and Asia. However, the climate risks in these regions are different, which leads to the instability of their agricultural environment. Secondly, from a macro perspective, the frequent occurrence of extreme climates in recent years, such as droughts and heavy rains, has also exacerbated this risk level, causing certain adverse effects on Nestlé's own raw material costs, including quality control. This risk is not conducive to the stability of its supply chain. From the suppliers' perspective, Nestlé's cooperation with small farmers also faces the weak risk-resistance ability of farmers and the risk of labor loss in some regions, which affects the long-term supply stability.

2.2. Manufacturing and Packaging Challenges

From the midstream perspective, Nestlé adopts an independent production model for mass production, which has a long production cycle. However, its production areas are relatively concentrated. If the production equipment fails, it will cause uncertainty in the high-quality standards of the products. Moreover, during the production process, the roasting of coffee beans and the aluminum packaging of capsule coffee consume a lot of electricity and heat energy. A large amount of electricity still relies on fossil raw materials, resulting in a large amount of carbon emissions, causing the greenhouse effect, and reducing the sustainability of production.

2.3. Downstream & Consumer-Related Issues

For the downstream sales and recycling stage, the operational risks it faces mainly include fluctuations in demand and prediction risks, as well as the effectiveness of resource recycling. Firstly, from the perspective of operational risks, capsule coffee products belong to FMCG (Fast Moving Consumer Goods), which have the characteristics of being frequently consumed, substitutability, and a large number of similar products[1]. The sales volume of such products is easily affected by product marketing, and the market demand is unstable[2]. Moreover, for specific markets, such as the Chinese market, under the current fierce competition in the e-commerce platforms in China, the sales volume of these products will also change according to the "promotion period"[3]. Therefore, unstable demand cannot be accurately predicted. Secondly, from the perspective of sustainable risks in the supply chain, the recyclability of aluminum capsule coffee is not proportional to the actual recycling rate. There is a problem that Nestlé designs recyclable packaging, but consumers' willingness to participate in the recycling program is not strong. Therefore, there is still a certain gap between the vision of recycling reuse and the actual implementation.

2.4. Analysis of the Whip Effect in Nestlé's Aluminum Capsule Coffee Supply Chain

The whip effect in Nestlé's aluminum capsule coffee supply chain mainly occurs in two links. The first link is the difference between the actual demand of consumers in the market and the orders from retail stores and platform e-commerce platforms. The second link is the difference between the retail orders and the platform e-commerce orders and the expected production of Nestlé. From the first production link, the demand for Nestlé's aluminum capsule coffee during promotional activities and special festivals will increase sharply. This unstable growth in consumer demand will lead distributors to increase their order quantities. At the same time, this is closely linked to the second link. The large increase in order quantities is reflected in the production department. Combined with the characteristics of batch production of aluminum capsule coffee, the production department will increase production. During this process, the transmission of information has a delay. When production increases and inventory builds up, the market demand decreases, increasing product inventory. This is the whip effect in Nestlé's aluminum capsule coffee.

3. Developing an End-to-End Closed-Loop Supply Chain

Regarding the operational and sustainability issues of the Nestlé aluminum coffee capsule supply chain mentioned in the previous chapter, this chapter will design a solution to alleviate its sustainability problems based on the theories of closed-loop supply chain, circular economy, life-cycle assessment (LCA), supply chain collaborative information sharing theory, and the mechanism for alleviating the bullwhip effect. This will address the sustainability issues existing in the upstream and downstream of the previous chapter and optimize its operational model.

3.1. Theoretical Basis

The closed-loop supply chain theory combines the process of raw material procurement to sales with recycling and re-manufacturing, as well as re-utilization of products, forming a closed system, which changes the traditional linear model[4]. The circular economy is more macroscopic, requiring the collaboration of manufacturers, suppliers, and consumers to achieve a national economy based on circular practices[5]. Based on this, combined with the analysis of the environmental impact of products from raw materials to final product production in the life-cycle theory, information sharing is used to alleviate the bullwhip effect in the supply chain.

3.2. Building an End-to-end Closed-loop Supply Chain for Nespresso Aluminum Coffee Capsules

The quality stability of coffee beans is affected by climate change and the income of farmers, which leads to potential long-term supply risks for Nestlé. To enhance the stability and sustainability of raw material supply, Nestlé has currently launched the AAA Sustainable Quality™ Program, aiming to establish a long-term stable partnership with small farmers to reduce the volatility of farmers' income. In addition, Nestlé also provides knowledge and training to the cooperators to ensure the high quality of coffee beans.

For the aluminum material indispensable for the production of aluminum coffee capsules, a large amount of heat and electricity are consumed during the production process, and the fluctuation of energy prices also causes fluctuations in the cost price of raw material packaging. In fact, the energy consumed for the reuse of aluminum packaging only accounts for 5%-10% of primary aluminum [6]. Therefore, recycling aluminum packaging and increasing the proportion of recycled aluminum become the key to reducing energy consumption and improving production sustainability. In the recycling of aluminum packaging, Nestlé collaborates with companies such as Veolia and Amcor to achieve the recycling of aluminum packaging [7]. However, Nestlé does not have its own packaging recycling points; instead, it recycles the aluminum packaging of capsule coffee through courier services and recycling bins. In this process, Nestlé can add more packaging recycling points and carefully select the location of these points, for example, between the store and the consumer's

residence, to enhance the convenience of the aluminum packaging recycling process for consumers, increase consumer participation and willingness to recycle, and strengthen the connection with recycling enterprises, stabilizing the cooperative relationship.

3.2.1. Reducing the bullwhip effect and operational rigidity in the middle of the supply chain

The bullwhip effect generated in the middle of the supply chain mainly stems from the inaccurate prediction of consumers' real demands in the production process, and due to the batch production characteristics of this product, it causes the inventory squeeze problem caused by the bullwhip effect. To address this issue, Nestlé needs to use POS data to track the real-time sales of the product on e-commerce platforms instead of relying on order data for prediction[8]. In addition, Nestlé is also actively carrying out digital transformation of the supply chain to achieve information sharing. In 2025, it proposed the CSV sharing concept to alleviate the adverse effects of the bullwhip effect[9]. Regarding the electricity and heat consumed by aluminum packaging, Nestlé can use renewable energy such as green electricity and PPA to replace it.

3.2.2. Building an efficient reverse logistics and truly closed-loop downstream supply chain

The recycling problem of aluminum coffee capsules still has the issue of relying on consumers' self-awareness. This is closely related to the environmental awareness of consumers in various regions and the policies of local governments. Nestlé can incentivize consumers' recycling behavior, for example, aluminum coffee capsules that are recycled after use can be saved as "recycling points", and these points can be exchanged for specific items such as cups and new flavor coffee capsules, thereby increasing consumers' willingness to recycle. In addition, Nestlé can design recycling guidelines to introduce the recycling process to consumers when they purchase coffee capsules, allowing consumers to understand the recycling process and increase their recycling awareness, increasing the product recycling rate[10].

3.3. Impact on Operational Performance

This set of sustainable optimization plans has several improvements for the supply chain issues of Nestlé's aluminum coffee capsules. Firstly, due to the enhanced accuracy of demand forecasting, the problem of product inventory backlog has been alleviated. Secondly, with the increase in the use of recycled aluminum, the energy consumed during packaging production has decreased, converting from thermal and electrical energy to green energy, thereby improving resource utilization efficiency and reducing packaging manufacturing costs. Thirdly, the cooperation between the supply farmers and the enterprise has been strengthened, alleviating the supply risks caused by unstable income for farmers. In terms of sustainability, due to the use of green energy and the increase in the proportion of renewable aluminum, carbon emissions have decreased, and the social and environmental performance of Nestlé's aluminum coffee capsules has been improved.

4. Conclusion

Given the increasingly frequent occurrence of extreme weather events in recent years and the enhanced environmental protection awareness among people, how enterprises can achieve sustainable development of their supply chains and realize closed-loop supply chains has become increasingly important for their future development. An enterprise with a highly sustainable supply chain and a high ESG rating can not only gain a good reputation but also save material costs. Based on the concept of the circular economy, this paper takes Nestlé's aluminum coffee capsules as the research object, analyzes and introduces the entire supply chain structure, and conducts a detailed analysis of the operations and sustainability issues in the supply chain's downstream. Through analysis, it can be seen that there is a bullwhip effect problem in the middle stream due to fluctuations in consumer demand, and the failure to promptly respond to real-time order quantities leads to inventory accumulation. For the downstream supply chain, there is a packaging recycling problem after consumers use the products. This paper proposes corresponding solutions for each problem.

Regarding the energy consumption issue, Nestlé should increase the recycling rate of aluminum coffee capsule packaging because the energy consumption for reusing aluminum packaging is only 5-10% of the original aluminum packaging. In addition, when Nestlé packages coffee capsules, it should also consider using green clean energy instead of traditional energy to avoid a large amount of carbon emissions. Through consumer incentive measures for aluminum capsule coffee recycling, the recycling rate of coffee capsules can be improved. The plan proposed in this paper aims to enhance the operational efficiency of Nestlé's aluminum coffee capsules and the sustainability of production. In summary, Nestlé's aluminum coffee capsules have a basic model of a circular supply chain, but it can also achieve a better and more sustainable closed-loop supply chain by optimizing the upstream, middle, and downstream separately.

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