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System dynamics modeling for evaluating the profits of the upstream supply chain of Citronella Oil

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ABSTRACT

Citronella oil is an aromatic oil obtained through the distillation of citronella stems or leaves. In Indonesia, the distillation process is predominantly carried out by small to medium-sized enterprises. Enhancing the reliability of the citronella oil supply chain has the potential to increase the profits of farmers and distillers. However, farmers and distillers in Indonesia face the challenge of fluctuating prices for citronella oil, leading to a decline in profits. This research aims to model the upstream supply chain system of citronella essential oil. The study has identified the key stakeholders involved in the citronella oil supply chain through a causal loop diagram, employing a system dynamics approach. The recommended scenario involves adding an essential oil processing industry as an additional participant in the citronella oil supply chain network. The simulation model's results over the period from 2023 to 2027 indicate an increase in profits for each stakeholder in the upstream citronella oil supply chain. The total profit of the upstream supply chain amounts to USD 2,284,829, representing a 52.3% increase.

Keywords: *Essential oil; citronella; supply chain; system dynamics.*

1 Introduction

Indonesia is a country rich in biodiversity, with numerous plant species that can be utilized for the production of essential oils, including citronella. Citronella oil offers various benefits and serves as a raw material in various industries. It can be used as a bio-additive for oil fuel, which enhances combustion quality (Milenia et al., 2022). Additionally, citronella oil contains compounds with antifungal (Devi et al., 2021), anticonvulsant (Rabiei, 2017), antiparasitic (George et al., 2010), anti-inflammatory (Francisco et al., 2011), and antioxidant (Sinha et al., 2011) properties. Its applications extend to the cosmetic and flavor industries. Moreover, monoterpenes such as citronellal, citronellol, limonene, geraniol, and α-pinene possess insect-repellent properties (Azeem et al., 2019; Eden et al., 2018; Rehman et al., 2014; Tisgratog et al., 2016).

Citronella oil is a highly prospective commodity for export as the demand for this oil tends to increase. According to export data from the Central Bureau of Statistics (BPS), the citronella oil exports have been growing significantly, ranging from 9% to 10%. The global market's demand for citronella oil is projected to increase by 3% to 5% annually. Indonesia holds the second position as a supplier of citronella oil in the world, following the People's Republic of China (Aviasti et al., 2021). To reach end-users, a synergistic coordination among the stakeholders involved in the supply chain of citronella oil is crucial. The supply chain for citronella oil involves multiple stakeholders, ranging from upstream to downstream players. However, the citronella oil supply chain still faces various challenges, particularly in the upstream segment, which is responsible for providing citronella oil (Sulaswatty, 2019).

The challenges faced by the upstream supply chain of citronella oil in Indonesia is the length of the supply chain. Distillers are unable to sell their products directly to exporters. In the domestic market, prices are determined by buyers, leaving distillers with limited bargaining power (Alighiri et al., 2017). Fluctuations in essential oil prices depend on the availability of raw materials (Mansyur et al., 2015), exposing producers to the risks of output and production price volatility, consequently affecting the profitability of the businesses (Nabila and Nurmalina, 2019). Such circumstances call for an effective management system throughout the citronella oil supply chain. If this sector is not properly addressed, it can significantly impact the profitability of the supply chain, particularly for farmers and citronella distillers.

This research aims to model the upstream supply chain system of citronella essential oil. Therefore, a dynamic approach is required to depict and address the complex profitability issues in the supply chain. The performance characteristics of the supply chain align with the principles of system dynamics, as developed by Forrester (1961), which enables the explanation of system behavior and instability. Moreover, system dynamics allows the utilization of various mathematical functions, which are the strengths of the model (Langroodi and Amiri, 2016). The design and experimentation of policy scenarios in the citronella oil supply chain are carried out using system dynamics simulation. This simulation method accommodates a system composed of numerous stakeholders with diverse characteristics and depicts their relationships quantitatively and qualitatively.

This paper is presented with chapters dealing with introduction, literature review, methodology, results and discussion followed by the conclusion. The paper ends with a discussion on the scope for future research.

2 Literature Review

2.1 Supply Chain of Citronella Oil

The supply chain of citronella oil comprises three sectors: upstream, midstream, and downstream. The upstream sector includes citronella farmers and distillers, while the midstream sector involves itinerant collectors, small and large traders, as well as exporter agents. The downstream sector consists of exporters who deliver the essential oil to end-users (Rahmayanti et al., 2018). In the supply chain of essential oil, all stakeholders are interdependent and collaborate to provide citronella oil products to consumers (Alighiri et al., 2017; Sulaswatty, 2019). The citronella oil supply chain is illustrated in Figure 1. As depicted in Figure 1, the supply of citronella oil originates from citronella farmers and distillers. In the network of the citronella oil supply chain, farmers engage in citronella cultivation. This cultivation is conducted during the rainy season, with 1-2 saplings planted per hole. The first fertilization is carried out after one month of citronella growth, followed by subsequent fertilizations after the first harvest and every six months thereafter. The first harvesting of citronella leaves can be performed after six months of plant growth, and subsequent harvests occur every three months. If harvesting is delayed, the plants will flower, leading to reduced yields in citronella distillation. Citronella leaves are first dried for 3-4 hours to facilitate the distillation process (Santoso et al., 2022; Sulaswatty, 2019; Udawaty et al., 2019).

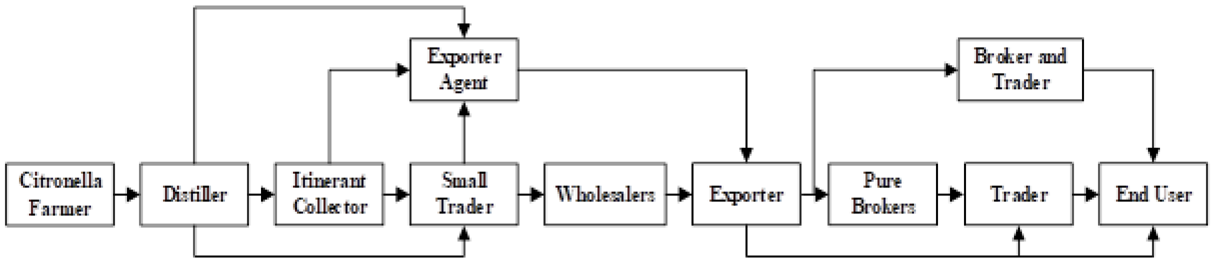

Figure 1. The Citronella Oil Supply Chain (Sulaswatty, 2019)

The citronella oil distillation process is typically carried out by distillers, who are predominantly small to medium-sized enterprises. In Indonesia, citronella oil distillation is commonly performed using steam distillation, which can be achieved through two methods: direct and indirect distillation. In direct distillation, citronella material or leaves are cooked with water, facilitating simultaneous evaporation of water and oil (Ermaya et al., 2017; Sembiring and Manoi, 2015). The quality of citronella oil is determined by its main components and purity (Sulaswatty, 2019).

The produced citronella oil is usually stored in metal drums, leaving 5% to 10% empty space within the drum before being sold to citronella oil collectors. Citronella oil collectors are classified into four types based on their capital: itinerant collectors, small traders, large traders, and exporter agents. These classifications are determined by the amount of capital they possess. Collectors engage in activities such as gathering citronella oil from distillers, storing the oil, and distributing it to exporters. If distillers have strong collaborative capabilities and high product volumes, they can bypass one or more distribution channels. Exporter agents then sell the citronella oil to exporters who send it abroad. The main countries that serve as destinations for citronella oil exports include the United States, France, Italy, Singapore, and Taiwan (Alighiri et al., 2017).

2.2 System Dynamics Simulation in Agroindustry Supply Chains

System dynamics, developed by Forrester in 1961, is a framework that focuses on system thinking and requires several steps to build and test simulation models (Sterman, 2000). The key characteristics of this system lie in its representation of complex systems, the change in system behavior over time, and the presence of feedback loops. These feedback loops provide new information about the system's condition, which can lead to decision-making.

System dynamic simulation aids in understanding the causality of events and decision-making processes. The application of system dynamic simulation in supply chains serves to generate knowledge about operational dynamics and simulate scenarios to support decision-making among stakeholders involved in the supply chain (Sterman, 2000). The use of system dynamics can foster positive coordination among participants in agroindustry supply chains, thereby enhancing market share and resulting in increased profitability for supply chain stakeholders (Ferreira et al., 2016; Miller and Newell, 2013).

Several studies on system dynamic simulation for supply chains in various products have been conducted by Hakim and Perdana (2017), Kodrat et al. (2019), Astria et al. (2021), Balkan et al. (2021), Jamaludin et al. (2021), Singh et al. (2021), Guo and Yin (2022), and Esteso et al. (2023). However, none of these studies have investigated the supply chain of citronella oil. This indicates a research gap, underscoring the necessity for the present study. From the perspective of stakeholders in this sector, a distinct characteristic is observed due to the dominance of collecting traders in the citronella oil supply chain.

3 Methodology

The stages of the research are as follows: first, developing criteria for variables and identifying the variables to be used in designing the conceptual model. Once the key variables have been identified, the next step is to construct a system thinking approach in the form of a causal loop diagram (CLD).

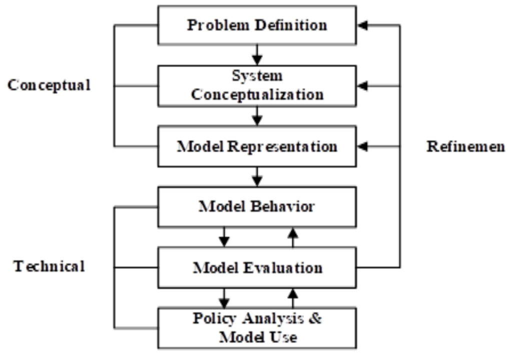

Figure 2. The Process Steps of System Dynamic Modeling

Figure 2 illustrates the process steps of system dynamic modeling. The stages in the development of this model are as follows:

1. Describing the problem and identifying the variables that have an impact on a particular issue.
2. Building the model structure. This model structure depicts:
   a. Subsystem-models with their respective variables and parameters.
   b. Patterns of interconnection among subsystems and variables, formulated in the form of a causal loop diagram (CLD).
3. Constructing the simulation model or model formulation. This stage involves:
   a. Formulating the model.
   b. Building the simulation model in the form of stock and flow diagrams.
4. Verifying and validating the mathematical model.
5. Conducting simulations to design alternative scenarios for decision-making, aiming to obtain optimal policy steps.

4 Results and Discussion

4.1 Model Development

Modelling of the system dynamic approach begins with articulating the problem (Permatasari, 2022). This stage involves defining the model's objectives, boundaries, which encompass the timeframe and key variables, and setting reference modes. The goal of this research is to model the upstream supply chain system of citronella essential oil.

Next, key variables are identified. Table 1 illustrates the key variables in the citronella essential oil supply chain system. Each variable can be classified as endogenous, exogenous, or exclusive. Endogenous variables are within the system boundaries, while exogenous variables are external to the system. Excluded variables are those not included in the system (Jamaludin et al., 2021).

Table 1.
Variables Classification

Endogenous Variables	Exogenous Variables	Excluded Variables
Citronella Oil Production	Distiller Capacity	Energy Usage
Number of Citronella Oil Demand	Raw Material Supply	
Number of Citronella Oil Supply	Land Availability	Distiller Education
Total Cost of Citronella Oil Supply Chain	Process Technology	
Profit of Citronella Oil Supply Chain	Price of Citronella Oil Supply Chain	Number of Competitors
Revenue of Citronella Oil Supply Chain	Inflation Rate	

Two types of data are utilized to analyze the variables in this study: primary and secondary data. Primary data are collected through interviews with stakeholders directly involved in the citronella essential oil supply chain, farmers and citronella oil distillers in Aceh Province. Aceh Province was chosen as the research location due to being one of the largest producers of citronella essential oil in Indonesia (Aziz et al., 2021).

Primary data:

1. Distillation process takes 3 - 4 hours through steam distillation.
2. Average yield of citronella oil is approximately 0.6 – 1.2%.
3. The average capacity of distillation kettle is 300 kg of citronella leaves and stems.
4. The average citronella productivity is 175 kg/ha.
5. Citronella oil price at the distillation level ranges from USD 8.38 - US$ 8.71/l.

Secondary data:

Secondary data consists of a six-year time series. The data sources for this research are the National Development Planning Agency and the Central Statistics Agency.

The modeling process continues with the development of a causal loop diagram (CLD). The CLD is constructed based on the variables identified in Table 1. The relationships between interconnected variables are explained based on their reference modes. For instance, Figure 3 depicts the relationship between raw material supply and land availability. It is assumed that an increase in land area leads to a greater raw material supply. This is demonstrated in Figure 3, showing an increase in raw material supply with an expanding land availability.

Figure 3. Relationship between Land Availability and Supply of Citronella Raw Materials in Aceh Province in 2017–2021 (Source: Central Statistics Agency Aceh Province)

These relationships are then translated into a causal loop diagram (see Figure 4) to illustrate the system's behavior based on interconnected variable nodes through arrows and feedback loops (Safii et al., 2021).

Figure 4 illustrates how variables in the citronella essential oil upstream supply chain system mutually influence each other. Positive sign (+) indicates variables changing in the same direction, while a negative sign (-) indicates variables changing in opposite directions (Panikkai et al., 2017). For instance, demand and the price of citronella oil have a negative relationship. An increase in price leads to a decrease in demand, and vice versa. Marketing strategies serve as a way to transform business to enhance demand (Wang, 2016).

Based on the Causal Loop Diagram (CLD) in Figure 4, a stock and flow diagram is constructed. The stock and flow diagram is used to analyze the behavioral changes of variables related to activities performed by stakeholders in the citronella essential oil supply chain. This study employs Vensim 5.2 to build a profit model for the citronella essential oil upstream supply chain. Figures 5 and 6 display the results of the Vensim 5.2 model for the upstream supply chain.

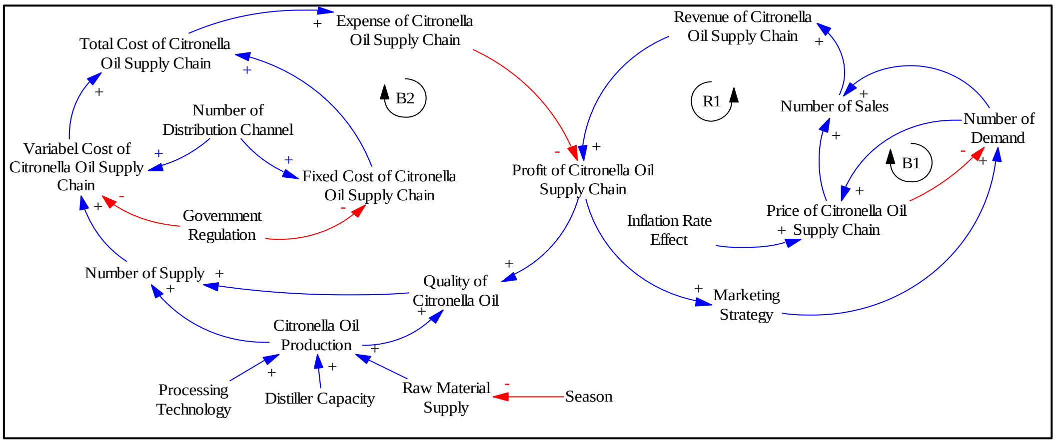

Figure 4. Causal Loop Diagram of the Profits of the Upstream Supply Chain of Citronella Oil

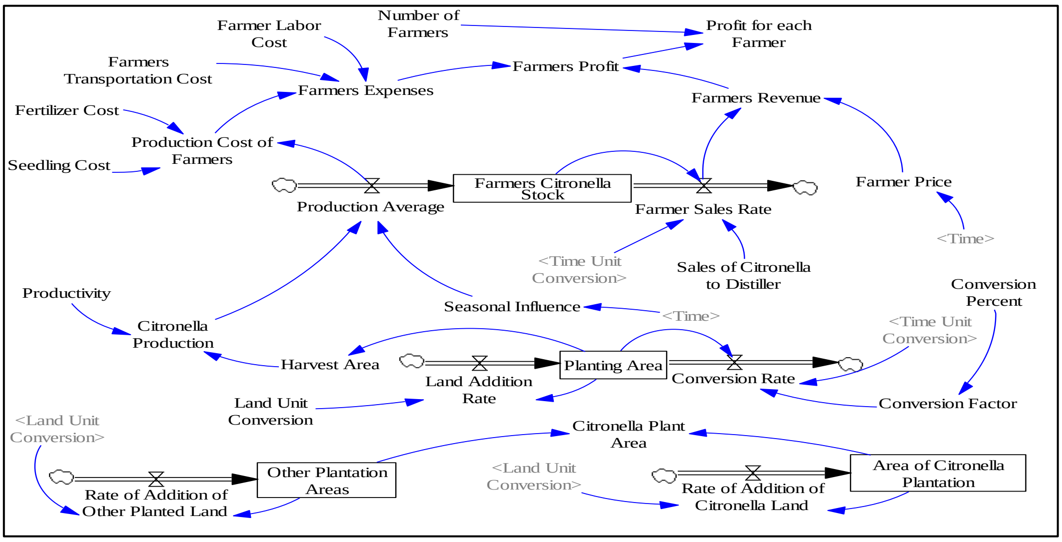

Figure 5. Stock and Flow Diagram of Farmer Profits

Figure 5 consists of variables representing the cultivation process of citronella plants. Citronella plant production is influenced by seasons, being a seasonal plant requiring a climate with rainfall between 1800 – 2500 mm per year. The first harvest takes place six months after planting (Sulaswatty, 2019). Each harvesting process requires at least 20 additional workers for cutting, tying, and transporting harvested citronella plants (Santoso et al., 2022). Labor costs, including the hiring of additional workers, constitute a variable cost incurred by farmers. Additionally, farmer expenses include fertilizer, seeds, and transportation costs. After harvesting, citronella leaves are sold to distillers. Distillers process citronella leaves into crude citronella oil through steam or water distillation. Distillers must consider production efficiency, raw material continuity, and product marketing. Distiller expenses consist of raw material costs, labor costs, fuel costs, transportation costs, and depreciation costs. Capital, labor, and equipment significantly influence distiller profits (Damanik, 2007). Distiller profit is defined as the difference between income and expenses incurred by the distiller, as explained in Figure 6.

4.2 Model Simulation

The challenge of imbalances in the supply and demand of citronella essential oil is faced by the upstream supply chain of citronella essential oil in Indonesia. Global demand for citronella oil reaches 2000 – 2500 tons per year, while Indonesia is currently able to supply around 450 - 650 tons per year (Aviasti et al., 2021). The selling price of essential oil is determined by market mechanisms, leading to prices at the distillation level being lower than expected (Alighiri et al., 2017). Due to the fluctuating prices of citronella essential oil, alternatives are needed to enhance the well-being of both farmers and citronella oil distillers. This consideration is crucial for the government to increase the value-added of citronella essential oil products.

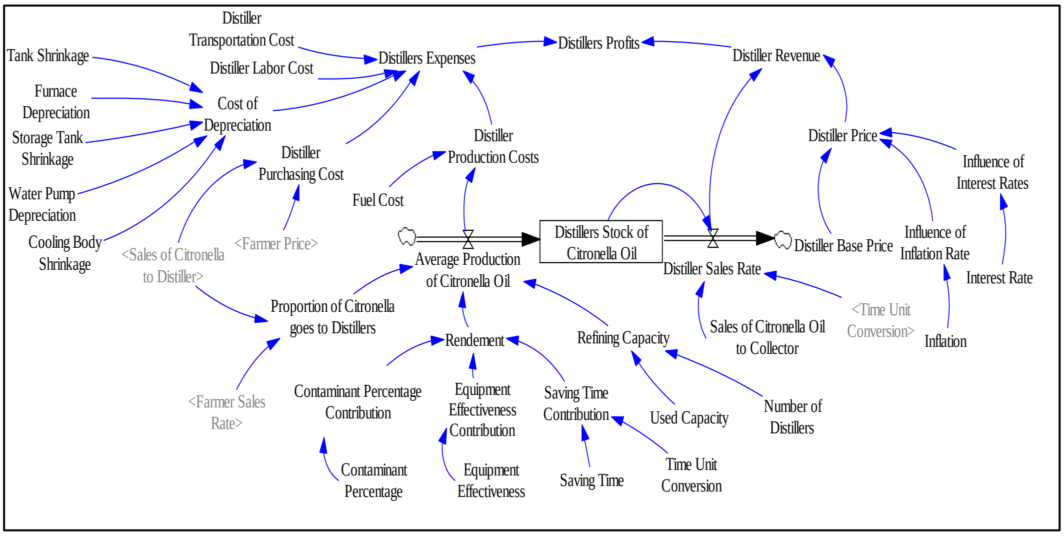

Figure 6. Stock and Flow Diagram of Distiller Profits

In simulating the model, attention is given to model verification and validation. The validation process ensures that the simulation results accurately represent the existing system and can be used to analyze system behavior (Sterman, 2000). Verification involves checking the formulation and unit of variables in the model. If there are no errors in the model, it is considered verified. Based on the simulation results, the model runs smoothly without errors in formulation or unit errors.

Model validation is conducted to ensure that the model fulfills its intended purpose and accurately represents the current system. The Barlas Model is employed to test the model's validity, considered valid when the percentage error from the mean (E1) is less than 5%, and the percentage error from the variance (E2) is less than 30% (Barlas, 1996). The recapitulation of actual data and simulation results for the citronella supply variable is presented in Table 2.

Table 2.
Validation Results of the System Dynamic Model of Citronella Raw Material Supply

Variables	Years	Actual Data	Simulation Output
Raw Material Supply (Ton)	2017	2539	2547.76
	2018	2609	2539.94
	2019	3187	3278.12
	2020	3414	3541.07
	2021	3208	3226.53
Mean		**2991.4**	**3026.684**
Variance		**153665.3**	**208509.8405**

The following are the results of calculation for the mean and variance error:

$$E = {|S - A|}/{A}$$

Where: A: Actual data; S: Simulation output

$$Error\ of\ mean\ (E1) = \frac{|2991{,}4 - 3026{,}684|}{3026{,}684}$$

= 0,011657642;
= 1,1657642%

$$Error\ of\ variance\ (E2) = \frac{|153665{,}3 - 208509{,}8405|}{208509{,}8405}$$

= 0,263030946
= 26,3030946%

Based on the calculations of the mean error and variance error above, it is evident that the mean error value is less than 5%, and the variance error value is less than 30%. Therefore, based on these calculations, the model can be considered valid.

4.3 Scenarios to Increase the Profit of the Upstream Supply Chain

This scenario is used to evaluate the changes in profit behavior within the upstream supply chain of citronella essential oil when its structure is altered. It involves introducing a new player into the citronella essential oil supply chain – an essential oil processing industry. This industry processes crude citronella oil into its derivatives, including citronellal, citronellol, and geraniol, obtained through fractional distillation (Sulaswatty, 2019). The scenario is designed to address the current practice of Indonesia exporting raw citronella oil while importing the main components of citronella oil and its derivatives. With increasing demand for these components, their derivatives have a competitive edge (Sulaswatty, 2019). The objective of this scenario is to enhance the value-added of citronella oil, thereby increasing its selling price. The elevated selling price can positively impact the prices of citronella plants at the farmer level and crude citronella oil at the distillation level.

The current condition scenario reflects the present state, projecting changes over a 5-year period. After simulating the policy scenario model, the simulation results for the distiller profit variable are presented in Figure 7.

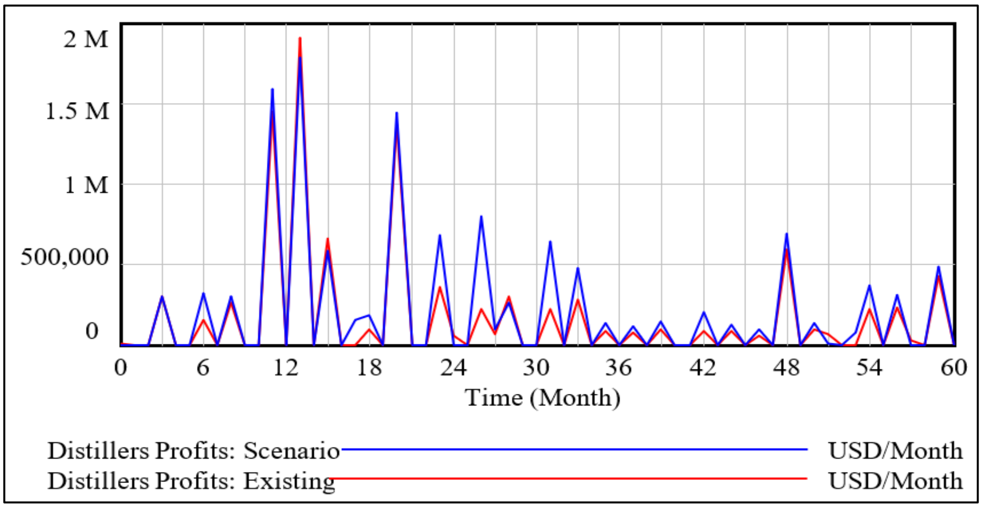

Figure 7. Simulation Results of the Distiller Profit Variables Policy Scenario Model

From Figure 7, it is evident that distillers experience an average profit increase of 25.1%. This increase in distiller profit influences the price of citronella plants at the farmer level. The simulation results for the farmer profit variable are illustrated in Figure 8.

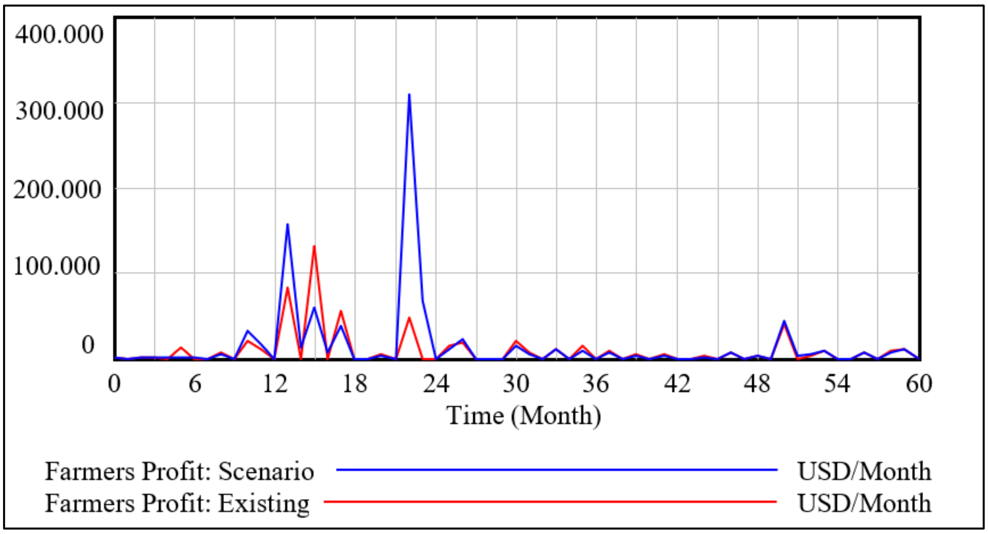

Figure 8. Simulation Results of Farmer Profit Variables in the Policy Scenario Model

Based on Figure 8, with the addition of an essential oil processing industry to the upstream supply chain, there is an average 26.8% increase in farmer profit. In this scenario, the overall profit within the citronella essential oil supply chain has significantly improved. A comparison of profits between the existing condition and the proposed scenario for each player in the citronella essential oil supply chain is presented in Table 3.

Table 3.
Comparison of Profits in the Upstream Supply Chain of Citronella Oil between the Existing System and the Policy Scenario

Stakeholder	Profit Average (USD)	
	Existing	Scenarios
Farmer	298,578	378,630
Distiller	1,201,330	1,502,586
Processing Industry	-	403,613
Total	**1,499,908**	**2,284,829**

Table 3 reveals a significant increase in profits within the citronella essential oil upstream supply chain. The profit within the supply chain increases by 52.3% after adding an essential oil processing industry, aligning with research by Agustina and Jamilah (2021), stating that processing crude citronella oil into derivatives enhances the value-added of citronella oil, given its high economic value.

5 Conclusion

This research has analyzed the structure of the upstream supply chain of citronella oil in Indonesia at the level of small and medium-sized enterprises (SMEs). Several actors are involved in the procurement and distribution of citronella oil until it reaches the consumers. The upstream sector of the citronella oil supply chain consists of farmers and citronella oil distillers as the providers of citronella oil. The middle sector comprises middlemen, including itinerant collectors, small traders, large traders, and export agents. The downstream sector of this supply chain includes exporters and end consumers. End consumers in this supply chain are manufacturing industries that process citronella oil into blends for perfumes, aromatherapy, antiseptics, cosmetics, medicines, food flavorings, and more. Variables influencing profits in the structure of the upstream citronella oil supply chain were obtained through interviews, field observations, and secondary data.

According to the simulation results, distiller profits fluctuate due to variations in the supply of raw materials from farmers, which are influenced by seasonal factors, as well as prices determined by market mechanisms. The selling price is determined by the availability and quality of citronella oil, which affects the profits of actors in the upstream citronella oil supply chain. Therefore, the recommended policy is to add a processing industry to increase the added value of citronella oil products, leading to higher selling prices. The scenario outcomes indicate an increase in profits for farmers and distillers in the upstream citronella oil supply chain. Further studies are required to assess the viability of the processing industry. Additionally, it is necessary to develop an effective configuration among the actors by testing alternative scenarios throughout the citronella oil supply chain.

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