International Journal of Future Engineering Innovations

# Quantifying and Reducing Whiteleg Shrimp Food Loss: A System Dynamics-Based Strategy Development

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## Article Info

**ISSN (online):** 3049-1215
**Impact Factor (RSIF):** 8.25
**Volume:** 03
**Issue:** 02
**March-April 2026**
**Received:** 15-01-2026
**Accepted:** 13-02-2026
**Published:** 11-03-2026
**Page No:** 76-86

**Abstract**

One of the key focuses in the development of the Sustainable Development Goals (SDGs) is environmental sustainability. A critical indicator within the SDGs framework is Food Loss and Food Waste (FLFW). Food loss in the upstream supply chain presents a significant challenge, particularly in the agricultural and fisheries sectors, which are characterized by highly perishable products. Shrimp farming within the supply chain also encounters food loss issues due to the perishable nature of shrimp, its sensitivity to weather conditions, and time constraints. Given these challenges, targeted actions are essential to address the issue, including the development of strategies to reduce food loss and maintain shrimp quality. Stakeholders must recognize the urgency of this matter to ensure the establishment of clear standards for managing food loss across the supply chain. This initiative aligns with the broader objectives of the SDGs. The novelty of this study lies in its use of a system dynamics approach—a systematic method capable of modeling complex systems such as the shrimp supply chain. The objective of this study is to formulate and identify strategies that can be implemented by supply chain actors to reduce food loss in the shrimp supply chain in South Sulawesi Province. This study proposes two strategies: Good Supply Chain Practice and the Circular Economy. Among these, the Circular Economy strategy is recommended as the most effective, with an estimated food loss reduction of 44,188.37 kg.

**DOI:** https://doi.org/10.54660/IJFEI.2026.3.2.76-86

**Keywords:** Food Loss, Supply Chain, Shrimps, System Dynamic, Sustainability

## 1. Introduction

As one of the world's leading maritime nations, Indonesia plays a significant role in the global production of marine resources. South Sulawesi, in particular, serves as a key hub for marine and aquaculture production due to its strategic location and favorable geographic conditions. These advantages have positioned Indonesia among the top exporters of marine commodities on the global stage. Shrimp has emerged as a vital commodity within Indonesia's aquaculture sector, offering considerable economic potential. According to data from the Ministry of Marine Affairs and Fisheries (KKP), shrimp exports contributed approximately 36.27% to the total value of Indonesia's fishery exports between 2012 and 2018. In 2023, Indonesia's shrimp export volume reached 241,200 tons, with a total value of USD 2.16 billion [1]. Export statistics indicate that shrimp accounts for approximately 35.48% of the country's total marine and fishery export value, underscoring its importance in the national seafood trade. Nevertheless, the industry is confronted with substantial obstacles—chief among them is food loss [2], which is prevalent along the shrimp supply chain. The shrimp industry faces significant challenges related to food loss, primarily due to the perishable nature of shrimp and the complexities of its supply chain [3]. The nature of shrimp as a perishable and time-sensitive product, combined with the complexity of its distribution process, makes it particularly vulnerable to spoilage.FAO [4] estimates that losses in fishery and aquaculture products can reach up to 35%. Shrimp, as a fresh commodity, is both voluminous and highly perishable-characteristics that complicate handling and transportation and require prompt processing and distribution. Any delays can accelerate deterioration, thereby increasing the overall food loss. Mitigating these losses is critical for enhancing supply chain performance and supporting sustainable practices in the aquaculture industry. Whiteleg shrimp (*Litopenaeus vannamei* Boone) is an introduced species that is currently in high demand due to several advantages. These include relative resistance to disease, high productivity, a relatively short cultivation period, a high survival rate during the grow-out phase, and steadily increasing market demand. The shrimp farming process encompasses all stages, from hatchery to grow-out. Hatchery activities for whiteleg shrimp are closely linked to the availability of high-quality fry, which plays a critical role in ensuring successful cultivation outcomes [5]. Shrimp has enormous potential to become a mainstay commodity in the aquaculture sector in Indonesia. One of the islands in Indonesia that promises to be the center of the shrimp industry is Sulawesi. This island with 6 provinces has a coastline of 6,000 km and has 4 sea boundaries, namely the Flores Sea in the north, the Sulawesi Sea in the south, the Makassar Strait in the west, and the Banda Sea in the east. Based on data from the Ministry of Maritime Affairs and Fisheries [6]. in 2021 the island of Sulawesi scored a volume of aquaculture production of more than 5,801 tons. Of this volume, South Sulawesi province held the highest production volume at 4,082 tons, followed by Central Sulawesi at 731,528 tons. The province with the smallest production during the period was Gorontalo at 49,377 tons. This shows that there is an increase in the performance of the fisheries sector, one of which is strengthening the competitiveness of Indonesian fisheries and marine products. Based on this data, it is known that there are approximately 140,000 bags of fingerlings distributed to various regions every month. Whiteleg shrimp are distributed to large traders, especially outside the city of Barru itself and also to special retailers in the city of Barru, which of course has the potential for Food Loos. Food loss can occur along the upstream supply chain with varying causes ranging from the possibility of high mortality rates in the production process to improper distribution management where in this case what is meant is the lack of management of the cold chain which is actually very vital because it is needed to maintain the quality of shrimp products while running in the existing supply chain considering that shrimp are classified as perishable goods which in fact have a relatively short product life. The percentage of food loss consists of 15 percent of food loss at the distribution stage, which is then followed by the processing and packaging stage at 9% percent of food loss, 8 percent at the production stage, and at the handling and storage stage reaching 6% food loss [7]. To address this food loss issue, which has actually become the focus of the FAO (Food and Agriculture Organization) through the introduction of Sustainable Development Goals No. 12 (Responsible Consumption and Production), interventions are needed to address this issue. The aims of this study are to provide an estimate of the impact of improvement strategies, if implemented, through testing using a dynamic system model by considering the presence of feedback elements in the shrimp supply chain map and to obtain the best alternative improvement strategies for all stakeholders in the shrimp supply chain.

## 2. Literature review

### 2.1. Food Loss on the Supply Chain

Although food loss and food waste are two distinct concepts, they result in similar consequences, as presented in Table 1 Both involve a reduction in the quantity or quality of food due to actions and decisions within the food supply chain, excluding the roles of retailers, food service providers, and consumers. Food loss typically occurs in the early stages of the supply chain, starting from harvesting or slaughter through processing, storage, and distribution. It involves food that is discarded, burned, or otherwise removed from the supply chain without being redirected to other productive purposes, such as animal feed or seed. On the other hand, food waste refers to food that remains safe for consumption but is discarded at the level of retailers, food service providers, or end consumers due to reasons such as expiration, undesirable taste, or leftover portions [8]

**Table 1:** The Differences of Food Loss and Food Waste

| | **Food Loss** | **Food Waste** |
|---|---|---|
| Stages | Production, storage, processing and distribution stages | Retailer, service provider and end consumer stages |
| Location | The highest levels of food loss are in developing countries | The highest level of food waste in developed countries |
| Causes | Limited technology Poor product quality Poor storage Long transportation | Consumer patterns in consuming food Unsold food (usually occurs in restaurants or food services) Expired products |

***Source:*** Lipinski, *et al*. [9] dan FAO [8]

Research related to Food Loss is limited to literature reviews and also secondary data processing obtained from NGOs and related government agencies. Only 1 study presents primary data on FLW specifically for the fisheries and aquaculture industry in specific locations. 22 other studies are only based on pre-existing studies or data for regional to global estimates. Previous studies have used more Factor analysis, Life Cycle Assessment, Optimization and more are only in the form of literature reviews. There are still few that discuss the potential risk of food loss that occurs in the food supply chain and how to reduce food loss. The main factors that cause food loss in the supply chain are complex networks, dependence on suppliers, the life cycle of a product (generally perishable products have a high risk) and also how stakeholders interact in the process and solve problems [10]. In order for the intervention to be appropriate, a systematic approach is needed in looking at this issue where one approach that can be used is the dynamic system approach.

### 2.2. System Dynamic as an approach to develop the food loss reduction strategies

The use of System dynamics (SD) in cases of Food loss in the supply chain is still limited. In fact, the dynamics caused by uncertainty in the supply chain system can be used as a consideration in using SD as an approach in designing policies in an effort to reduce the level of FL. Previous studies have used more Factor analysis [11], Life Cycle Assessment [12] and Mathematical models [13]. Optimization and more are only in the form of literature reviews. Most studies that use SD in FLFW in cases related to waste management but are still very rarely used in cases of food supply chains. Archip, *et al.* [14] used system dynamics to determine the impact of recycling and disposal of waste. Tseng, *et al.* [15] also used system dynamics in their research discussing waste management in agri-food. There are several studies that also use SD but in the realm of waste management [16-18]. Ranjbari, *et al.* [18] used SD to build a model of circular economy in order to manage the waste. In fact, the complexity of the supply chain due to uncertainty factors that occur along the supply chain and are greatly influenced by time makes this case quite dynamic. Zahedi, *et al.* [19] employed a system dynamics (SD) model to simulate the effectiveness of sectoral water and energy management policies over a 20-year period. Their study further explored the integration of these policies within an optimized framework, revealing that a combination of water demand and food resource management strategies yielded the most favorable outcomes. Inspired by this approach, the present research adopts a system dynamics methodology to address challenges within the shrimp supply chain. Specifically, this study analyzes the roles and interests of various actors—each with distinct objectives and constraints—through actor analysis, and integrates these insights within a dynamic system model. The goal is to formulate alternative strategies and policy recommendations aimed at reducing food loss across the shrimp supply chain. is known to have their own interests and obstacles.

## 3. Material and Method

The research was conducted in 2024 in South Sulawesi. This study investigated the shrimp supply chain, with PT. Esaputlii Prakarsa Utama and its sellers serving as the primary research subjects. Food loss analysis of shrimp supply chain using dynamic system approach includes causal model, model simulation diagram and model formulation. These models are developed based on the real system and described into each sub model. The system model is not only an embodiment of the goal but also an assumption, because a system model has eliminated some elements that are considered irrelevant.

### 3.1. Conceptualization Using Causal Loop Diagram

Minimizing food loss in the distribution supply chain of whiteleg shrimp in Barru Regency—which includes factors that hinder shrimp distribution at the farm level—involves various interrelated and time-integrated variables. Regionally, this issue can be viewed as a system dynamics problem, characterized by changes over time and influenced by other dynamic factors.

### 3.1.1. Sub System Shrimp Farmer

The shrimp cultivator sub-model captures the mortality rate during each shrimp cultivation cycle. Several variables influence the level of food loss, including the effectiveness of maintenance activities, which impacts food loss during distribution; the quality of cooling equipment, which affects losses during storage; and the varying percentages of food loss at different stages of the supply chain. This system incorporates specific technologies and cultivation techniques aimed at optimizing shrimp growth and maximizing yield. Figure 1 shows some of the key elements involved in the shrimp farming system.

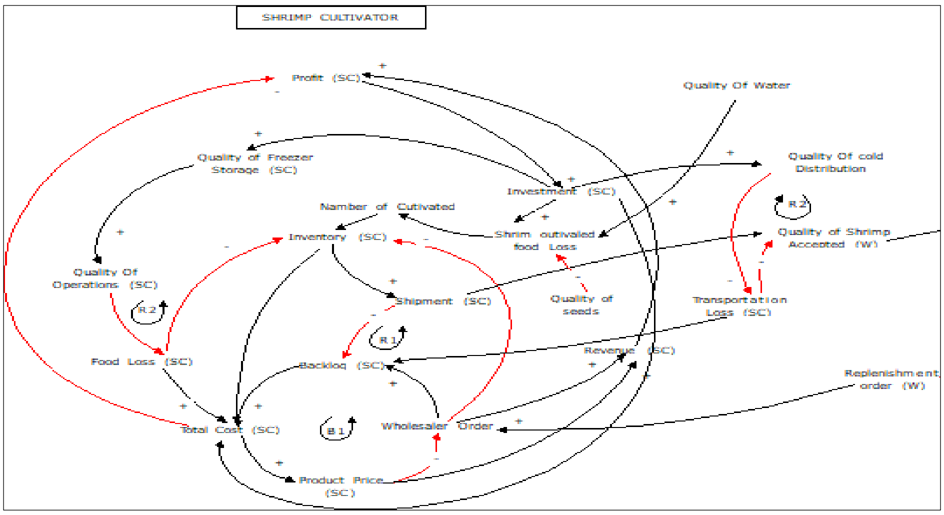


**Fig 1:** Sub System Shrimp Farmer

### 3.1.2. Sub System Shrimp Seller

Shrimp sellers play a vital role in the shrimp supply chain by ensuring that shrimp products reach the market in optimal condition and meet consumer demand. The efficiency and effectiveness of this subsystem contribute significantly to the overall success of the shrimp industry and have a direct impact on both local and international economies involved in shrimp trade as shown in Figure 2

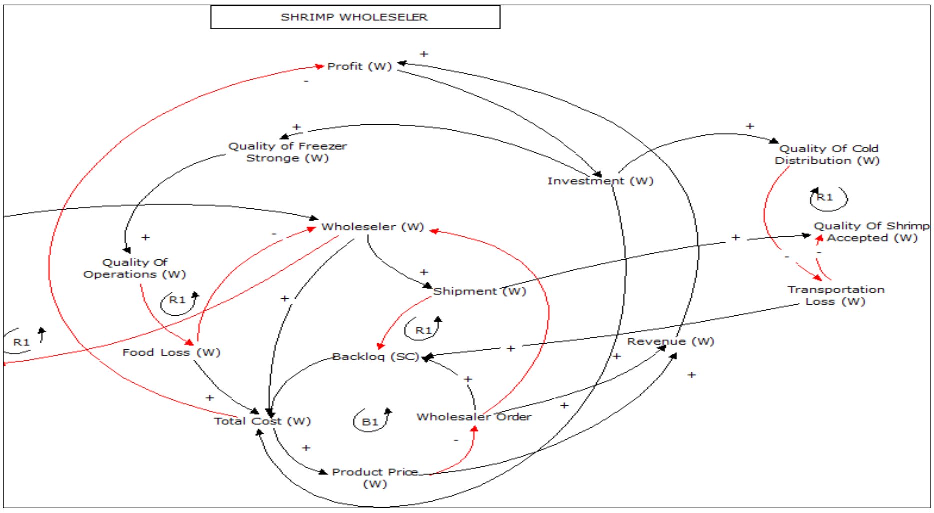


**Fig 2:** Sub-system Shrimp Seller

### 3.2. Conceptualization Using System Diagram

The conceptual model of this research is made in a causal loop diagram that departs from a system diagram. The system diagram shows an overview of the problem in this research which consists of the objective of this research which is to reduce the level of food loss, the criteria for achieving the objective, and the measures of these criteria as shown in Figure 3. System Diagram.

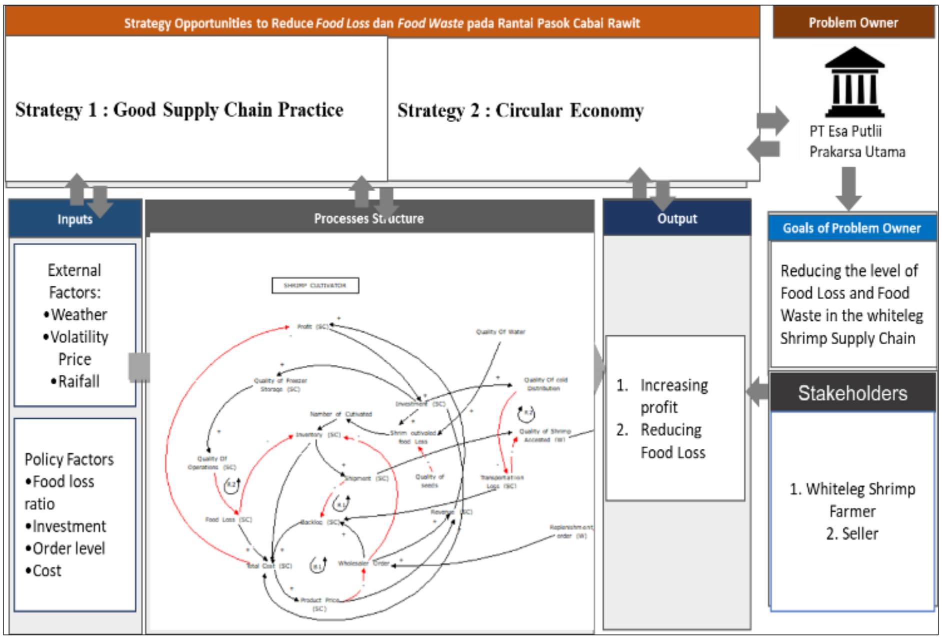


**Fig 3:** System Diagram

### 3.3. Stock Flow Diagram Model Development

The output to be described from the export supply chain module is the dynamics of orders and shipments from each actor in the supply chain where the timestep used in this model is a quarter unit. The determination of the initial inventory level for each supply chain actor is obtained from historical data where the basic basis for its determination is seen from fluctuating historical data. In the economic module, profit is the output indicator. The capital price and selling price of shrimp per kilogram are obtained from the average price data each year. As for the calculation of profit, it is obtained from revenue per quarter minus the cost per quarter where if the revenue per quarter increases, the profit will increase and if the cost per quarter decreases, the profit will also decrease. After the profit is obtained, the investment variables to be issued by the related supply chain actors are also describe. In the SFD Food Loss Module, the output is in the form of total food loss resulting from the running of the shrimp supply chain system where the food loss comes from loss while the shrimp are in storage, transportation loss that occurs during the distribution process, and food loss that occurs during the shrimp cultivation period where there is a mortality rate for each cultivation period. As for some variables that affect the level of food loss, the effectiveness of maintenance activities will affect the level of food loss at the distribution stage, the quality of the cooling machine will affect the level of food loss at the storage stage, and the percentage of food loss is different at different stages of the supply chain.

## 4. Results and Discussions

The output of this module simulation is the dynamics between orders and shipments from each shrimp supply chain actor based on the amount of demand and inventory available. The simulation results as shown in Figure 4, there are fluctuations in the delivery and receipt of different supply chain actors depending on the level of demand and the level of inventory to be maintained. But it has the same pattern for the next two years. Business as Usual (BAU) is a model or approach that describes the conditions or situations in which business operations and activities are carried out without any significant changes or adjustments to new external or internal conditions. In this context, everything continues as usual, without any innovation, change in strategy, or response to new challenges and developments.

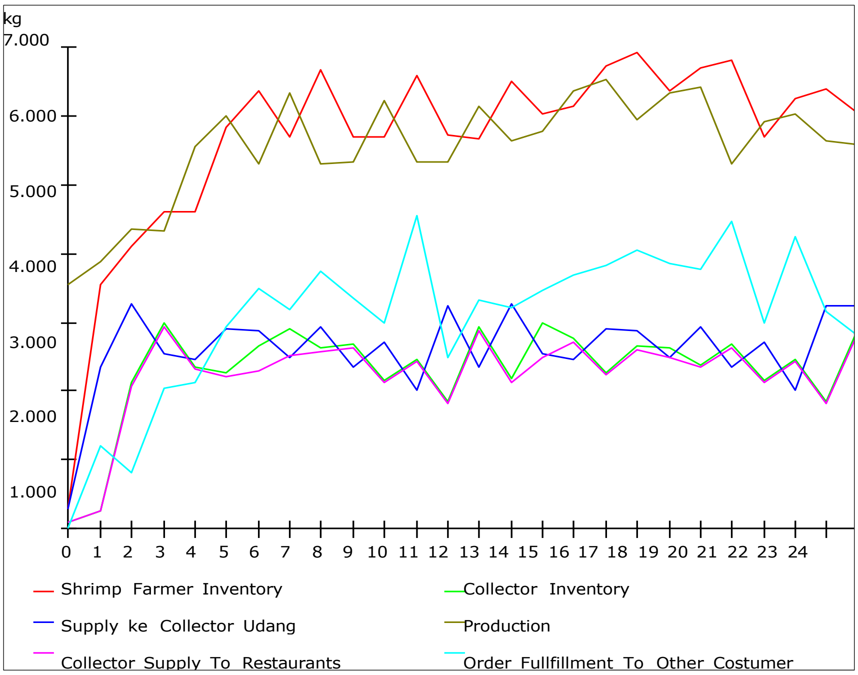


**Fig 4:** BAU Model Simulation Results for Supply Chain Sub-Systems

In this module simulation, the output indicator is the total food loss accumulated throughout the simulation time where the total food loss comes from a variety of food losses experienced by each shrimp aquaculture export supply chain actor. The simulation results show that there is an exponential increase in total food loss from 2024 to 2025 where the food loss is an accumulation of food loss at the storage and distribution stages. At the end of 2025, the total food loss level amounted to 187,817 Kg.

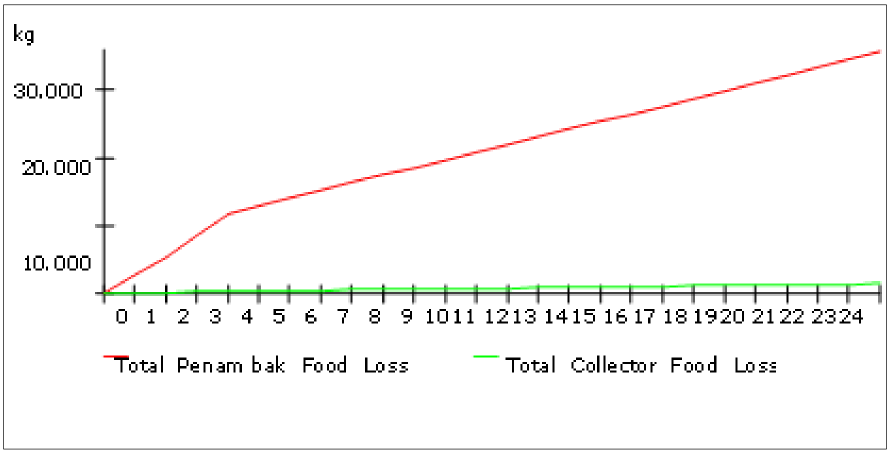


**Fig 5:** BAU Model Simulation Results for the Food Loss Sub-System

The output indicator of the simulation of the economic module is the level of profit obtained by the actors of the shrimp export supply chain from 2024-2025, in this case the actors are shrimp farmers, and shrimp wholesalers, From the simulation results, it can be seen that at the end of the simulation year, the supply chain actors with the highest level of profit are shrimp farmers with a profit level reaching Rp15,528,351,127 at the end of 2025.

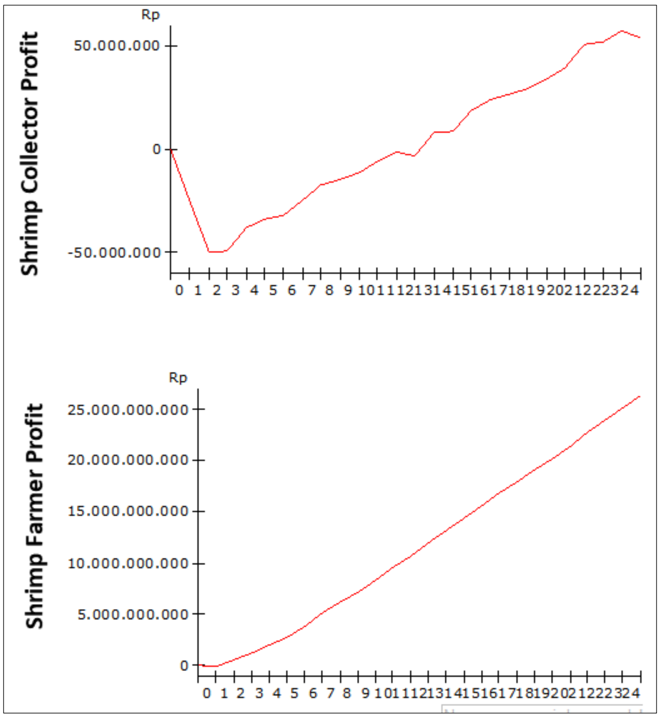


**Fig 6:** BAU Model Simulation Results for Financial Sub-Systems

### 4.2. Verification and Validation
The model testing conducted in this study used five model tests from Sterman [20], which are model tests adapted from Senge and Forrester [21], namely Boundary adequacy test, Structure assessment, Dimensional consistency, Behavior Reproduction, and Extreme conditions test. The model testing conducted in this study has included three stages of model validation as explained by [22].

#### 4.2.1. Model Structure Test
The purpose of this test is to determine whether the structure of the model that has been built is in accordance with the real system to be modeled. Every factor that influences and is considered important in the real system must be represented in the model. The structure test in this study was carried out by involving several experts who are familiar with the concept and are directly involved in the system as validators of the model structure. All the validators confirmed the model as a valid model to represent the system.

#### 4.2.2. Dimensional Consistency Test
The software used in this simulation model is Powersim Studio 2010 where in using the software, the new simulation model will run if the units of the variables in the system are well defined. This can be seen from the model that has been successfully simulated and then analyzed the results.

#### 4.2.3. Behaviour Reproduction Test
Model behavior testing can be done in two ways, namely quantitatively and qualitatively. The qualitative method is to compare the actual data pattern and the simulation result pattern of the model. Behavior reproduction testing can also be done using descriptive statistics such as measuring the mean percentage error (MAPE). In this dynamic system model, the model is simulated for one year with a period of 12 months. From the calculation results in the table, it is found that the mean percentage error (MAPE) value which shows the difference between the simulation value and the actual data is 2,3%. This value is below 30% which is the maximum limit of data declared valid. So that the model can be declared valid and reflects the actual conditions that occur.

### 4.3. Alternative Strategies
Alternative strategy design is carried out to simulate strategies that can be carried out by the Indonesian government as a form of intervention to address the issue of food loss in the shrimp supply chain which has actually received attention from the government where there is a plan to issue a Presidential Regulation which will later form regulations on this issue. The alternative strategies are prepared based on a literature study on efforts that can be made to reduce the level of food loss. Table 2 shows alternative strategies along with their impacts and sources.

**Table 2:** The Alternative Strategies

| Alternative Strategies | The effect of Strategies |
| --- | --- |
| Good Supply Chain Practice | Reducing the level of food loss at the storage and distribution stage of the shrimp supply chain by investing in maintenance activities and the quality of storage and distribution cooling systems. |
| Circular Economic | Reducing the level of food loss at the storage and production stages by processing low-quality shrimp that do not meet market standards into new products with added value. |

### 4.4. Impact Analysis of Alternative Strategies

#### 4.4.1. The simulation result of good manufacturing practice strategy

This alternative strategy demonstrates that product quality must be maintained from the production stage through to marketing and delivery to consumers. Quality levels are maintained based on established standards to minimize potential risks throughout the process. Good Manufacturing Practice (GMP) encompasses all aspects, including the raw materials used, the machinery and facilities employed, training and hygiene standards, as well as various other factors considered in GMP evaluations. In this context, GMP is implemented through investments aimed at enhancing the effectiveness of maintenance activities and improving the quality of the cooling machines used. The output of this model includes a comparison of food loss levels before and after the implementation of the alternative strategy. Another output is an assessment of the financial benefits for supply chain actors who comply with the established rules and procedures of good supply chain practices. Fig 7. Shows the result of GSCP

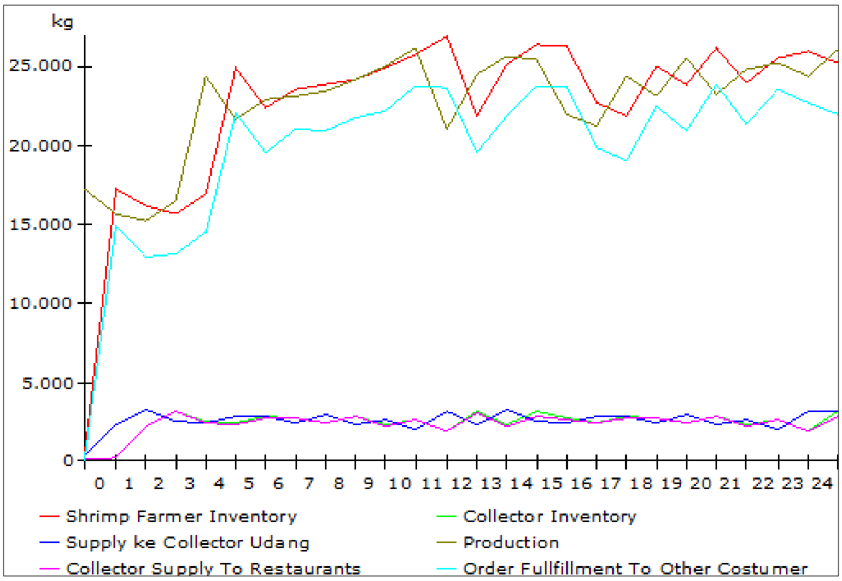


**Fig 7:** Good Supply Chain Practice Strategy simulation results

Fig 8. shows a comparison of the level of profit obtained by supply chain actors in the BAU scheme and after the implementation of the GSCP strategy alternative. After the simulation ended, a profit level of Rp 16,096,701,494 was obtained for the BAU scheme and a profit of Rp 16,369,021,512 for the GSCP scheme. This shows an increase in profit of 3% over two years.

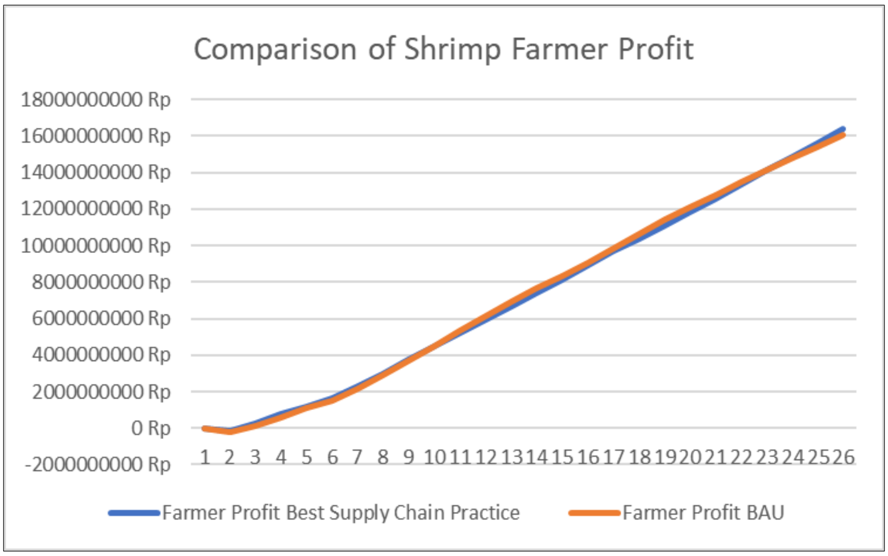


**Fig 8:** Comparison of Shrimp Farmer Profit

Fig. 9. shows a comparison of the accumulated total food loss levels in the shrimp export supply chain where the schemes being compared are the BAU scheme with the alternative GMP strategy which respectively produce food loss levels of 665,957.74 tons and 479,803.10 where this shows that there is a decrease in the overall food loss level of the supply chain by 38.8%.

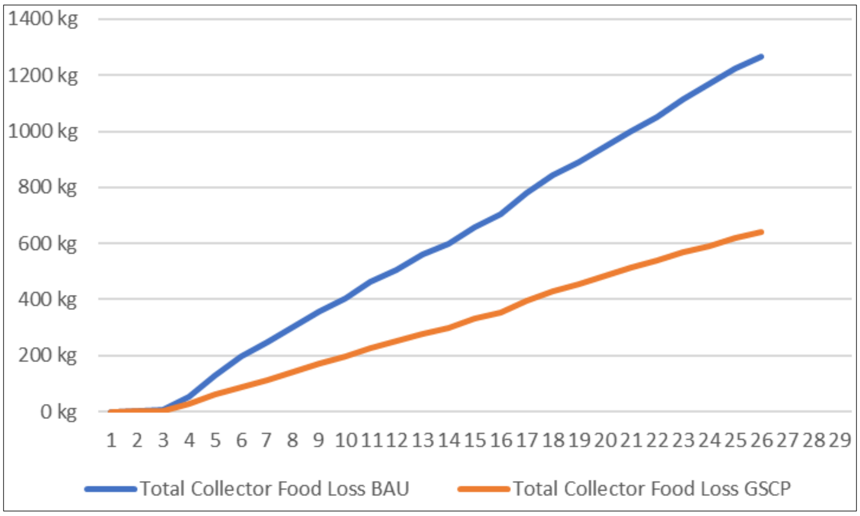


**Fig 9:** Simulation Results Comparison of Total Food Loss Collector Good Supply Chain Practice Strategy

### 4.4.2 The simulation result of Circular Economy Strategy

This alternative strategy illustrates that waste in this case is food loss can be reduced by processing the food loss into a new product that has value. In this strategy, food loss in shrimp in the shrimp farmer section is processed into processed shrimp when the quality has decreased so that food loss can be avoided. Circular Economy requires initial investment and of course maintenance and operations. So that costs will increase but this also has an impact on the revenue obtained. In this case, GMP is realized through investment to increase the effectiveness of maintenance activities. The output of this model is a comparison of the level of food loss before and after this alternative strategy is implemented. Another output is to see the financial benefits of supply chain actors if they comply with the rules and execution processes that have been set in the circular economy. This strategy is only applied in the upstream part of the supply chain, namely in the Farmers, which in the BAU model, produces the most food loss. The result was shown in Fig 10.

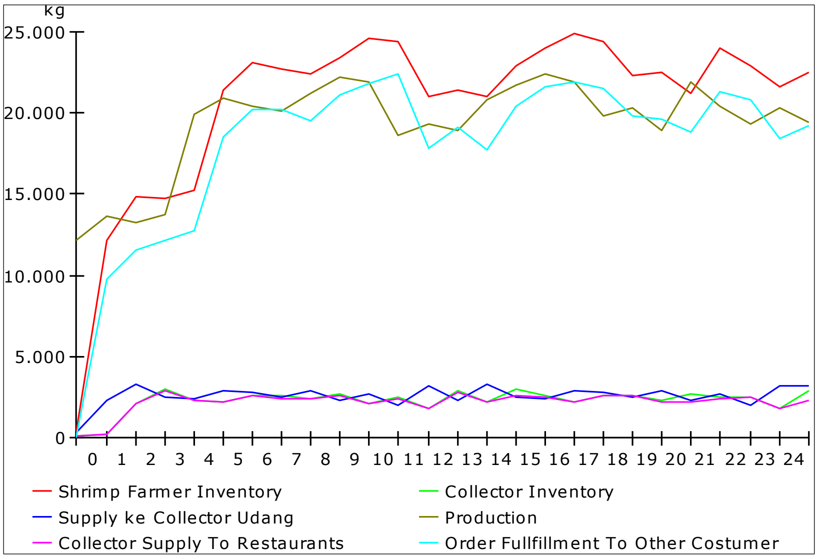


**Fig 10:** Circular Economy Strategy Supply Chain Simulation Results

Fig. 11. shows a comparison of the level of profit obtained by supply chain actors in the BAU scheme and after the implementation of the CE strategy alternative. After the simulation ended, a profit level of Rp 16,096,701,494 was obtained for the BAU scheme and a profit of Rp 24,083,699,129 for the CE scheme. This shows an increase in profit of 32% over two years.

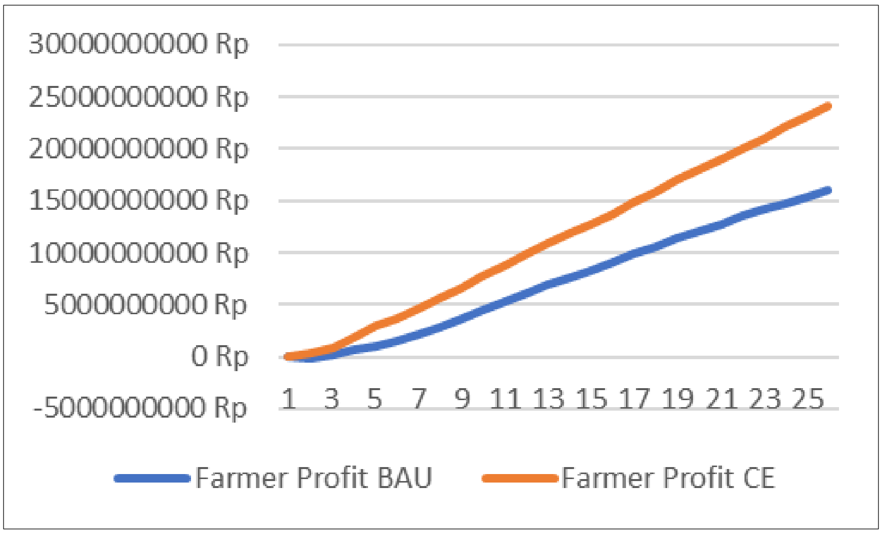


**Fig 11:** Comparison Simulation Results of Profit of Farmer on CE Strategy

Fig.11. shows a comparison of the accumulated total food loss levels in the shrimp export supply chain where the schemes being compared are the BAU scheme with the alternative GMP strategy which respectively produce food loss levels of 181,264.826 kg and 42,923.54 kg, which indicates that there is a decrease in the overall food loss level of the supply chain by 77%.

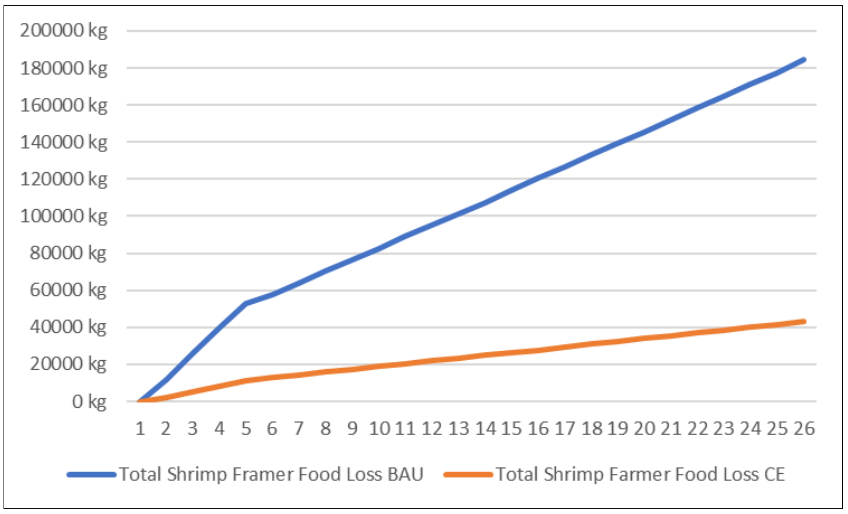


**Fig 12:** Comparison Simulation Results of Total Food Loss of Farmer on CE Strategy

### 4.4.3. Comparison of Strategy Simulation Results

The results of the system dynamics model simulation conducted in this study indicate improvements across all strategies. However, the magnitude of improvement varies for each strategy and for each stakeholder. Therefore, the selection of the most appropriate strategy is determined by identifying the one that results in the lowest food loss across the supply chain. Among the evaluated strategies, the Circular Economy strategy yields the lowest total food loss, amounting to 44,188.37 kg along the entire supply chain. Furthermore, it also generates the highest total profit of IDR 24,398,266,563. Although the Good Supply Chain Practice (GSCP) strategy also has a positive impact—particularly benefiting shrimp sellers—the Circular Economy strategy demonstrates a more comprehensive benefit, especially in reducing food loss at the shrimp farming level.

**Table 3:** Comparison of Simulation Results of Alternative Strategies Based on Supply Chain Value

| Strategy | Stakeholder | Profit (IDR) | Food Loss (kg) |
|---|---|---|---|
| Good Supply Chain Practice | Shrimp Farmer | 16,096,701,494 | 104,879.40 |
| | Seller | 437,554,055 | 639.22 |
| | Total | 16,534,255,549 | 105,518.62 |
| Circular Economy | Shrimp Farmer | 24,083,699,129 | 42,923.54 |
| | Seller | 314,567,434 | 1,264.83 |
| | Total | 24,398,266,563 | 44,188.37 |

The system dynamics simulation applied in this study provides a comprehensive comparison between two alternative strategies—Good Supply Chain Practice (GSCP) and Circular Economy (CE)—in terms of their impact on food loss reduction and supply chain profitability. The results demonstrate that while both strategies contribute positively to performance improvements, the magnitude and distribution of benefits vary across supply chain stakeholders. From the simulation results in Table 3, it is evident that the Circular Economy strategy outperforms GSCP in minimizing food loss. The total food loss under the CE strategy is 44,188.37 kg, which is significantly lower than the 105,518.62 kg recorded under GSCP. This finding highlights the strength of CE in optimizing resource use and minimizing waste, especially at the shrimp farming level where the most substantial reductions are observed. The key mechanism through which CE achieves this reduction is by improving post-harvest handling, utilizing waste as input for other processes, and ensuring closed-loop systems that reduce loss at each stage. These elements are aligned with the broader principles of sustainable production and consumption. In terms of financial impact, the Circular Economy strategy again proves superior, yielding a total profit of IDR 24.40 billion, which is a 47.6% increase compared to the IDR 16.53 billion under the GSCP strategy. This significant increase in profitability is mainly due to the efficiency gains and reduced waste at the production (shrimp farming) level. Interestingly, the GSCP strategy offers relatively better profit margins for shrimp sellers (IDR 437.55 million vs. IDR 314.57 million under CE). This suggests that while CE enhances efficiency upstream (farmer level), GSCP may provide more direct benefits to downstream actors (e.g., sellers). Thus, for a balanced supply chain development approach, hybrid strategies that combine the upstream efficiency of CE with the downstream orientation of GSCP could be considered. The findings highlight the trade-offs and synergies between strategies focused on sustainability (CE) and those aimed at operational good practices (GSCP). The CE strategy's alignment with Sustainable Development Goals (SDGs), especially in reducing waste and increasing resource productivity, offers a long-term competitive advantage and environmental benefit. Its application also supports resilience in the supply chain by promoting circularity and reduced dependency on raw material inputs. However, the GSCP strategy still holds relevance, especially in enhancing coordination, standardization, and compliance throughout the supply chain. GSCP may also require lower initial investments compared to CE, making it more feasible for smaller-scale operators.

## 5. Conclusion

This study has evaluated two alternative strategies—Good Supply Chain Practice (GSCP) and Circular Economy (CE)—using a system dynamics simulation to assess their impact on food loss and profitability in the shrimp supply chain. The findings indicate that both strategies yield improvements, though with varying degrees of effectiveness across stakeholders. The Circular Economy strategy emerged as the most effective approach in minimizing food loss, achieving a significant reduction to 44,188.37 kg, compared to 105,518.62 kg under the GSCP strategy. It also generated the highest total profit for the supply chain, amounting to IDR 24.40 billion, with the greatest benefit observed at the shrimp farming level. While the GSCP strategy provided a relatively higher benefit for shrimp sellers, its overall impact on food loss and total profit was lower than that of CE. Thus, the CE strategy not only enhances economic performance but also supports sustainability goals, aligning well with the principles of resource efficiency and waste reduction promoted by the Sustainable Development Goals (SDGs). Further research is recommended to assess the long-term environmental and social impacts of implementing CE strategies, as well as to explore potential hybrid models that integrate operational best practices with sustainable innovations

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**How to Cite This Article**

Chairany N, Lantara D, Nur T, Riski M. Quantifying and Reducing Whiteleg Shrimp Food Loss: A System Dynamics-Based Strategy Development. Int J Future Eng Innov. 2026 Mar-Apr;3(2):76-86. doi: 10.54660/IJFEI.2026.3.2.76-86.