Improving the productivity of palm oil industry using system dynamics model

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Abstract. This study examines the implementation of sustainable practices in Indonesia's national palm oil industry and investigates how it affects plantation productivity. The Indonesian Ministry of Agriculture launched the Indonesia Sustainable Palm Oil (ISPO) framework to guide both farmers and corporations. Additionally, major palm oil companies have adopted the Roundtable on Sustainable Palm Oil (RSPO) standards throughout their operations to address sustainability challenges. To identify the optimal strategy for boosting fresh fruit bunch (FFB) yield and land productivity, a system dynamics simulation model has been built. The findings suggest that a collaborative governance approach leads to a significant increase in FFB production over time. In this scenario, plantations in Sumatra, the focus of this study, are projected to generate approximately 57 tonnes of FFB per hectare within 20 years. The increase of production will help industry to sustain, increase its competitive advantages, and generate more benefits to labours, farmers, local communities, and government. However, further research is required to incorporate additional factors for a more comprehensive model. This would allow for a more in-depth analysis of return on investment and potentially reveal an even more effective strategy.

1 Introduction

The palm oil industry in Indonesia is generally supported by palm oil production, the majority of which comes from plantations on the islands of Sumatra and Kalimantan. The production of palm oil in Indonesia has touched 45.12 million tonnes in 2021 or twice the national production of Malaysia as one of its main competitors. Thus, Indonesia's palm oil production is the largest in the world [1]. The production of oil palm is divided based on the type of plantation, large private plantations contribute to 60.64% of the overall area, smallholder plantations contribute to 34.36%, and the remaining 5% comes from large state plantations. [2]. This surge in production makes palm oil industry contributes to 15 million USD of Indonesia's Gross Domestic Product (GDP) as of 2021. Palm oil industry also enhance job vacancies for local labour workers by taking nearly 16 million labour workers to support their operations nationwide [3].

The Ministry of Agriculture of the Republic of Indonesia released several important problems in the national palm oil industry. Some of these crucial problems include the low productivity of local farmers, inadequate infrastructure supporting oil palm agriculture, the small selling value (competitive value) of oil palm, and low funding for the entire oil palm farming process [4]. In addition, there is an issue that has become a demand from companies and consumers from the European Union to ensure that the production of palm oil commodities is not related to the issue of deforestation and the legality of plantation land [5]. Regional demands in the Southeast Asian region through mandate and investment programmes are also one of the things that must be considered by palm oil industry players. One of the big issues is the environmental issue that is often associated with the palm oil industry due to land clearing through deforestation and the emergence of other losses such as soil pollution [6].

Efforts to realise the achievement of global and regional demands on the palm oil industry in Indonesia cannot be separated from the role of the government in drafting regulations. The role of the government through the Ministry of Agriculture or specifically through the Palm Oil Replanting Fund Management Agency (BPDP-KS) is needed to ensure that the contribution of the palm oil industry to the national economy can be maintained and even increase in value over time [7].

The government, through relevant institutions, has a crucial role to play in solving these problems and responding to these challenges. Regulations that are developed holistically and can accommodate various needs from the side of industry players, independent business actors, to consumers both on a national and international scale are needed so that oil palm production continues to consider the economic side along with realising a sustainable industry [8]. Therefore, policy formulation based on the current industry conditions is considered to be carried out

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through a system dynamic method that can generate a policy based on interconnected parameters [9].

The purpose of this research is to develop the right scenario to get governance in the palm oil industry that can increase productivity and can be implemented by all palm oil business actors in Indonesia. This research can contribute to support government's initiative in developing data-driven decision-making. System dynamics modelling will ensure that all palm oil business actors in Indonesia implements good governance in running their business processes.

2 Literature review

2.1 System dynamics

System dynamics is a computer-aided approach to analysing and designing policies. Every dynamical system is characterised by dependency, mutual interaction, information feedback and causal cycling [10]. The dynamic systems approach starts by defining the problem dynamically over time, followed by the mapping and modelling of significant variables that affect it. After the variables are deemed sufficient, the next stage is the development of stock and flow diagrams. At this stage, the process carried out is the identification of inflows or accumulations (levels) in the system and outflows (rates). The next stage is the development of the model and simulation with the help of a computer and then collect understanding and policies that apply from the resulting model [11].

2.2 Palm oil governance in Indonesia

Indonesia's palm oil industry is growing in 22 of the country's 38 provinces. The two main oil palm plantation centres in Indonesia are Sumatra and Kalimantan. Around 90 per cent of Indonesia's oil palm plantations are located on these two islands, and they produce 95 per cent of Indonesia's crude palm oil (CPO) production. The history of palm oil development in Indonesia is characterised by a revolution in the palm oil plantation industry between 1990 and 2015. The majority of palm oil production comes from large private plantations totalling 60.64%, then smallholder plantations as much as 34.36%, and the rest comes from large state plantations or as much as 5% [2].

The implementation of governance and certification through the Roundtable on Sustainable Palm Oil (RSPO) is one of the steps taken by each large-scale palm oil producer to ensure that the products produced meet international standards [12]. This is also in line with the Indonesian government programme through the Minister of Agriculture Regulation number 19/Permentan/OT.140/3/2011 which regulates the implementation of Indonesia Sustainable Palm Oil (ISPO) [13]. The regulation is implemented to ensure the management of the palm oil industry with quality standards and ensure that the series of operational implementations in palm oil production is environmentally friendly [14].

The RSPO Principles and Criteria is a standard established by the Roundtable on Sustainable Palm Oil (RSPO). It provides guiding principles for the palm oil industry to achieve sustainability through commitments and strategic plans. The 2018 edition of the Principles and Criteria outlines three expected impacts on the global palm oil industry, focusing on long-term outcomes and covering various areas:

1. People: Sustainable livelihoods & poverty reduction dan Human rights protected, respected, & remedied; leads to efforts that can be made by stakeholders so that the welfare of farmers and workers and the surrounding population affected by the palm oil industry can enjoy equality.
2. Prosperity: Competitive, resilient, & sustainable sector; leads to increased income from palm oil products produced.
3. Planet: Conserved, protected & enhanced ecosystems that provide for the next generation; leads to efforts to conserve and protect ecosystems and utilise technology to reduce the environmental impact of the palm oil industry.

ISPO (Indonesian Roundtable on Sustainable Palm Oil) is a national certification established by the government through the Ministry of Agriculture. According to the Minister of Agriculture Regulation No. 38 of 2020, palm oil businesses must meet specific criteria for ISPO certification, including:

1) Compliance with laws and regulations, including land legality and plantation business legality.
2) The implementation of good plantation practices includes plantation planning and the application of technical cultivation and management of products.
3) Management of the environment, natural resources and biodiversity.
4) Labour responsibility.
5) Social responsibility and community economic empowerment include community social responsibility, empowerment of indigenous peoples, and local business development.
6) Implementation of transparency.
7) Sustainable business improvement includes a system for monitoring and renewing the validity of licensing documents and corporate social responsibility and community economic empowerment programmes that are measurable for a certain period.

However, based on a study conducted by the government on RSPO as a global standard, contradictory points are stating that RSPO as a product of a private institution is considered to be incompatible with the principles and is considered to minimise the role of state institutions. In addition, RSPO is also considered incompatible with government standards because it is considered not in favour of countries that have a large role in the palm oil industry. RSPO also has many shortcomings including little accountability, large investments that must be made to support its implementation, and a small level of legitimacy [15]. According to the Palm Oil Farmers Union [16], the investment required by a Village Unit Cooperative (KUD) to carry out ISPO certification starting from a

series of audit applications, assessment fees, and certification decision fees is around Rp 150.000.000, -.

Research showed relatively low scores on four ISPO certification principles, namely income structure, land legality, seed legality, and environmental management legality. Furthermore, other findings in the study [17] stated that the achievement of ISPO implementation in the national palm oil industry in the Riau Islands as a whole was only 18.5%. In addition, this study also showed that out of a total of 48 (forty-eight) indicators that must be achieved, there was not a single indicator that had been successfully achieved by palm oil business actors.

So, it can be concluded that the implementation of Indonesia Sustainable Palm Oil (ISPO) has not been widely achieved by palm oil business actors, especially business actors who have small capital and limited access to information and supporting infrastructure (independent business actors). Meanwhile, another research conducted [5] shows that the factors that hinder the achievement of sustainability standards in the palm oil industry in Indonesia are caused by the high deforestation rate, land fires, and the legality of plantation land.

3 Research method

3.1 Problem definition

The first activity carried out at the modelling stage is to articulate the problem based on the problems found in the implementation of governance in the palm oil industry. Based on the availability of data, this research will use reference data obtained from secondary sources such as the Central Statistics Agency (BPS), the Ministry of Agriculture, the Ministry of Environment, and open data sites of several provinces in Sumatra, as well as reports on the implementation and achievement of environment, social, and governance (ESG) from several palm oil plantation in Sumatera Island. Fig. 1 shows the research design and flows that being represented by each sequence in this part.

Identification of endogenous and exogenous variables that will form the basis of modelling is carried out as the next step. These variables are obtained from the results of the analysis of significant variables of system development which include several key performance indicators of the palm oil industry in Indonesia, namely: livelihoods of industry, the prosperity of industry, sustainability of the environment, and traceability of production.

Livelihoods of industry in the system describe the ability, assets owned, and all activities carried out by palm oil industry workers to live [18]. Prosperity of industry is a commitment based on the achievements of RSPO and ISPO to reduce poverty in oil palm farmers and provide future economic opportunities for the next generation [12], [19]. Sustainability of the environment in the context of the industry is described as the consumption ratio of production does not affect the natural replenishment ratio and ensures that emissions and pollution resulting from the production process in the industry do not interfere with the ability to restore nature [20], [21]. The last indicator, traceability, describes the relationship between variables such as the maturity of long-term plans, the completeness of reports, the information provided to the public, the quality of communication, and the ratio of commitment to industrial ethics [12], [22].

3.2 Model development

In developing a causal loop diagram (CLD), it is necessary to identify endogenous and exogenous variables and references from additional literature. This mapping stage was carried out based on analyses in previous studies [23], [24] and the results of observations on the palm oil business process to produce a conceptual model that will be the basis for model development in the following stages. The results of the CLD development for the palm oil governance system can be seen in Fig. 2.

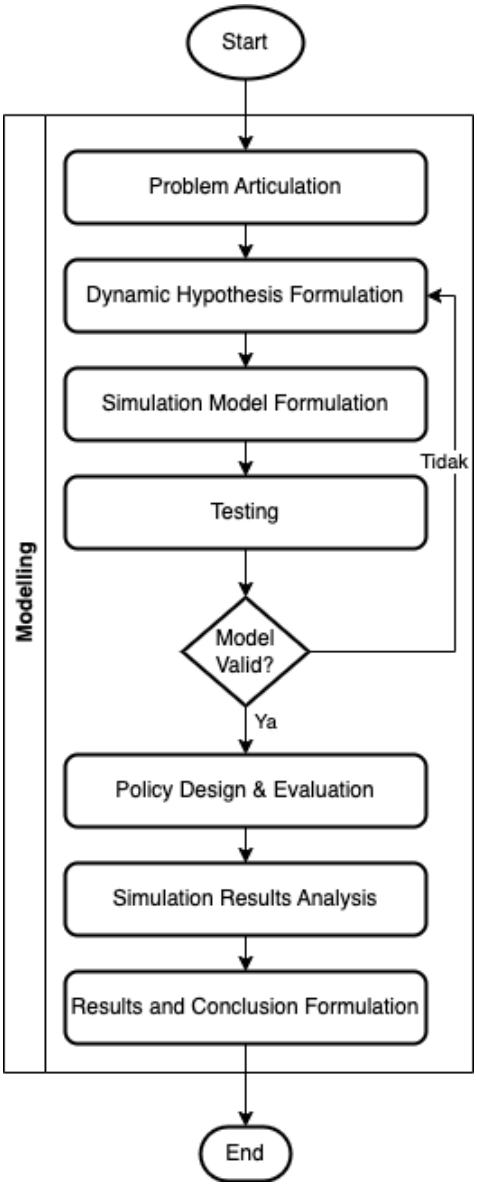

Fig. 1. Flowchart of research methodology.

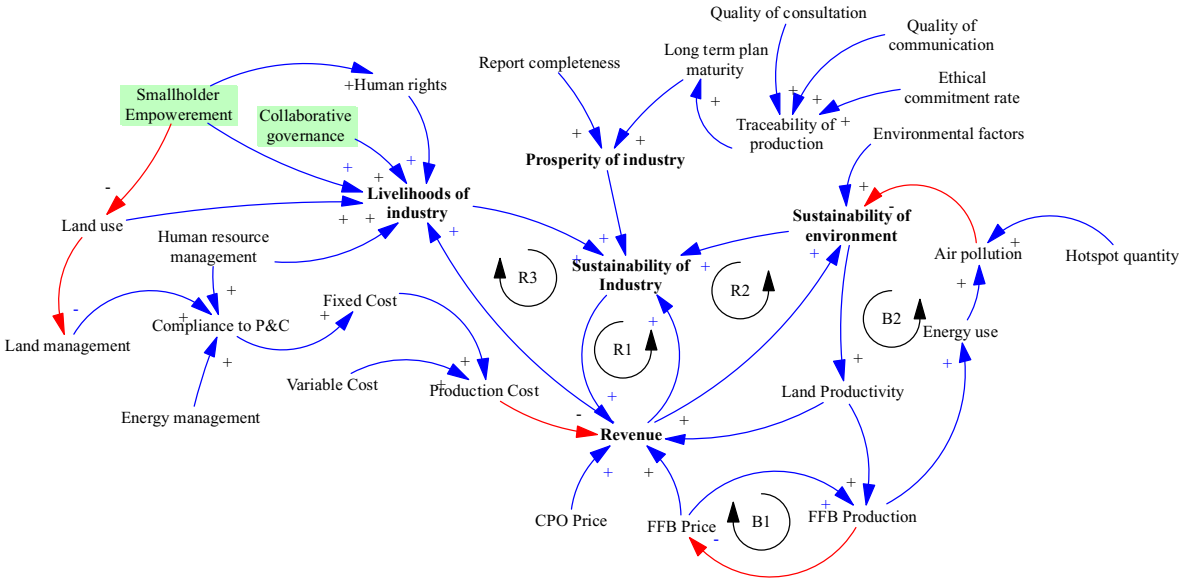

Fig. 2. Causal loop diagram for palm oil governance.

In the next stage of the system dynamics cycle, a stock and flow diagram (SFD) will be developed based on the CLD that has been built. The SFD developed will be divided into sub-models of palm oil productivity and revenue and sustainability of the environment.

3.2.1 Sub-model palm oil productivity and revenue

The Palm Oil Productivity and Revenue sub-model is described as a sub-model that shows the relationship between the factors supporting the increase in revenue from oil palm plantations obtained from the main activity of planting oil palm. Fresh fruit bunch (FFB) will be the main commodity of the plantation that has high economic value. The amount of FFB production depends on the amount of productivity that is influenced by supporting and inhibiting factors. Productivity Increment Rate reflects the supporting factors that risen the productivity level for FFB of the plantations across Sumatera. This variable includes the impact of seeds, impact of workforce, and related to another SFD—sustainability level of the industry. In contrast, Productivity Decrement Rate is a variable that will reduce the FFB productivity. This variable is influenced by the impact of pest and disease as well as the impact of bad weather. This relationship shows that if the increment rate is higher than the decrement rate, it will result to the rise of productivity level of FFB.

Another factor influencing the amount of FFB Production is palm oil harvest area. This variable describes the area of plantation that will produce FFB. The number of harvest area will rise if the plantation index and the plantation area are high. In this stock and flow diagram, FFB Production contributes to the total revenue gained by the farmers for each hectare. Revenue is calculated by subtracting the revenue gained from both fresh fruit bunches (FFB) trade and crude palm oil (CPO) trade with the production cost for a plantation. The relationship between the variables in this sub-model can be seen in the stock and flow diagram (Fig. 3).

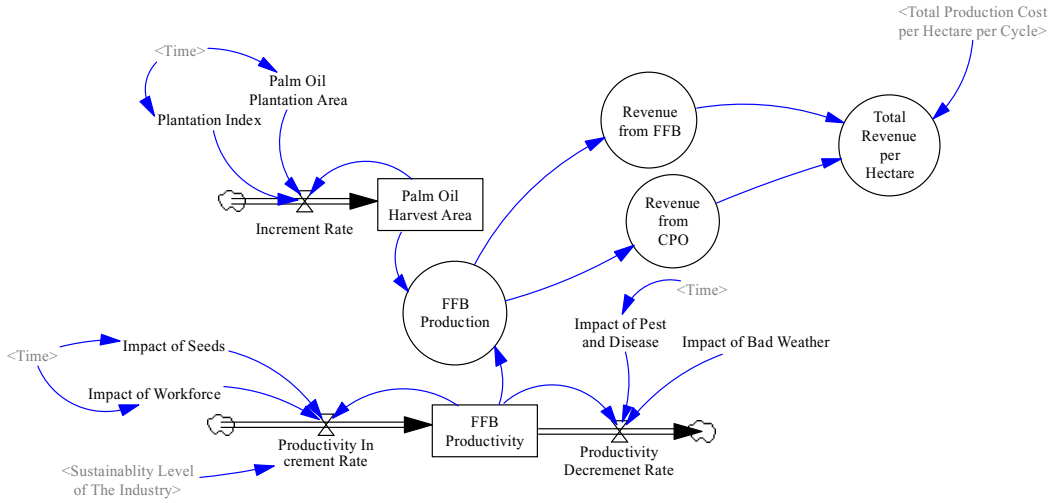

Fig. 3. Stock and flow diagram for palm oil productivity and revenue.

3.2.2 Sub-model sustainability of environment

The sustainability of the environment sub-model is described as a sub-model that shows the relationship between factors that influence a palm oil industry to be sustainable per the standards issued by the RSPO. According to the RSPO Principle & Criteria standard, sustainability of the industry is being influenced by sustainability of environment level, impact of livelihoods, and the impact of traceability level. In a more granular level of stock and flow diagram, environmental factors such as peat soil thickness, water quality, pests and diseases, soil fertility, and quantity of hotspots affects the sustainability level of the palm oil's plantation environment. In addition, there are another variable such as the level of waste management which is influenced by the amount of contribution of waste reduction efforts, recycling, incineration, and landfill management, as well as the utilisation of waste into energy that contributes to the sustainability level. The utilisation of waste into energy will also affect the amount of energy used which will reduce the level of pollution. The stock and flow diagram also illustrates the relationship between the conformance of land use, compliance to P&C level, impact of human resource management, and the impact of human rights protection level to the livelihoods level of a palm oil plantation. On the other hand, report completeness, maturity level of the plants, ethical commitment rate, quality level of both communication and consultation will impact the level of palm oil plantation's traceability. The relationship between these variables will be illustrated in the following diagram (Fig. 4).

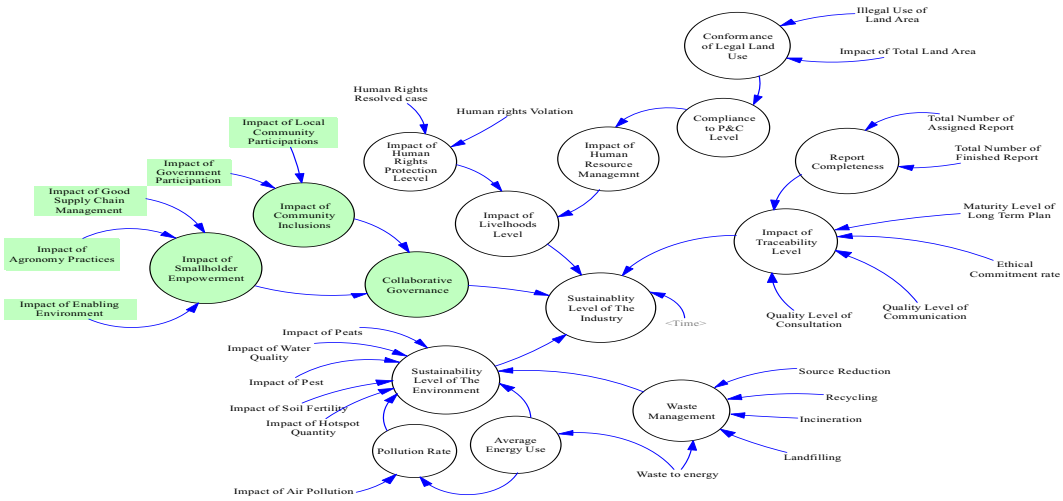

Fig. 4. Stock and flow diagram for sustainability of environment.

3.3 Model validation

Model validation is a step to determine the accuracy of the model created through two stages: calculating the average comparison (error rate) and comparing the standard deviation (error variance). The error rate calculation formula with S is the average simulation result and A is the average data as follows:

$$Error\ Rate = |S - A| / A \quad (1)$$

The calculation formula for error variance with Ss is the standard deviation of simulation results and Sa represents the standard deviation of data in the following Eq. (2):

$$Error\ Variance = |S_s - A_a| / A \quad (2)$$

Thus, Table 1 below will show a comparison of the error rate and error variance of the Revenue variable. The results of the calculation of error rate and error variance in Table 1 can led to the conclusion that the model is valid. Behaviour pattern test based on the research by Barlas [25] stated that to be considered as valid, the statistical correspondence of simulation results and real data should be less than 5% for the error rate and less than 30% for the error variance.

4 Results and conclusions

This research was conducted to develop an appropriate scenario to obtain governance in the palm oil industry that can increase productivity and can be implemented by all palm oil business actors in Indonesia. The dynamical system model created has been able to accommodate the analysis of interconnected factors in the palm oil industry through CLD. The dynamic system model has also accommodated the need to see the differences and dynamics of the system without intervening in the original system that is still operating. The results of the model simulation can also be said to be valid or in accordance with the original system conditions based on the validity test results which show the error rate is at 0.07% and the error variance is at 1.44%.

Table 1. Validation results table.

Year	FFB Production (ton/ha) – Sistem	FFB Production (ton/ha) – Model
2004	6.173.578	6.172.180
2005	6.761.121	6.612.990
2006	9.889.983	7.839.010
2007	10.068.893	9.010.370
2008	9.997.679	9.870.450
2009	11.014.847	10.909.800
2010	12.516.128	12.734.900
2011	13.165.028	14.458.000
2012	14.828.845	16.567.400
2013	15.835.742	17.318.000
2014	16.688.568	16.953.700
2015	17.709.909	17.921.300
2016	18.086.648	17.952.200
2017	21.640.178	21.300.000
2018	24.443.670	22.478.400
2019	26.858.541	26.284.900
2020	26.072.852	27.498.100
2021	26.707.040	26.754.600
2022	27.494.181	27.591.200
2023	28.304.521	28.275.600
Average	17.225.155	17.212.898
Std. Deviasi	7.489.932	7.383.636
Error Rate (E1)		0.07%
Error Variance (E2)		1.44%

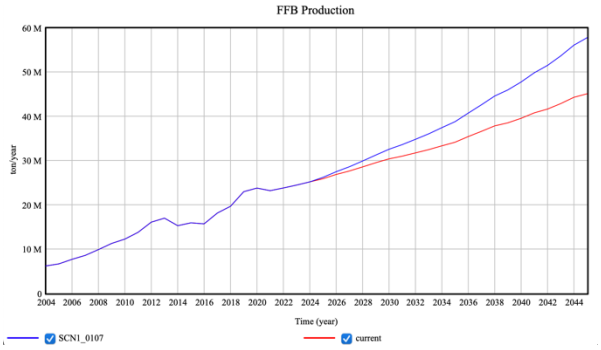

Fig. 5. Comparison chart for base model and scenario simulation results.

The simulation results contained in Fig. 5 show the changes experienced by the base model after scenario implementation. Red line shows the growth of FFB Production during 2004 to 2044, this trend line also reflects the 'as-is' simulation results according to the stock and flow diagram in Fig. 2. However, the blue trend line shows the 'to-be' simulation results which already including the collaborative governance scenario. The implementation of the scenarios starting from 2025 to 2045 shows an increase in the level of FFB production. Based on Fig. 5, it can be concluded that collaborative governance scenario makes around 12 million tonnes increase of FFB Production by 2044.

Based on the calculation results, it was found that the implementation of the collaborative governance scenario through initiatives such as community inclusion and smallholder empowerment activities was able to increase the average annual production of palm oil's fresh fruit bunch (FFB) by 14% when compared to normal conditions according to the base model. In addition, it was also found that the year-on-year increase in income tends to increase by 1-2% when the scenario is implemented.

The implementation of the scenarios also showed an increase in the important variables observed in accordance with the modelling objectives, which are land productivity, FFB price, and revenue. The collaborative governance scenario shows that in order to achieve significant increases in land productivity, FFB price and revenue, the government must play a role in developing policies that favour businesses and local communities. The government's role in making rules is needed to regulate the involvement of local communities and local governments to develop a palm oil industry ecosystem with high sustainability maturity. So, if the rules have been implemented and obeyed by business actors, then an increase in FFB production of 14% per year can be realised by 2045.

In order to achieve this rise of production, government needs to implement the real strategic plan. The strategic plans can be generated from collaborative governance scenario. Government through Badan Pengelola Dana Perkebunan Sawit (BPDP-KS) can help industry to achieve sustainability by incorporating advance technologies in palm oil harvesting, empowering local communities to engage with the production's value chain, implementing Good Agricultural Practices (GAP), and provide financial assistance for smallholders.

However, some things can be improved from this research. Some of these suggestions involve expanding the data sample used to support the research, increasing the complexity of the model to include scenario options from the customer's perspective, and adding more inclusive technology innovation-based scenarios to the model. Expanding data sample and increasing model complexity are crucial to ensure validity of the research. A more diverse dataset helps generalize findings beyond limited contexts. Additionally, complex models capture more extensive patterns, reducing bias and enhancing future predictions. These practices ensure robustness and reliability in research outcomes [32], [33].

In addition, further analyses are needed to refine the collaborative governance scenario to generate better returns. This is reinforced by the assumption that the ratio of the average increase in annual income from one hectare of oil palm per year between the base model and the scenario results is 2:3. This findings can certainly be improved through the implementation of more complex scenarios that have a significant influence on the variables that determine the high and low annual income.

4.1 Scenario formulation

Scenario development is the last stage to be carried out. The formulation of the scenario is based on the objectives to be achieved in modelling [11]. Thus, some

scenarios that will be applied to the model include the implementation of collaborative governance.

A research [26] states that collaborative governance is an effort by a government institution to involve stakeholders from various institutions to carry out a learning process in its organisation. One of the concrete efforts that can be made to increase productivity through active stakeholder collaboration is to ensure the empowerment of independent entrepreneurs can run well. The empowerment of independent smallholders is one of the issues of concern with efforts to increase their inclusiveness in the palm oil production chain [27]. In recognizing the scenario within the context of modelling the palm oil industry, the success of independent smallholders can be described by the increase in productivity [28].

Therefore, in addition to maintaining and increasing the high productivity of oil palm plantations managed by independent smallholders, several things can be done such as not limiting the participation of independent smallholders in oil palm planting, giving them full freedom to do planning, and giving farmers the freedom to use their land as fields, forests, and other purposes [29], [30], [31].

References

1. J. Horas, V. Purba, and T. Sipayung, *Perkebunan Kelapa Sawit Indonesia Dalam Perspektif Pembangunan Berkelanjutan* (2017)
2. Badan Pusat Statistik, *Statistik Kelapa Sawit Indonesia 2021* (2021)
3. H. Limaho, Sugiarto, R. Pramono, and R. Christiawan, Sustainability, **14** (2022)
4. N. Permatasari and E. Suryani, 2016 International Conference on Data and Software Engineering (ICoDSE) (2016)
5. J. Z. Abidin, JASSU Journal of Agrosociology and Sustainability JASSU 1 (2023)
6. F. N. Muzayanah, E. R. Cahyadi, and J. M. Munandar, Jurnal Manajemen Dan Agribisnis (2018)
7. N. Astria, M. Dachyar, and R. Nurcahyo, *System Dynamics Modelling Approach for Palm Oil Supply Chain under Various Policy Interventions: A Case Study in Indonesia's Private Company* (2021)
8. M. Zabid, M. Faeid, N. Zainal Abidin, and D. *Applanaidu, Palm Oil Supply and Demand Characteristics and Behavior: A System Dynamics Approach* (2018)
9. A. Ibragimov, S. F. Sidique, and Y. S. Tey, J Clean Prod 213, **1051** (2019)
10. I. J. Martinez and G. P. Richardson, *Best Practices in System Dynamics Modeling* (2013)
11. J. D. Sterman, *System Dynamics: Systems Thinking and Modeling for A Complex World*, (2002)
12. RSPO, *For the Production of Sustainable Palm Oil 2018* (2018)
13. Menteri Pertanian Republik Indonesia, *Permentan Nomor 19 Tahun 2011* (2011)
14. A. Rizal, S. Hamidah, and S. Wuryani, Universitas Mercu Buana Yogyakarta-Yogyakarta (2018)
15. S. Y. Ariadhy and D. Arkum, in Proceedings of the International Conference on Sustainable Environment, Agriculture and Tourism (ICOSEAT 2022) (Atlantis Press, 2023)
16. Serikat Petani Kelapa Sawit (2023)
17. M. Intan Sari, S. Hadi, M. Jurusan Agribisnis, F. Pertanian, U. Riau, and J. Agribisnis, **24**, (2022)
18. R. Chambers and G. R. Conway, *Sustainable Rural Livelihoods: Practical Concepts for the 21st Century* (1991)
19. Indonesia Palm Oil Facts, Https://Www.Indonesiapalmoilfacts.Com/Unsdgs, (2023)
20. E. Esselink, S. Rivera Tamayo from EPOA, B. Olajide, A. Subramanian, F. Morgante, H. Sung Yen, R. Brunsveld, and D. Bajpai, Colophon *Sustainable Trade Initiative and the Roundtable on Sustainable Palm Oil (RSPO)* (2022)
21. McGill University, *What Is Sustainability?* (2020)
22. C. Gallemore and K. Jespersen, Sustainability (Switzerland) **11** (2019)
23. R. K. Larsen, M. Osbeck, E. Dawkins, H. Tuhkanen, H. Nguyen, A. Nugroho, T. A. Gardner, Zulfahm, and P. Wolvekamp, J Clean Prod 183, **544** (2018)
24. E. Suryani, R. Agus Hendrawan, I. Muhandhis, and L. Puspa Dewi, *Dynamic Simulation Model of Crude Palm Oil Supply Chain to Determine Fulfillment Ratio and Manufacturing Efficiency of Cooking Oil Industry* (2018)
25. Y. Barlas, Syst Dyn Rev 12, **183** (1996)
26. C. Bianchi, G. Nasi, and W. C. Rivenbark, *Public Management Review*, **23**, 1581 (2021)
27. N. Kurniawati, H. a, P. Glasbergen, and A. Offermans*, Sustainability Certification and Palm Oil Smallholders' Livelihood: A Comparison between Scheme Smallholders and Independent Smallholders in Indonesia* (2015)
28. J. Lee, J. Ghazoul, K. Obidzinski, L. Koh, J. Ser Huay Lee, and L. Pin Koh, **34**, 501 (2014)
29. F. Baudron and K. E. Giller, Biol Conserv 170, **232** (2014)
30. R. Cramb and J. F. McCarthy, THE OIL PALM COMPLEX, (2016)
31. I. Jelsma, M. Slingerland, K. E. Giller, and J. Bijman, J Rural Stud, **54**, 198 (2017)
32. X. Hu, L. Chu, J. Pei, W. Liu, and J. Bian, Knowl Inf Syst, **63**, 2585 (2021)
33. M. M. Syfert, M. J. Smith, and D. A. Coomes, PLoS One, **8**, e55158 (2013)