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Unearthing Agricultural Land Use Dynamics in Indonesia: Between Food Security and Policy Interventions

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Abstract: Despite its essential and irreplaceable role in food security, the agricultural sector is often perceived as having the potential to be sacrificed in the name of economic growth, leading to significant land cover transformation into built-up areas and plantations. This complexity prompts critical questions regarding the efficacy of agricultural policy interventions, including augmenting production capacity, diversifying commodities, and expanding agricultural land in light of Indonesia Emas 2045, which embodies Indonesia's ambitious multidimensional developmental transformation. This study employed a system dynamic approach with region-based closed feedback, focusing on four primary commodities: rice, cassava, corn, and palm oil. It concludes that food vulnerability will become increasingly severe by 2045, particularly in Java Island, which, despite being the sole area with a food surplus, is also experiencing escalating development pressures. In other regions, this pressure transforms transitory land from areas growing rice to areas growing other agricultural commodities, and subsequently to built-up land. The policy intervention scenario, albeit less impactful in reflecting substantial land cover changes nationally, can facilitate swift commodity production. This study emphasizes the necessity of intensifying rather than expanding agricultural land.

Keywords: agriculture land use; food security; policy; system dynamic

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1. Introduction

The agricultural sector is critical to Indonesia's economy because it absorbs labor, particularly that of low-income workers, and serves as a social safety net during times of crisis. Between 2014 and 2023, the agricultural sector generated 13.1% of Indonesia's GDP [1]. This circumstance aligns with the elevated labor absorption rate, projected to reach 28.2% by 2023 [2]. Furthermore, World Bank statistics (2020) indicate that this sector is the predominant source of employment for impoverished individuals, with 64% being engaged in it in 2018. Moreover, transitioning away from agriculture does not ensure that the poor will be elevated out of poverty. Moeis et al. [3] found that most Indonesian farmers had limited employment skills beyond agriculture. Nonetheless, the FAO [4] identified the resilience of this sector as a safety net adept in addressing the COVID-19 crisis while continuing to thrive. In other words, despite the stigma associated with this sector, characterized by low-income workers and the workforce's inflexibility to transition, this sector demonstrates robust performance in the face of challenging circumstances.

Furthermore, the agricultural sector encounters significant issues regarding land use changes. There is a propensity to acquire agricultural land, particularly rice fields, to facilitate the development of metropolitan areas, as elaborated by Utami and Ahamed [5] in Greater Jakarta and Fuadina et al. [6] in the Bandung Metropolitan Area. Permatasari [7] observed a 6% annual reduction in agricultural land per year in Jombang Regency, East Java Province, due to manufacturing expansion and pressure regarding infrastructure development. A comparable scenario was observed in Semarang, Central Java Province, as

articulated by Kelly-Fair et al. [8]. Moreover, this sacrifice pertains not only to construction endeavors but also to the expansion of oil palm cultivation, which is more profitable than other agricultural products [9]. A comprehensive investigation in Sumatra and Kalimantan conducted by Juniyati and Situmorang [10] substantiated the problem stemming from economic, institutional, and political forces. The pressure of land changes is evident in Figure 1, where the extent of agricultural land directly influences agricultural production, particularly that of rice; thus, a reduction in rice fields correlates with diminished production levels. This shows that land intervention will promote intricate issues concerning rice consumption, which accounts for 50% of the caloric intake in Indonesia [11], indicating a profound dependency [12,13], where even the onset of food diversification does not markedly alter this trend [14].

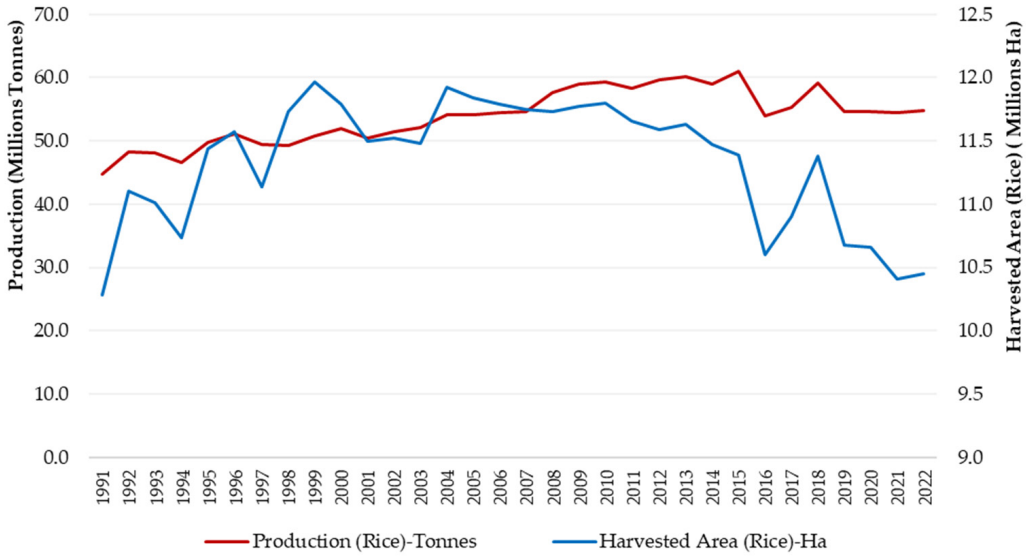


Figure 1. Rice production quantities and harvested land in Indonesia, 1994–2022. Source: FAO statistics 2024.

The competition in the agricultural sector and other industries is increasingly complicated in light of Indonesia Emas 2045, which emphasizes sustainable economic development as one of its pillars. Law No. 59 of 2024 concerning the National Long-Term Development Plan 2025–2045 anticipates an optimistic economic growth scenario of 7%, with the agriculture, forestry, and fishery sectors projected to grow by 4.2% [15]. The dynamics of changes in agricultural land cover pose a significant question regarding how to attain optimal performance in the agricultural sector, especially when its efficacy is constrained by the advancement of other sectors, such as manufacturing, which aims to contribute 28% to the Indonesian economy. Encouraging sustainable development in the agriculture industry, which faces multifaceted pressures, represents a significant challenge. This paper examines the dynamics of agricultural land cover change, focusing on policy interventions to balance this sector's dual role in realizing Indonesia Emas 2045.

This research provides some theoretical novelty. This study enhances existing research, which typically views land cover change as a static and linear process (business as usual), by incorporating government intervention scenarios to elucidate the impact of policies on the dynamics of land cover change. Furthermore, given the diverse policy goals and objectives, it is anticipated that there will be a variation in the impact of agricultural sector performance on land cover changes. Secondly, exploration will be conducted at the meso level with closed feedback mechanisms. Current land cover studies typically focus on the national level [16], disregarding regional variations, or, conversely, are excessively detailed at the micro level, as exemplified by Indrawan and Trisasongko [17] in Badung Regency, complicating the Central Government's ability to address these diversities. Meso-level research is translated on an island scale, accommodating the diverse characteristics of

Indonesia, such as Java, which features extensive urbanization, in contrast to Sumatra and Kalimantan, predominantly characterized by plantations, and Papua, noted for its extensive forested regions. Moreover, when the research investigates land cover in an open system without a maximum extent, the land cover prediction employs closed feedback, utilizing the area of each island as a constraint in each zone.

This paper begins by examining the studies on the dynamics of agricultural land cover change from the viewpoints of victims and perpetrators. The discussion expands on the methodologies used by developing a system dynamics model incorporating region-based closed feedback. The analysis and discussion are divided into two main sections: addressing the scenario without policies and examining agricultural policy. Finally, this research seeks to determine the future trajectory of agrarian land development and its theoretical implications for the study of land transformation.

2. Dynamics of Agricultural Land Cover Change: Victim or Perpetrator?

Land use activities are frequently interpreted as the influence of human endeavors on the transformation of the natural landscape [18], influenced by the reconfiguration of market opportunities due to the constraints of finite natural resources [19]. Furthermore, numerous initiatives have been undertaken to regard land cover dynamics not merely as a transition between different types of land cover but also as a reconstruction of regional and urban development [20,21]. The cases of Greater Jakarta [22] and Iran [23] demonstrate that land cover change creates an immense urban structure that shapes the metropolitan area as a conglomeration of the population's economic and social activities. Conversely, research emphasizes land development to facilitate urban physical change rather than economic activity based on natural resources [24,25]. This process does not yield a significant expansion of built-up areas; instead, land transformation indicates competition among stakeholders exploiting scarce, immobile land for agricultural purposes. Lubowski et al. [26] and Scherr and Yadav [27] discovered that changes in agricultural land cover result in the deterioration of environmental quality.

Despite the extensive research on changes in agricultural land cover, there is a propensity to depict the agricultural sector as the most susceptible in this process. Research conducted by Pribadi and Pauleit [28] and Firman [29] in the Greater Jakarta Metropolitan Area revealed that the demands of proximate urbanization compromise agricultural land in the periphery to benefit residential and commercial development. This rapid agricultural transformation generates further apprehensions regarding food vulnerability [30,31]. In addition, the presence of land grabbing by large corporations, resulting in speculative purchases of agricultural land, further diminishes agricultural activities [32]. This situation is intensified by the predominance of land ownership among small-scale farmers, who often lack power in many developing countries [33]. This situation progressively compels landowners to relinquish their agricultural properties to developers, yielding minimal return from the land conversion. It is also important to mentioning factors relating to climate change; not only is agriculture a major contributor to greenhouse gas emissions [34], but also the decrease in productivity due to changes in the planting season contributes to the increasing conversion of unproductive agricultural land [35] in the name of land use intensification and urban expansion.

The agricultural sector's vulnerability is unavoidable, but the literature frequently neglects to acknowledge that agriculture serves as both a victim and a perpetrator of inequitable capitalism. Münster and Münster [36] highlighted that when agrarian capitalism hit its ecological threshold, the agricultural sector's expansion became progressively speculative due to the coercive expropriation of forested areas and the escalating marginalization of natural species. The competition for agricultural land will undoubtedly lead to diminished land utilization rates and a very low land price, which can be addressed by utilizing forest land. Myers [37] and Franklin and Johnson [38] mentioned that corporations can generate revenue from selling trees in the forestry sector while removing agricultural land. Forest land grabbing is frequently characterized by eco-political conflict between

large corporations allied with politicians [39] and the local community. In instances of power imbalances, local and indigenous groups invariably endure the most detriment, as they do not obtain value commensurate with the environmental consequences. The studies by Grünzweig et al. [40] in Alaska, Merloti et al. [41] in the Amazon, and Ramdani and Hino [42] in Indonesia collectively demonstrated that the conversion of forest land to agricultural use results in elevated levels of carbon and nitrogen, indicating a reduction in conservation functions, with local communities disproportionately affected by the negative externalities of this process. Moreover, research has sought to expand its focus beyond the interactions between agriculture and developed land to the dynamics of agricultural land and plantations. However, the primary critique directed at these studies is that they exclusively examine the alterations in two categories of land cover in more detail, but few endeavor to depict the dynamics of land cover that are continuously interacting and evolving.

A further critique leveled at the study of land cover change, especially within the agricultural sector, is the propensity to characterize land cover as a singular entity, specifically agricultural land. Research predominantly focuses on two principal commodities: palm oil, which is frequently used to represent the power of large corporations in land acquisition [43,44], and rice, which is commonly sacrificed for the sake of urbanization [45,46]. A greater disparity in agricultural land is indicated by the diversity of agricultural land commodities, which is expected to influence land cover change in multiple ways. Rice, for instance, produces far more emissions than other primary food sources [47]. Another example is the predominance of large companies in oil palm land, enabling them to acquire different types of land cover [44,48], as opposed to other commodities that small-scale farmers widely develop [49], reducing the likelihood of land use change. Another rationale for investigating commodity diversification is food security, which is occasionally concentrated in particular commodities, such as rice [50]. As a result, this circumstance engenders a heightened awareness of catastrophes while simultaneously eradicating local cultures that depend on alternative essential food sources. Although this situation may arise due to the limited ability to translate satellite maps, which can only record the image from above [51,52], this generality must not be overlooked. It pertains to identifying which land with commodities is more susceptible to change, enabling the government to implement more targeted actions instead of perceiving all characteristics as homogeneous.

Despite its limitations in describing the detailed aspects of each land cover, the examination of land cover change is comprehensive. It may forecast future land cover by employing diverse, sophisticated methodologies, as demonstrated by Aburas et al. [53], utilizing machine learning; Mishra et al. [54], using remote sensing; and Saputra and Lee [55], applying cellular automata. However, these studies primarily examine changes in land function mainly due to geographical characteristics. Consequently, non-spatial factors, including agricultural product demand, production, and policy interventions, have not been extensively investigated. This situation encourages land cover change research based on business-as-usual conditions and is limited to other factors. In this regard, this study aims to address the shortcomings by focusing on changes in agricultural land cover that can accommodate the diversity of agricultural commodities and considering aspatial elements in its prediction.

3. Methodology: A System Dynamic Model with Region-Based Closed Feedback

This research utilized system dynamics, introduced by Forrester [56,57] as a method that emphasizes the dynamics of a complex system where the structure is a logical consequence of the interaction between components, both spatial and aspatial, hence fostering the dynamic tendency of a system. Although some studies, such as Wilmar and Faoziyah [58] and Samat et al. [59], utilize geographic information systems (GIS) with the cellular automata method to capture land cover prediction, this approach has significant limitations in addressing the complexity of this study. These limitations include its weakness in depicting the aspatial element that serves as the benchmark for policy interventions, rendering

it unclear to what degree the government's aspatial interventions, such as augmenting agricultural production, influence land cover changes. Furthermore, Veldkamp and Lambin [60] elucidated that using system dynamics encompasses not only forecasting historical land cover alterations but also examining the driving factors that precipitate these changes. This method enables researchers to examine the process of change rather than concentrating on the outputs of the complexity. Forrester [61] further noted that this method exemplifies persuasive communication, linking individuals' cognitive frameworks to foster new understandings and harmonize perspectives and voices among stakeholders. Ghaffarzadegan et al. [62] asserted that this approach could address weaknesses in public policy that indicate a lack of concern for the environment by observing the feedback structure in extensive systems and modeling multiple scenarios to select the optimal scenarios, thereby facilitating enhanced stakeholder participation [63]. Therefore, system dynamics was chosen to facilitate the authors in understanding policy scenarios that significantly influence land cover, so that we could provide input on the formulation of regional-based policies.

Research conducted by Shen et al. [64] and Zhao et al. [65] endeavored to incorporate land cover changes in evaluating optimal land resource allocation and its correlation with spatial planning. In Indonesia, various studies have been conducted in West Kalimantan [66], Central Java [67], and throughout Indonesia [68]. However, these studies' limitations lie in their characterization of land cover changes as an open system, susceptible to external variables and lacking constraints on the maximum area. Consequently, while future land cover predictions may still be generated, they are less reflective of real-world conditions. Moreover, due to Indonesia's considerable diversity, a change in extensive rice fields renders it infeasible to identify the main contributor's location. As a result, this work created a land cover change model that incorporates closed feedback. Vedkamp and Verburg [69] asserted that constructing a model with closed feedback will enhance comprehension of the causes and effects of land use changes, which can subsequently be integrated with additional driving elements, such as policies, to facilitate the formulation of future land use prediction scenarios. For example, local dynamics and objective policies control Sumatra's land stock. This model accounts for the unique geographical characteristics of Indonesia and facilitates a comprehensive knowledge of land cover changes on a macro scale, leading to more effective policy implementation.

Although this model cannot describe land change dynamics at the micro or district/city level, it seeks to utilize regional elements within each island to show how much land cover change occurs. This situation is expected to accommodate differences in character between regions. Indonesia has six main regions: Sumatera, Java, Kalimantan, Sulawesi, Bali-Nusa Tenggara, and Maluku and Papua (Figure 2).

The data collection for this research was carried out by combining secondary and primary data. Secondary data were collected from the Central Statistics Agency on each studied commodity related to production, productivity, land area, harvest area, planting intensity, labor, and farmers' income in the 2020–2022 period. In addition, we utilized data from the Ministry of Agriculture to determine the use of fertilizer per hectare and its cost in 2022. Details of the data can be observed in Table 1. Furthermore, primary data were obtained through interviews with the Ministry of Agriculture and local governments, including information on the extent of each policy's target, thus representing an effort to involve stakeholders in the formulation of public policies, as explained by Forrester [61] and Ghaffarzadegan et al. [62].

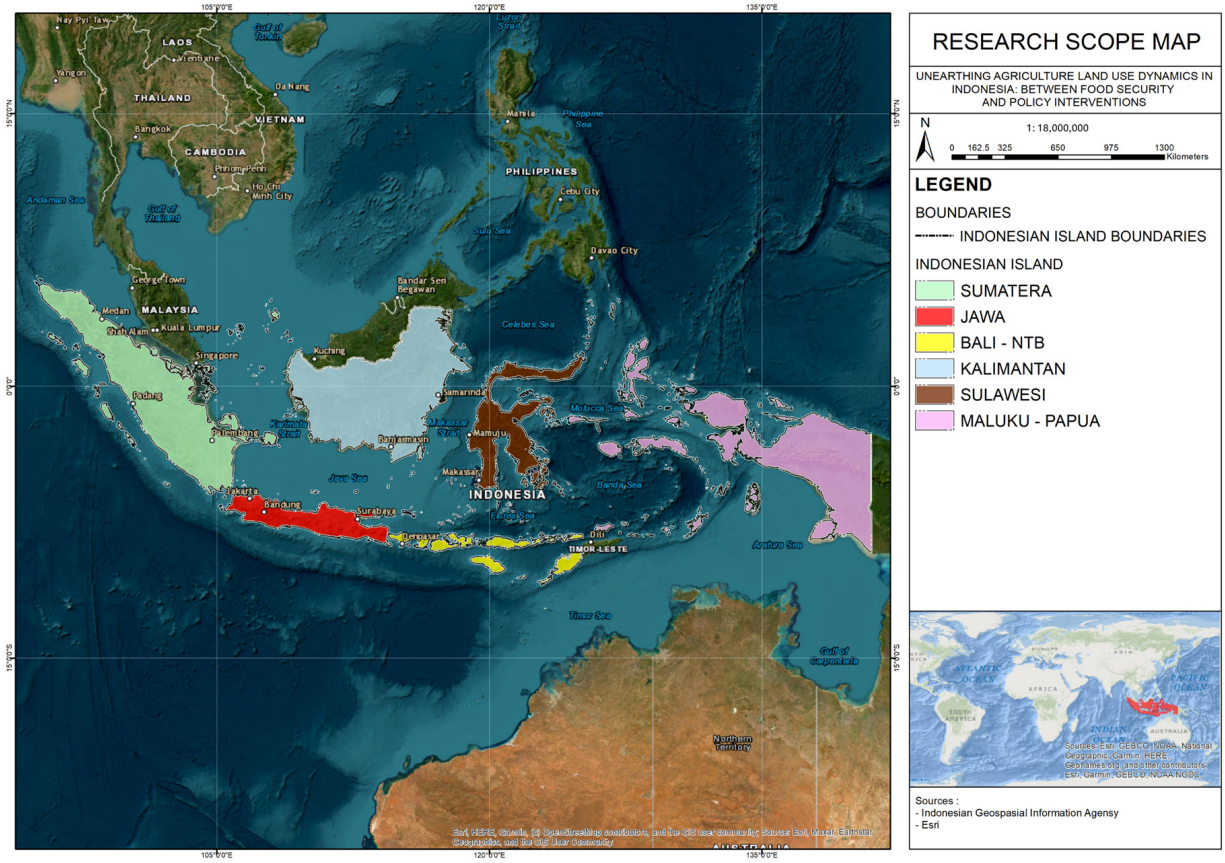


Figure 2. Research scope. Source: analysis results, 2024.

Table 1. Data Needs.

No.	Commodity	Data	Year	Source
1	Rice	Rice production (tons/year)	2010–2022	Central Statistics Agency
		Rice productivity (tons/ha)	2010–2022	
		Rice fields area (Ha)	2010–2022	
		Rice harvest area (Ha)	2010–2022	
		Rice planting intensity (/year)	2010–2022	
		Labor in the agricultural sector (rice fields) (people)	2010–2022	
		Farmer income (IDR/year)	2022	
		Fertilizer utilization per hectare of paddy land	2022	Ministry of Agriculture
		Fertilizer cost per ton (IDR) (ton/ha/year)	2022	
2	Cassava	Cassava production (tons/year)	2010–2022	Central Statistics Agency
		Cassava productivity (tons/ha)	2010–2022	
		Agricultural land area (Ha)	2010–2022	
		Cassava harvest area (Ha)	2010–2022	
		Cassava planting intensity (/year)	2010–2022	
		Labor in the plantation sector (cassava) (people)	2010–2022	
		Farmer income (cassava) (IDR/year)	2022	
		Fertilizer utilization per hectare of agricultural land	2022	Ministry of Agriculture
		Fertilizer cost per ton (IDR) (ton/ha/year)	2022	

Table 1. *Cont.*

No.	Commodity	Data	Year	Source
3	Corn	Corn production (ton/year)	2010–2022	Central Statistics Agency
		Corn productivity (tons/ha)	2010–2022	
		Agricultural land area (Ha)	2010–2022	
		Corn harvest area (Ha)	2010–2022	
		Corn planting intensity (/year)	2010–2022	
		Labor in the plantation sector (corn) (people)	2010–2022	
		Farmer income (corn) (IDR/year)	2022	
		Fertilizer utilization per hectare of agricultural land	2022	Ministry of Agriculture
		Fertilizer cost per ton (IDR) (ton/ha/year)	2022	
4	Palm-oil	Palm oil production (tons/year)	2010–2022	Central Statistics Agency
		Palm oil productivity (tons/ha)	2010–2022	
		Plantation land area (palm oil) (Ha)	2010–2022	
		Share of oil palm land that has not produced, has produced, and does not produce (%)	2022	Ministry of Agriculture
		Time for palm oil to produce a harvest (from not yet to having produced) (year)	2022	
		Palm oil productive time (from having become non-productive) (year)	2022	

The analysis was carried out in several stages. The first stage was to develop a causal loop diagram that reflected the author's framework for understanding the complexity of issues in the agricultural sector, which was the basis for developing the model structure in the later parts of the Powersim Studio 10 software (Figure 3). The second stage focused on developing the structure of the land model and each commodity (Figures 4–8) to show the operationalization of the model developed in the software. The third stage sought to model business-as-usual, meaning that no additional policy interventions will exist until 2045. The last stage was carried out by considering policies that influence land cover change (discussed in detail in Table 1).

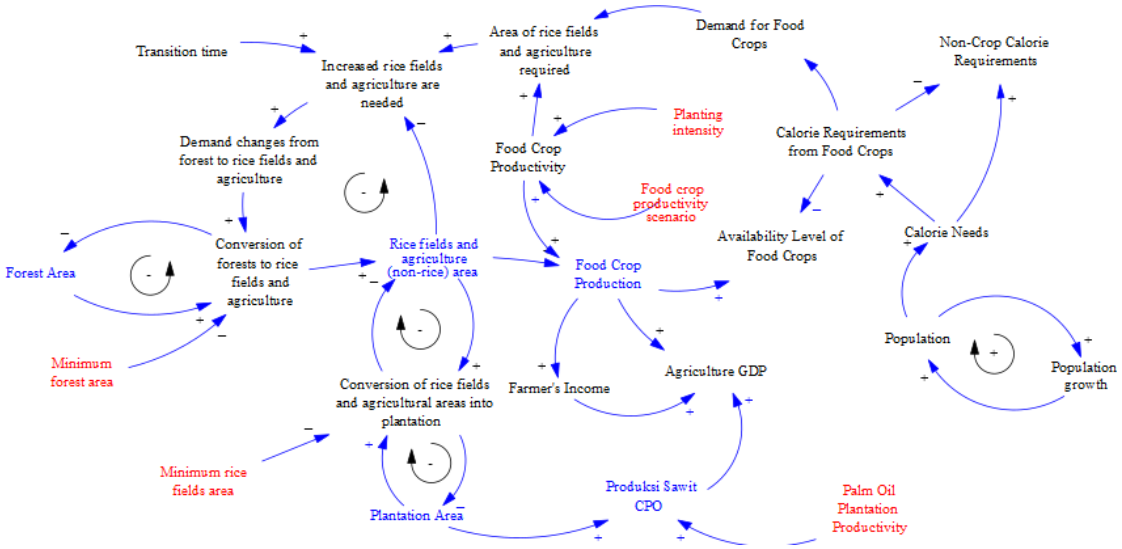


Figure 3. Causal loop diagram. Source: Analysis results, 2024. Notes: Red text indicates policy intervention, blue indicates the analyzed output, and black indicates the modeling process.

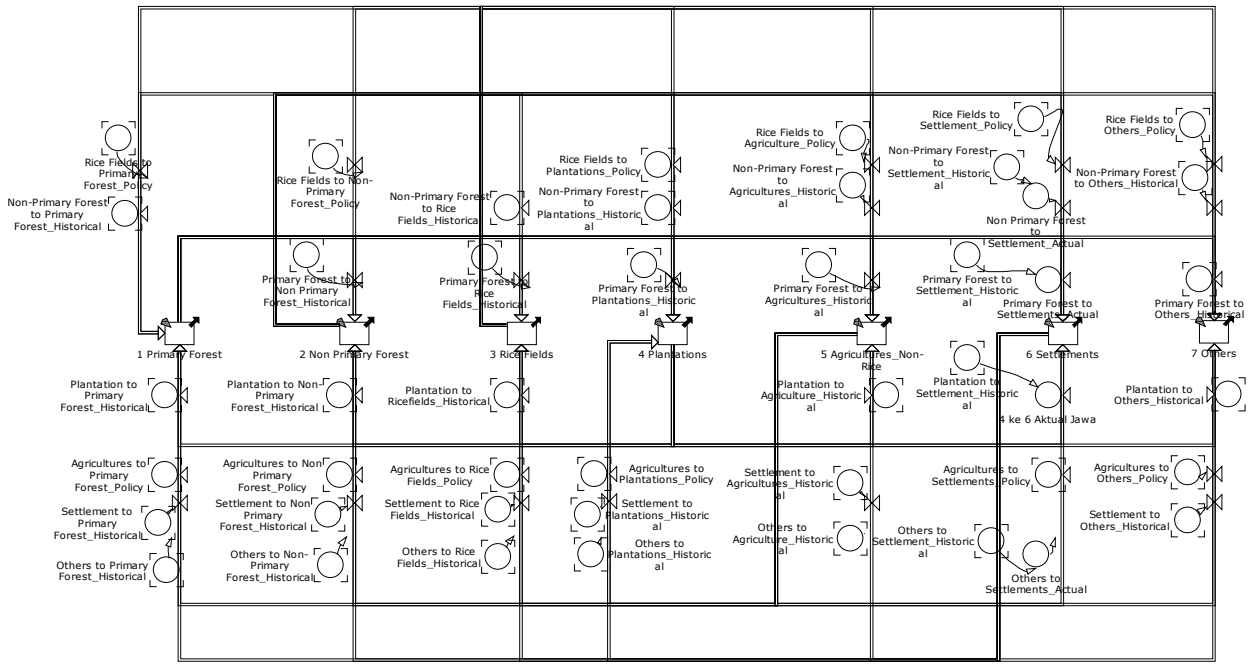


Figure 4. Structure of land cover change model. Source: analysis results, 2024. Notes: Squares depict stock variables and circles indicate auxiliary variables. The inflow arrow depicts inflows to the stock or factors influencing the auxiliary.

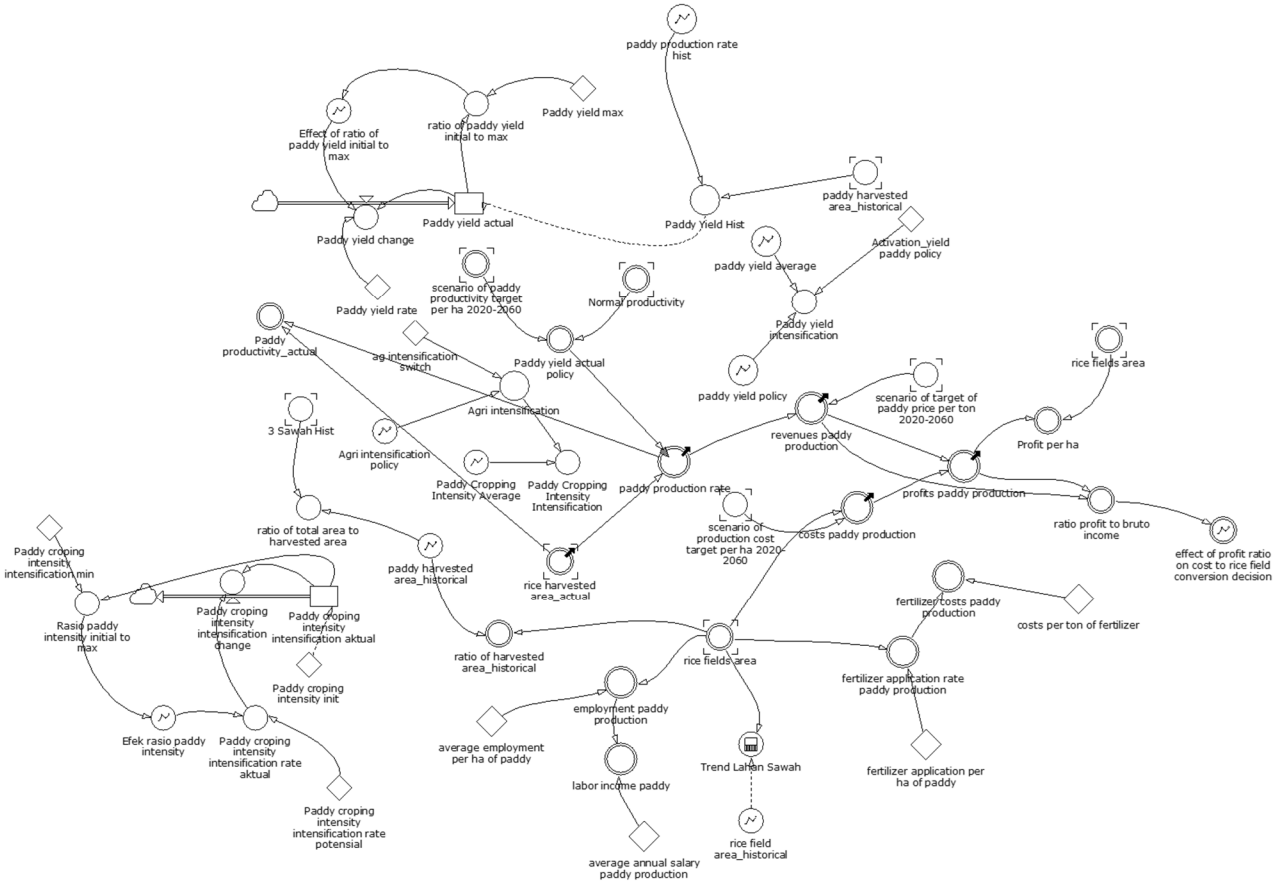


Figure 5. Structure of the rice commodity model. Source: analysis results, 2024. Notes: Squares depict stock variables and circles indicate auxiliary variables. The inflow arrow depicts inflows to the stock or factors influencing the auxiliary.

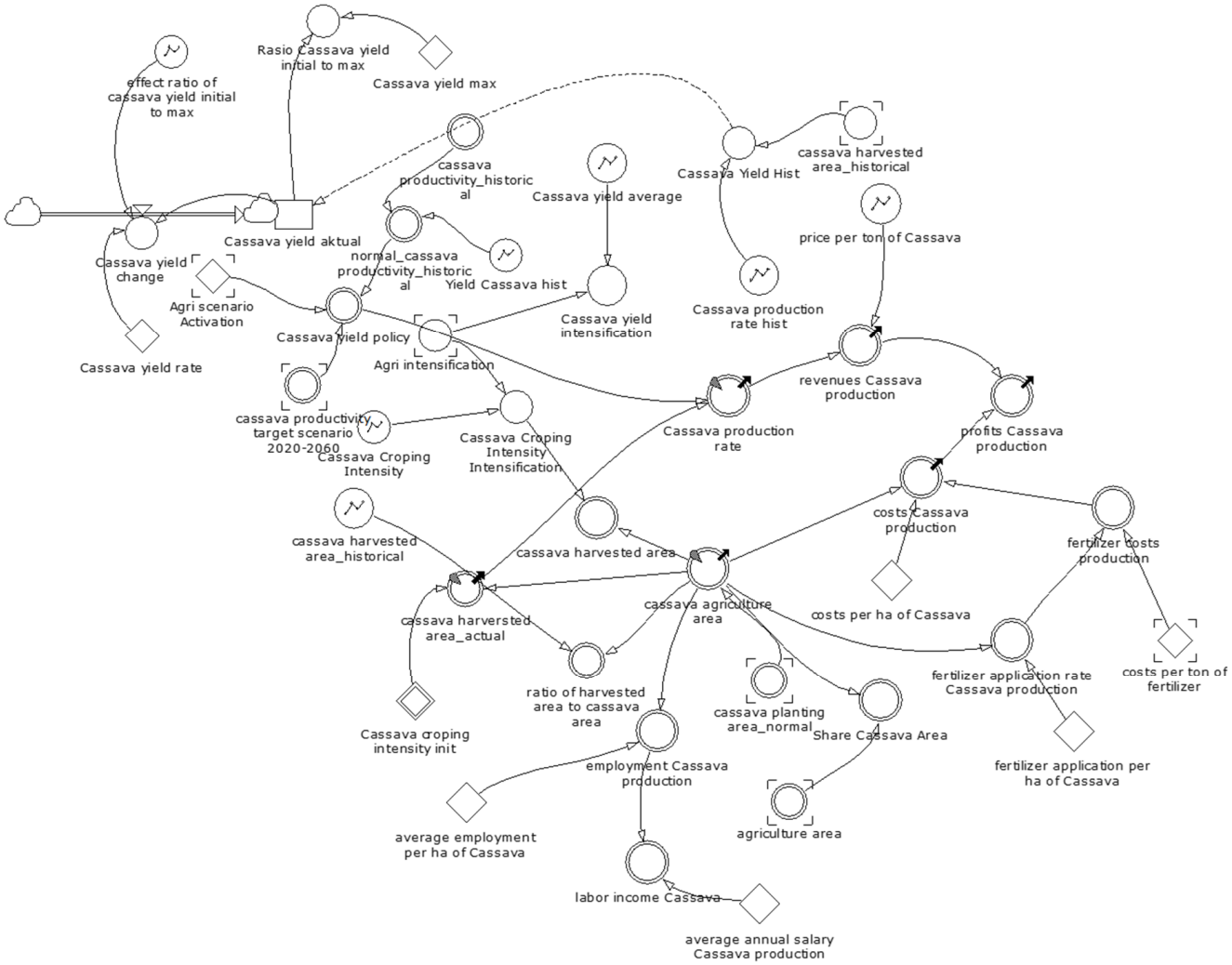


Figure 6. Structure of the cassava commodity model. Source: analysis results, 2024. Notes: Squares depict stock variables and circles indicate auxiliary variables. The inflow arrow depicts inflows to the stock or factors influencing the auxiliary.

3.1. Causal Loop Diagram

The increase in population is the basis for increasing demand for food crop products. Then, a larger land area is needed, which can be met through land conversion from other land uses to rice fields and agriculture (non-rice). Then, with the increasing land area, this has a positive opportunity to increase production and farmers' income and will ultimately affect agricultural GDP. Interventions are focused on productivity through planting intensity and productivity improvement scenarios, as well as minimum rice field area interventions (Figure 3).

Then, plantation land also faces a similar situation where there are efforts to convert other land to meet plantation land needs, or vice versa. The larger the oil palm area, the higher the oil palm production, which will be intervened through the palm oil productivity scenario. Ultimately, this situation will also increase agricultural GDP.

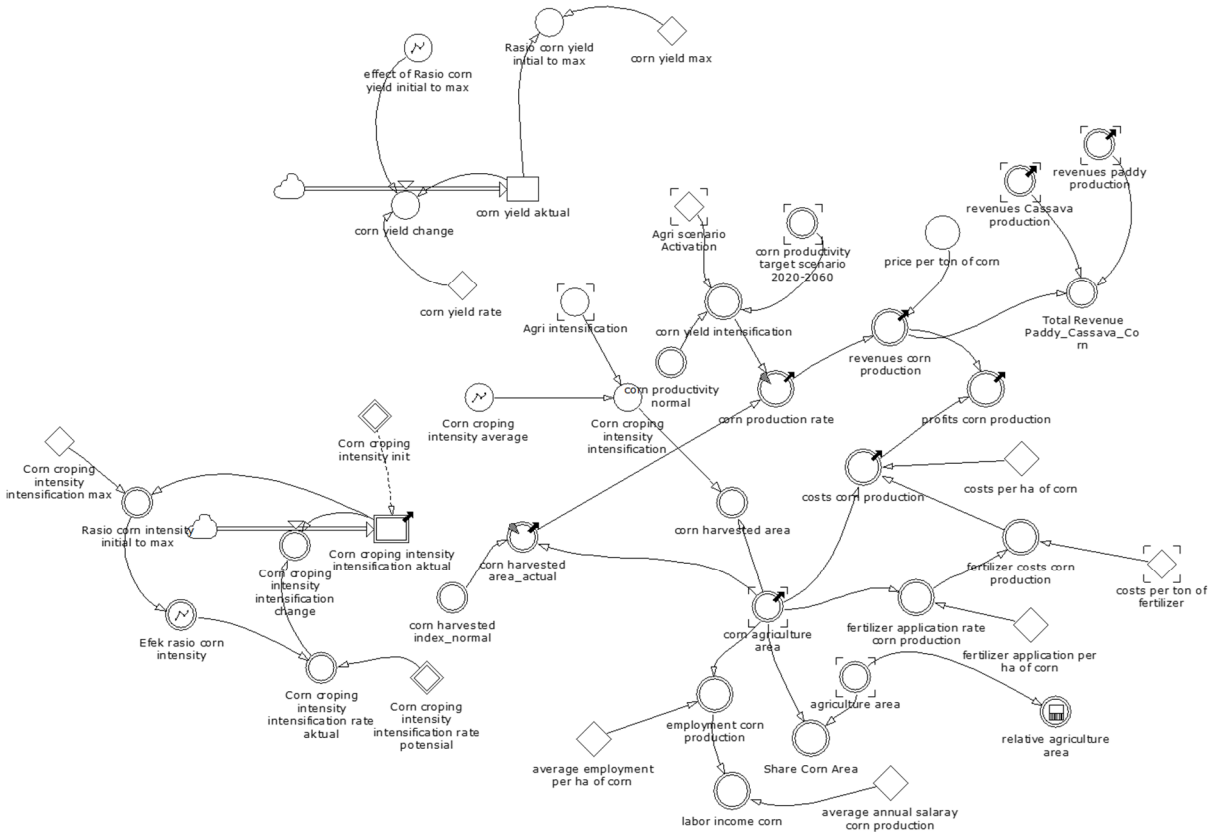


Figure 7. Structure of the corn commodity model. Source: analysis results, 2024. Notes: Squares depict stock variables and circles indicate auxiliary variables. The inflow arrow depicts inflows to the stock or factors influencing the auxiliary.

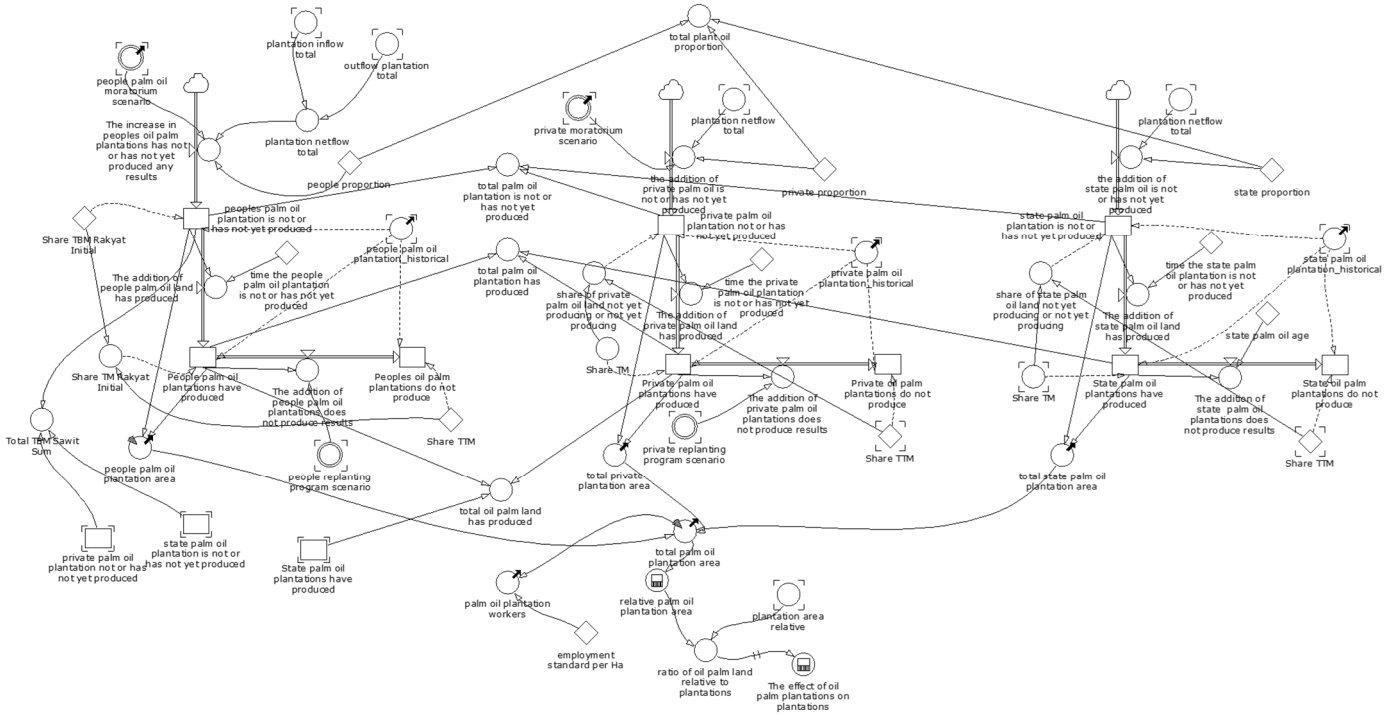


Figure 8. Structure of the palm oil commodity model. Source: analysis results, 2024. Notes: Squares depict stock variables and circles indicate auxiliary variables. The inflow arrow depicts inflows to the stock or factors influencing the auxiliary.

3.2. Land Model Structure

Figure 4 illustrates the structure of land cover change dynamics in Indonesia. The Indonesian Ministry of the Environment and Forestry Planning Agency has determined 23 land cover types in satellite imagery interpretation. However, considering the consistency between longitudinal spatial data, land reclassification was carried out for seven land cover types: primary forest, non-primary forest, rice fields, plantations, agriculture (non-rice), settlements, and others (details in Appendix A). Veldkamp and Lambin [60] developed structural and statistical models based on two fundamental principles. The structural model used in this work allowed us to see the most significant rate of influence of land change. Land-related policy frameworks, such as restrictions on rice field conversion, agriculture, and deforestation, are endogenously linked, allowing feedback and scenarios to be presented for the influence of future changes in land use conversion behavior caused by policy intervention.

Inflows and outflows (Figure 4) were determined by accounting for trends in land cover change since 2010 and changes influenced by policy actions. The calculation of the trend in land cover change was based on Aspinall's article [70], which stressed the processing of GIS overlays so that each land use model area shares commonalities with the land-cover transition matrix data. However, it is essential to note that the linear model was created structurally (Figure 4) and was linked to the land-related policy framework. Furthermore, there are distinctions in critical concepts that must be grasped, particularly rice fields, agriculture, and plantations. The classification of rice fields refers to the land utilized to produce rice. Agriculture uses land to generate agricultural commodities other than rice and plantation commodities. Meanwhile, plantations represent the type of land cover that yields plantation commodities.

3.3. Structure of the Commodity Model

Furthermore, this study considered the dynamics of land cover change due to trends or governmental interventions and the dynamic elements that occur during primary commodity production expansion. This study also investigated how production growth affects land cover change. However, it must be acknowledged that it is impossible to define all agricultural and plantation products in Indonesia. As a result, this model was created by considering several critical commodities that represent potential contributors to food diversification and economic growth. The first commodity was rice, Indonesia's primary food commodity, represented by rice field coverage. Second, agricultural land cover was solely represented by cassava and corn, which can be used as alternative food commodities. Then, palm oil was considered to represent plantation land. Furthermore, palm oil highlights the dynamics of large-scale land tenure via multinational enterprises. Then, the next stage is to create a model framework for each commodity (Figures 5–8).

The rice commodity model was created by considering three significant elements: rice production, rice-added value, and farmer income (particularly for rice field farmers) (Figure 5). Production was computed using the area of rice fields, productivity, and the crop index. Policy interventions are implemented by increasing output and planting. The added value of rice indicates the profits of rice production, represented by the value in IDR obtained from rice production minus production costs (seed, pesticide, labor, land rent, and other expenses). Furthermore, rice field agriculture income considers the average number of workers required per hectare of rice field and the average worker wage.

Conceptually, the development of the cassava commodity model structure did not differ greatly from that of rice, only in calculating the land using the assumption of a certain percentage of agricultural land planted with this commodity (Figure 6). The value of these shares is dynamic over time.

Like that for cassava, the corn commodity model assumes that a certain percentage of agricultural land is developed to produce corn commodities (Figure 7). The share value of this commodity has also changed.

Furthermore, the palm oil commodity model considered palm oil land owned by the people, the private sector, and the state. The development of this model also considered oil palm land that has produced commodities and has not yet produced commodities (Figure 8). The calculation of this model considered policy interventions in the form of palm oil replanting to increase the area of productive land for palm oil.

3.4. Policy Interventions

This study presents policy possibilities that affect the performance of land cover change. It confirms Haraldsson and Sverdrup's [71] theories about the role of system dynamics in evaluating achievements, hence facilitating consensus on stakeholders' efforts to achieve the goals. Policy interventions have two objectives, namely increasing the productivity of each selected commodity and maintaining the number of plantations, rice fields, and forests, with the goal of forecasting or correcting changes in land cover performance. These interventions are not fully considered in Indonesia's planning papers, which are now focused on rice and palm oil commodities. However, this scenario can provide a more comprehensive view of interventions related to other commodities. Furthermore, this model analyzes three scenarios: the baseline scenario, which is the lack of policy; the moderate scenario, which only considers interventions in terms of productivity; and the optimistic scenario, which includes interventions in terms of land cover (Table 2). We then aim to establish target statistics for each scenario developed through conversations with the National Planning and Development Agency and other regional technical ministries (Appendix B).

Table 2. Model development policy scenario.

Policy Intervention	Policy Indicators	Baseline Scenario	Moderate Scenario	Optimistic Scenario
Increasing Productivity and Rice Planting Index	Rice Productivity Target	-	√	√
	Rice Planting Intensity Target	-	√	√
Increased Cassava Productivity	Cassava Productivity Target	-	√	√
Increased Corn Productivity	Corn Productivity Target	-	√	√
Increasing Productivity and Replanting of Oil Palm	People's Palm Oil Productivity	-	√	√
	Private Palm Oil Productivity	-	√	√
	Replanting of Smallholder Oil Palm Plantations	-	√	√
	Replanting Private Oil Palm Plantations	-	√	√
Moratorium on Plantation Land	Minimal Agricultural Land	-	-	√
Protection of Rice Fields and Agriculture	Minimum Rice Field Land (LP2B)	-	-	√
	Transfer of Plantation Increase Function	-	-	√
Primary Forest Moratorium (Specifically on Maluku Island, Papua)	Minimum Primary Forest Land	-	-	√

Source: Analysis results, 2024.

4. Results

4.1. Development of Agricultural Land Cover Without Additional Policies (Business as Usual)

4.1.1. Production Dynamics and Commodity Land Area

Various studies, such as Firmansyah et al. [72], Andari and Farid [73], and Redfern et al. [74], have highlighted the significant vulnerability of rice commodities in fulfilling food requirements due to alterations in land cover and climate change. This underscores the imperative need for the government to diversify food sources into alternative commodities, such as corn and cassava. However, the results of the baseline scenario simulation found that without additional policies, the harvest area and production of these commodities tend to experience a drastic decline, suggesting that food security issues remain and are intensifying. Nonetheless, there are limited favorable opportunities for corn commodity advancement in Sumatra, Sulawesi, and Bali-Nusa Tenggara (Figure 9).

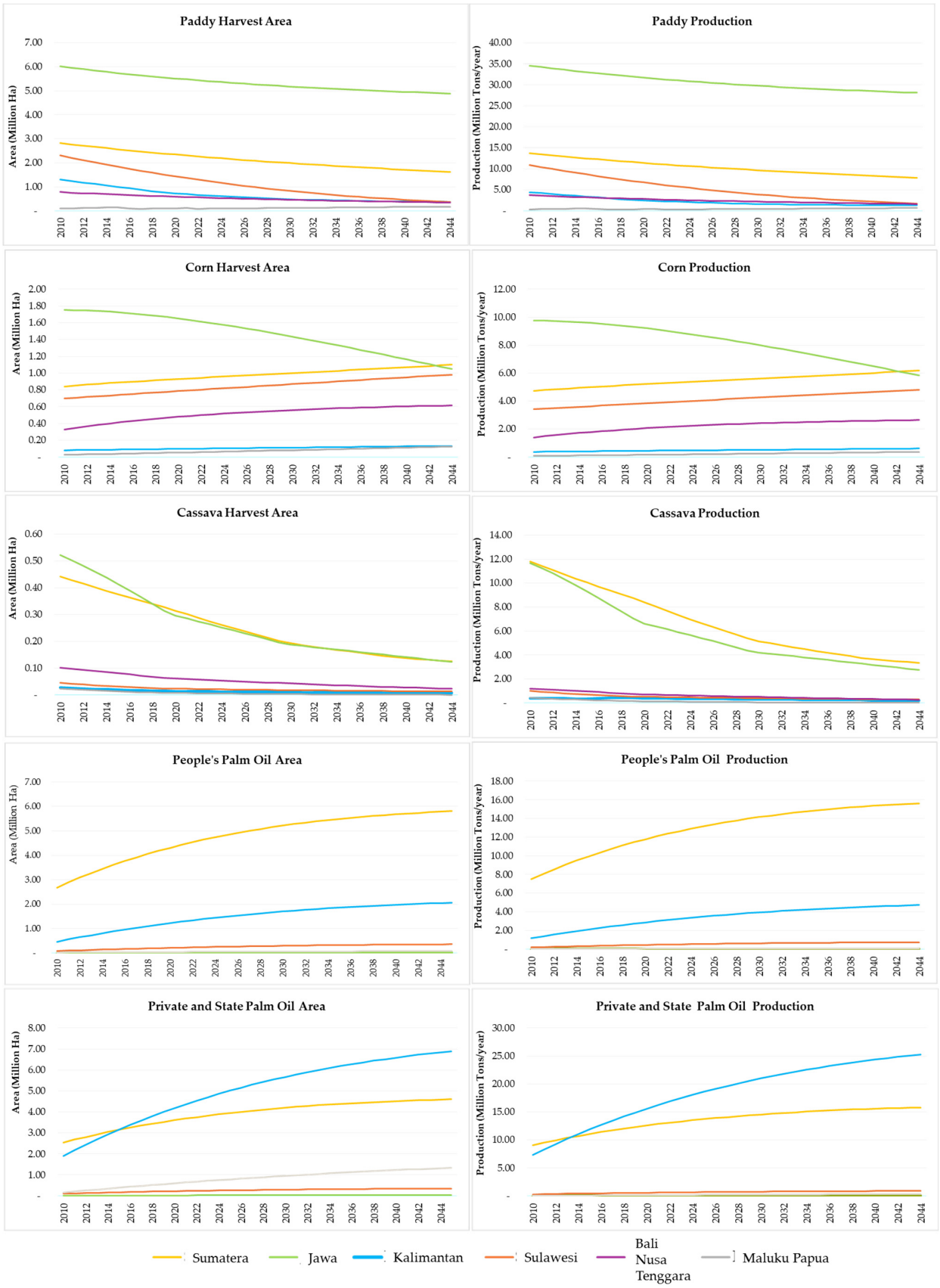


Figure 9. Harvested area and production of rice, corn, cassava, and palm oil commodities (people-, privately, and state-owned) baseline scenario. Source: Analysis results, 2024.

The simulation emphasizes the crucial role of Indonesia's Western Region, encompassing Sumatra and Java, in providing the majority of the food supply. The simulation results indicate that only Java Island experienced a slight rice surplus by the end of the analysis period. Conversely, the other regions have encountered substantial deficits, with the islands of Maluku and Papua having faced this situation since 2010. This underscores the necessity for Indonesia's Eastern Region to enhance food production and progressively lessen its reliance on the Western Region.

Diverse behaviors are noted in palm oil commodities possessed by the people, the private sector, and the state. Simulations imply that palm oil development will remain concentrated on two Indonesian islands: Sumatra and Kalimantan. Palm oil which the people own predominates throughout Sumatra. Meanwhile, state- and private-sector-controlled palm oil land predominates in Kalimantan, which strongly correlates with the production structure of palm oil commodities. The geographical organization of palm oil production might encapsulate the fundamental elements of the findings. Despite Sumatra's substantial contribution to palm oil harvesting and production, encompassing people-, private-sector-, and state-owned palm oil commodities, there is a discernible decline. For example, people-owned palm oil production will decrease from 74% in 2020 to 70% in 2045 (Figure 9). In contrast to Kalimantan, which experienced a notable rise in state- and privately held palm oil from 48% to 52%, a similar trend occurred with people-owned palm oil (ibid). This suggests a more pronounced tendency for oil palm expansion in Kalimantan, potentially encroaching upon other land cover types, particularly forests, which dominate the region. Simultaneously, Sumatra has transitioned to higher-value commodities beyond palm oil, leading to a decelerated growth rate.

4.1.2. Land Cover Dynamics

Figure 10 illustrates a substantial increase in plantation area from 9,841,610 ha in 2010 to 31,567,001 ha in 2045. Subsequently, without any intervention, the area of rice fields is projected to experience a modest increase of 7.5%, whereas agricultural land area (without rice) will diminish by 7.01% during these 35 years (Figure 10). This indicates that, at a national level, the area designated for agriculture, especially rice fields, is comparatively secure and stable. However, with a considerable increase in land in the plantation category, new disputes emerge about which land cover is created, given the significant decline in non-primary forests and others. Moreover, Figure 8 reveals that the expansion of rice fields does not correspond with the reduction in harvested area, indicating that despite a minor increase in land, it was insufficient to promote an increase in harvested area.

Micro-level exploration uncovered heterogeneity in spatial patterns, highlighting the contrasts in land competition experienced by each location. On Sumatera, plantation land cover is projected to increase dramatically from 6,045,679 Ha to 16,644,033 Ha between 2010 and 2045, with more than 2.5 times the growth coming from the conversion of agricultural land compared to forests (primary and non-primary) and rice fields (Figure 10). Then, the circumstances in Kalimantan exhibited comparable spatial attributes to those in Sumatra, where a notable expansion in plantation land was identified, believed to originate from large corporations [75]. The distinction is apparent in land transformation, which facilitates this structural change. Non-primary forests and other regions contribute to alterations in land use in Kalimantan. For instance, a decrease of 1,478,895 hectares in non-primary forests can be identified during the 35-year period (Figure 10). Although this category does not have a conservation function, it is essential in preventing and protecting against landslides and erosion.

Moreover, unlike Sumatra, Java encounters greater land competition between agricultural rice fields and urban development. The baseline simulation results indicate a consistent trend of increasing settlements (from 1,290,539 Ha to 2,606,871 Ha) and reducing other land cover. Rice fields and other agricultural areas are projected to experience the most significant decline (Figure 10). On the other hand, this region's contribution to national food security is critical (Figure 9), implying that settlement expansion, a measure of

the region's growth rate, will jeopardize the region's ability to sustain food security. If this tendency is not mitigated, Java will encounter food scarcity akin to that in other regions in Indonesia, exacerbating the area's inability to support human endeavors competitively. Moreover, the harvest area of rice commodities in this region is projected to diminish at a faster rate than the area of rice fields (Figures 9 and 10). This further substantiates the prior notion concerning barren rice fields exclusively on Java.

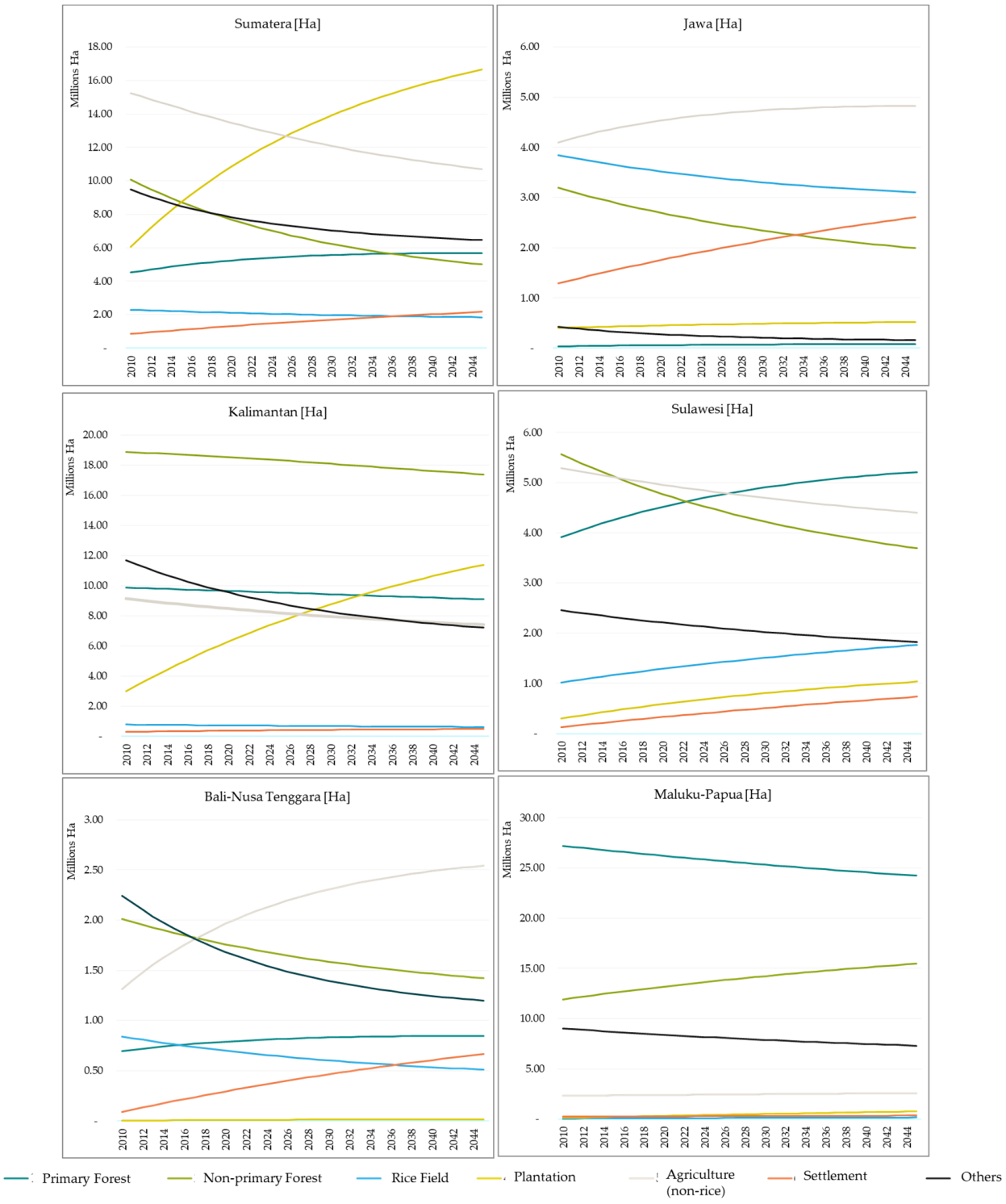


Figure 10. Land cover area by baseline scenario area. Source: Analysis results, 2024.

Sulawesi exhibits a distinct pattern compared to other islands. The coverage of rice fields is projected to increase significantly from 5.47% (1,021,212 Ha) to 9.46% (1,766,811 Ha) (ibid). While this is not predicted to achieve food security for the region by 2045, there are positive indications concerning the region's advancement in fulfilling food requirements. The switch to rice fields was predominantly influenced by an expansion of agricultural land cover by 504,682 hectares from 2011 to 2022, signifying a shift in the region's primary food commodity from non-rice to rice. Aside from agriculture, other land totaling 54,023 hectares in area was transformed into rice fields (ibid). Another feature of geographical pattern distinction is the enormous increase in primary forests in conjunction with a decrease in non-primary forests, signifying a transition between the two categories. These results cannot be directly interpreted as indicating a process of nationalization of non-primary forests into primary forests, as triangulation with data from the Ministry of Environment and Forestry reveals that this process was not identified that year, leading to inaccuracies in the translation of satellite images before their conversion into spatial data.

The character of the Bali–Nusa Tenggara region is shaped by the geological features of the archipelago, leading to a unique foundational land cover structure. The simulation findings reveal a significant increase in agricultural land from 1,313,754 Ha to 2,542,842 Ha from other land categories (ibid), including non-primary forests, signifying initiatives to diversify food production beyond rice. Meanwhile, the area of rice fields decreased significantly, with transitions particularly from rice fields to agriculture (36,462 ha) and settlements (16,190 ha) between 2011 and 2022 (ibid). The significant pressure on the rice field sector is propelled by the expansion of the tourism industry, which is the primary economic sector in this area. Rice fields are progressively being transformed into agricultural land, facilitating the conversion to residential land for homeowners. This study contributes to the findings of Handayani et al. [76], Lanya et al. [77], and Budhi et al. [78] regarding the dynamics of rice field changes in Bali, which is undergoing population growth and tourism sector expansion.

The final image shows Indonesia's easternmost region, Maluku-Papua. The most divergent dynamics are evidenced by the decrease in primary forests, predominantly transformed into non-primary forests (ibid), underscoring the significance of preserving degraded forests in this region. The modeling findings reveal that many agricultural areas are converted from non-primary forests and other categories. The transition from primary forests to non-primary forests, which are then used for agricultural land, illustrates a cycle of land cover schemes aimed at securing cultivated land for economic pursuits, often to the detriment of primary forest conservation.

4.2. Policies in the Agricultural Sector: How Do They Affect Agricultural Land Cover?

4.2.1. Dynamics of Commodity Production with Policy Interventions

Appendix B illustrates the policy target scenarios for each Indonesian island. It demonstrates that intensification strategies, including enhancing food productivity and optimizing planting intensity through technology and cropping management in rice, corn, and cassava, can increase domestic food production in the short term. For instance, rice production in Java amounts to 28,119,222 tons annually without intervention (Figure 9). With policy intervention to enhance productivity and the planting index (optimistic scenario), rice production might increase by 30,779,722 tons annually by 2045 (Table 3). This figure is still below the baseline established for 2010, which was 34,597,022 tons annually (ibid). Nevertheless, policy measures enhance the worst-case scenario without additional intervention.

Table 3. Comparison of rice, corn, cassava, and palm oil commodity production (people-, privately, and state-owned) baseline, moderate, and optimistic scenarios.

Commodity	Island	Baseline 2010 (ton/year)	Scenario (% Growth Compared to Baseline 2010)		
			Baseline 2045	Moderate 2045	Optimistic 2045
Rice	Sumatra	13,701,014	−42.46%	−30.67%	−25.99%
	Javanese	34,597,022	−18.72%	−13.77%	−11.03%
	Kalimantan	4,449,599	−71.25%	−58.20%	−53.32%
	Sulawesi	10,850,981	−84.35%	−72.55%	−72.55%
	Bali Nusa Tenggara	3,707,648	−56.24%	−41.49%	−33.55%
	Maluku Papua	360,010	83.27%	160.40%	160.40%
Corn	Sumatra	4,735,671	30.53%	38.55%	114.14%
	Javanese	9,752,351	−40.10%	−34.52%	−34.26%
	Kalimantan	374,614	63.71%	77.31%	92.23%
	Sulawesi	3,416,447	40.88%	52.18%	59.27%
	Bali Nusa Tenggara	1,412,102	87.45%	104.10%	100.87%
	Maluku Papua	80,439	381.57%	455.10%	455.10%
Cassava	Sumatra	11,812,746	−71.71%	−70.92%	−67.19%
	Javanese	11,685,613	−76.38%	−76.38%	−74.56%
	Kalimantan	399,488	−45.54%	−37.96%	−32.74%
	Sulawesi	1,001,269	−71.16%	−65.00%	−63.37%
	Bali Nusa Tenggara	1,196,001	−76.77%	−67.33%	−67.33%
	Maluku Papua	455,689	−96.43%	−96.31%	−96.31%
People's palm oil	Sumatra	7,497,395	108.54%	121.68%	84.69%
	Javanese	5176	23.34%	23.34%	−46.48%
	Kalimantan	1,170,624	315.15%	315.15%	226.74%
	Sulawesi	180,456	316.56%	483.13%	263.46%
	Bali Nusa Tenggara	-	-	-	-
	Maluku Papua	35,143	199.89%	212.90%	199.89%
Private and state palm oil	Sumatra	9,088,541	74.55%	102.73%	73.33%
	Javanese	31,315	140.55%	150.07%	−42.92%
	Kalimantan	7,320,509	108.65%	323.45%	240.28%
	Sulawesi	296,432	205.97%	254.98%	166.33%
	Bali Nusa Tenggara	-	-	-	-
	Maluku Papua	43,263	731.24%	731.24%	694.91%

Source: Analysis results, 2024. Notes: Blue color indicates positive growth compared to the 2010 baseline situation.

Secondly, it was found that various policy interventions exhibit varied effects across regions, indicating the efficacy of policy implementation. Returning to the previous illustration of rice commodities in the Java region, production decreased by 11.03% from the baseline situation in 2010 (ibid). This slight decline also occurred in Sumatra, which is also part of the Western Region of Indonesia. Conversely, this contrasts sharply with the situation in the Eastern Region of Indonesia, where the reduction in production is significantly more severe. Even in Sulawesi, it reached −72.55% (optimistic scenario) (ibid). The polarization of rice commodity development in Western Indonesia impacts the efficacy of policy execution in improving production performance. An exception is the Maluku-Papua region, where rice sector policy increased production by 2.6 times over the 2010

baseline (ibid). Furthermore, the difference in performance is evident in corn and cassava commodities, with Eastern Indonesia reaping greater benefits from policy interventions than Western Indonesia. This illustrates the growing significance of food diversification in the region, progressively diminishing the area's profound dependence on rice commodities that are not extensively cultivated.

Meanwhile, palm oil commodities exhibit a unique pattern, in contrast to rice fields and other agricultural commodities. Assuming that other commodities with favorable projections may elevate production to unprecedented levels (even if they do not attain the 2010 baseline), this commodity could facilitate production increases surpassing the 2010 baseline (ibid). Interventions in palm oil policy will exert a substantial economic influence, especially in Sumatra and Kalimantan.

The findings also show that while productivity and crop index initiatives might improve short-term performance, they must be followed by land-side interventions in the long run. This policy aims to enhance performance by allocating more substantial space to commodities like rice. Policy interventions like productivity and agricultural indices can boost output, but there are limits to the extent that it can be increased. In this instance, the government and regional governments must provide space exclusively for rice fields, agriculture (non-rice), and plantations.

4.2.2. Land Cover Dynamics with Policy Interventions

The proposition in this study is that heightened commodity production will induce agricultural land cover changes. Table 4 depicts rice fields and agricultural (non-rice) land cover; the simulation results demonstrate that this is less significant nationally. In contrast, it has a negligible impact in the optimistic scenario relative to the baseline scenario. The lack of an effect is not due to the intervention's ineffectiveness but because this analysis is limited to a few commodities, specifically rice, corn, and cassava, which constitute only a minor segment of Indonesia's commodity dynamics. Furthermore, a more significant change is observed in plantation land cover, wherein the optimistic scenario encourages a lower plantation land area than the baseline or moderate scenario, at 18%. This suggests a saturation point in the intervention outlined in the moderate scenario, indicating that, as the scenario target increases, the extensification of plantation land diminishes.

Table 4. Comparison of land cover percentages for the baseline, moderate, and optimistic scenarios in 2045.

Land Cover	Baseline 2010 (% of Total Area)	Scenario (% of Total Area)		
		Baseline 2045	Moderate 2045	Optimistic 2045
Primary Forest	13.47%	14.80%	14.79%	14.82%
Non-Primary Forest	28.10%	20.88%	20.87%	21.25%
Rice Field	6.22%	5.56%	5.55%	5.82%
Plantation	6.89%	20.96%	21.05%	17.60%
Agriculture (non-rice)	24.82%	21.15%	21.12%	22.71%
Settlement	1.89%	4.72%	4.71%	4.78%
Others	18.61%	11.94%	11.90%	13.01%

Source: Analysis results, 2024.

The following section investigates the island level to better understand spatial patterns based on their geographical characteristics. Starting with the situation in Sumatra, the land cover structure has changed significantly since 2010. Land cover will shift from agricultural land and primary forests to other categories by 2045. The plantation classification elevates the agricultural classification to the most common land classification in the region at the expense of primary forests. Even with this change, primary forests still surpass non-primary forests (Table 5). Nonetheless, this policy is significant when assessing policy

interventions, particularly for rice fields, which exhibit a 0.27% impact on the optimistic scenario relative to the 2045 baseline scenario (ibid). A notable alteration transpired in agricultural (non-rice) land, wherein policy interventions in the optimistic productivity scenario exhibited a 2.82% larger impact than the baseline scenario (ibid). Nevertheless, the proportion remained considerably lower than the baseline established in 2010. Then, unlike in agricultural land, in plantation land represented by palm oil commodities, the people, private sector, and state's productivity and replanting policies constrain the land structure in this region. This scenario is shaped by efforts to enhance palm oil production rather than oil palm cultivation.

The dynamics of Java involve land competition between cities and the utilization of rice fields, agriculture, and plantations, which are significantly shaped by the island's increasing urbanization. As a result, the proportion of residential land is projected to increase from 9.71% in 2010 to 19.66% in 2045, under an optimistic scenario (ibid). Furthermore, the dynamics of rice fields indicate a deterioration in the land's contribution to food security. However, governmental actions such as a rice field moratorium are adequate to support attempts to conserve rice fields rather than simply raising production and planting indexes. The rice field moratorium policy has implications for other land cover types, such as primary and non-primary forests, which are sacrificed to enable development in this region. The intervention barely has a 0.15% influence on agricultural (non-rice) land cover compared to the baseline situation (ibid). This condition is influenced by the variability of the region's agricultural food commodities, although this model depicts the dynamics of the two commodities.

The circumstances in Kalimantan do not substantially modify the land cover structure. Notwithstanding the optimistic scenario, non-primary forests predominate land utilization. The point of distinction is simply the enormous development of plantation land, which restructures the character of land in Kalimantan. In 2010, plantation land accounted for only 5.58% of total land; under the baseline scenario, it increases to 21.25% by 2045 (ibid). However, the difficulty in this region, as in Sumatra, is that the expansion of plantation land is mainly accomplished by acquiring other land qualities owned by small-scale proprietors. Anticipating this situation, the policy intends to establish a maximum limit for oil palm land so that production increases can be attributed to production intensification rather than land area expansion. Interventions in optimistic scenarios have also averted significant land cover shifts in non-primary forest areas and other classifications.

In 2010, Sulawesi's land cover pattern was predominantly characterized by non-primary forests and agriculture, unlike regions with large areas of plantation land. As stated in the preceding section, the simulation findings put pressure on the shift from non-primary to primary forests. Furthermore, while the land cover structure remains unchanged, the simulation revealed a considerable increase in the acreage of rice fields and plantations, demonstrating this area's ability to improve food security. The simulation also revealed that the target variation between scenarios does not significantly change practically all land categories. The only substantial variance is in the agricultural (non-rice) land category, where the optimistic scenario for 2045 diverges by 1.15% from the baseline (ibid).

The scenario in Bali and Nusa Tenggara demonstrates a dramatic shift in the land cover pattern, characterized by the predominance of agriculture and non-primary forests. This indicates that other land types and non-primary forests influence changes in agricultural and non-primary forests. Moreover, it was found that, in contrast to other islands where policy interventions regarding plantation and agricultural land are considerable, policies in the rice sector, particularly concerning the rice field moratorium, will significantly contribute to preserving the paddy area at 8.08% by 2045 (optimistic scenario) (ibid). This is linked to the land change dynamics in the region, which are directly connected to the tourism business, which appropriates several rice fields [79]. Consequently, the preservation of sustainable agricultural land is crucial in this context.

Finally, in the Maluku-Papua region, which is dominated by primary and non-primary forests, the situation is projected to remain stable until the conclusion of the simulated

period under various scenarios (ibid). Although the prior section found that policy interventions positively improved rice, maize, and oil palm production, they did not significantly add to land cover. This condition has implications for intensifying output rather than expanding the area in this region.

Table 5. Comparison of land cover percentage to total area on the main islands in Indonesia based on baseline, moderate, and optimistic scenario in 2045.

Island	Land Cover	Baseline 2010 (% of Total Area)	Scenario (% of Total Area)		
			Baseline 2045	Moderate 2045	Optimistic 2045
Sumatra	Primary Forest	9.32%	11.68%	11.68%	11.71%
	Non-Primary Forest	20.76%	10.33%	10.29%	10.43%
	Rice Field	4.73%	3.80%	3.80%	4.07%
	Plantation	12.47%	34.32%	34.60%	29.04%
	Agriculture (non-rice)	31.41%	22.07%	21.97%	24.89%
	Settlement	1.77%	4.47%	4.45%	4.56%
	Others	19.55%	13.32%	13.22%	15.30%
Java	Primary Forest	0.27%	0.62%	0.62%	0.62%
	Non-Primary Forest	24.02%	14.97%	14.97%	14.81%
	Rice Field	28.93%	23.36%	23.36%	24.15%
	Plantation	3.04%	3.92%	3.92%	3.13%
	Agriculture (non-rice)	30.84%	36.30%	36.30%	36.45%
	Settlement	9.71%	19.61%	19.61%	19.66%
	Others	3.19%	1.21%	1.21%	1.19%
Kalimantan	Primary Forest	18.41%	16.96%	16.96%	17.00%
	Non-Primary Forest	35.16%	32.41%	32.41%	33.35%
	Rice Field	1.47%	1.17%	1.17%	1.31%
	Plantation	5.58%	21.25%	21.25%	17.79%
	Agriculture (non-rice)	17.03%	13.82%	13.82%	15.03%
	Settlement	0.56%	0.92%	0.92%	0.98%
	Others	21.79%	13.47%	13.47%	14.55%
Sulawesi	Primary Forest	20.95%	27.92%	27.92%	27.94%
	Non-Primary Forest	29.38%	19.80%	19.80%	19.81%
	Rice Field	5.47%	9.47%	9.47%	9.44%
	Plantation	1.59%	5.54%	5.54%	4.35%
	Agriculture (non-rice)	28.32%	23.57%	23.57%	24.72%
	Settlement	0.69%	3.94%	3.94%	3.98%
	Others	11.15%	9.76%	9.76%	9.76%
Bali-Nusa Tenggara	Primary Forest	9.67%	11.75%	11.75%	11.72%
	Non-Primary Forest	27.93%	19.77%	19.77%	19.58%
	Rice Field	11.68%	7.08%	7.08%	8.08%
	Plantation	0.02%	0.18%	0.18%	0.18%
	Agriculture (non-rice)	18.25%	35.33%	35.33%	34.76%
	Settlement	1.27%	9.24%	9.24%	9.27%
	Others	31.19%	16.65%	16.65%	16.42%

Table 5. *Cont.*

Island	Land Cover	Baseline 2010 (% of Total Area)	Scenario (% of Total Area)		
			Baseline 2045	Moderate 2045	Optimistic 2045
Maluku-Papua	Primary Forest	53.55%	47.68%	47.68%	49.31%
	Non-Primary Forest	23.46%	30.43%	30.43%	29.08%
	Rice Field	0.06%	0.38%	0.38%	0.38%
	Plantation	0.21%	1.48%	1.48%	1.42%
	Agriculture (non-rice)	4.54%	5.04%	5.04%	5.00%
	Settlement	0.42%	0.64%	0.64%	0.63%
	Others	17.75%	14.36%	14.36%	14.18%

Source: analysis results, 2024.

5. Discussion: What Is the Future Direction of Agricultural Land Development?

Applying a system dynamics approach with region-based feedback demonstrates the intricate challenges Indonesia faces to achieve the ambitious target of the agricultural sector outlined in Indonesia Emas 2045. This initiative aims for Indonesia to transition from a food importer to a food sovereignty, coinciding with projections that the population will reach 324.05 million by 2045, an increase of 54.47 million from 2020 [15]. The complexity involving elements of land cover change positions the agricultural sector as the victim and actor of this process.

The agricultural sector's vulnerability is observed in food crop commodities, projected to rise until 2045. The Western Region of Indonesia, particularly Java, is the sole area capable of sustaining a secure status for food security on rice commodities. Nonetheless, massive development as the nucleus of Indonesia's economic expansion has rendered this region susceptible to the trend of diminishing agricultural productivity and land. This phenomenon enriches the findings of prior studies, including those by Firman [29], Verburg et al. [31], and Cahya et al. [45], through the concept of pseudo-diversification. Although the Government of Indonesia seeks to diversify food production through corn and cassava, this situation reflects a temporary illusion of increased agricultural land (non-rice) before it is repurposed for residential land. This means that land expansion is not directly related to food commodity production, exacerbating food vulnerability intensified by attempts to diversify commodities.

Conversely, the dismal state of the agricultural sector is not reflected in non-food commodities, which are the catalysts of the agricultural economy, particularly outside Java, where agricultural land is the perpetrator of land cover changes. Building upon previous findings regarding the substantial impact of state-private and community palm oil in this region (Section 4.1.1), the land cover change in Sumatra illustrates the competition for land use and the unequal distribution of capital power between large corporations and local communities with restricted land holdings. It corroborates the conclusions of Ichsan et al. [80] and Purnomo et al. [81], who mentioned that small-scale oil palm farmers encounter detrimental economic circumstances that force them to divest their land to alleviate the risks related to land tenure. Then, the findings in Kalimantan reveal a distinct pattern of transition starting from non-primary forest lands, predominantly characterized by oil palm plantations under private and state ownership. The transferred land does not explicitly have a conservation function but still has a role in protecting the surrounding area. Hence, this change contributes to ecosystem damage in the agricultural sector.

The Indonesian Government acknowledges the interconnected complexities of the agricultural sector and is actively seeking to address this issue. Nonetheless, these approaches possess deficiencies that further exacerbate this dynamic. For example, through the moratorium on Sustainable Food Agricultural Land, the Government aims to maintain food security by prohibiting the conversion of rice fields into built-up areas. However, this prohibition excludes agricultural land (non-rice fields) and rice fields not supplied by technical irrigation systems. Landowners use legal loopholes to make their land un-

productive, one of which is draining and disconnecting irrigation networks on rice fields, as documented by Ashari [82] and Sudrajat et al. [83]. Subsequently, once the rice field ceases to be productive, the landowner may sell the rice field to be repurposed as non-rice agricultural land. After the land is seen to be converted into a commodity, it will be easier to transform it into residential land. Then, considering the character of rice field ownership in Indonesia, which is dominated by small business actors with low rice field area [84,85] this process is an easy way for them to get the proceeds from the sale of land to survive during low rice commodity prices and structural poverty [86].

While not exclusive to the agricultural sector, the legalization of National Strategic Projects under Presidential Regulation Number 109 of 2020, which aims to promote growth and equitable development, also puts pressure on food security. This policy pays attention to the agricultural sector through the construction of 48 dams and the construction and rehabilitation of 9 irrigation networks. Still, more priority is given to encouraging economic growth by constructing 54 new toll roads, 13 ports, 8 airports, and 18 industrial estates, most of which are located on the island of Java. This study does not provide detailed information on the specific locations of land cover changes; however, the substantial rise in residential land amidst a marked decrease in rice fields, particularly in Java, reinforces this notion. Makbul et al. [87] noted a propensity among rice farmers to divest their agricultural land near the infrastructure development of the Trans Java toll road. This scenario again exemplifies the paradox between endeavors to enhance economic growth and compromise food security components.

Furthermore, the ambition of encouraging faster economic growth is also specifically implemented within the agricultural sector, albeit at the expense of conservation land. In 2020, the Government of Indonesia legalized the Job Creation Law to increase employment and investment by simplifying policies for business licenses and land acquisition processes. One of the things that is regulated is the ease of legalization of oil palm land in forest areas. The principle of ultimum remedium in the policy, which advocates for the remediation of oil palm land instead of enforcing criminal sanctions [88], threatens the existence of conservation forests, especially in Kalimantan and Papua. It also raises a big question about the equivalence of causality caused to the environment and small-scale farmers. These findings exacerbate the antagonistic role of the agricultural sector regarding the phenomenon of forest land grabbing [39,75] as a product of the imbalance of capital power.

The debate will ultimately encompass intensification and extensification strategies as evidenced in the policy interventions within the model. The extensification of agricultural practices on Java island is hindered by rising urbanization, which renders agricultural intensification an unavoidable option. In contrast to the situation outside Java, ample land is accessible to facilitate the expansion of the agricultural sector. However, this cannot be interpreted unilaterally, given the dynamics of land acquisition mainly originating from rice fields and agriculture (non-rice), which, as noted by Medrilzam et al. [89] and Bakri et al. [84], are predominantly controlled by small-scale farmers. Palm oil commodities encounter analogous challenges, compounded by environmental degradation. If this condition persists, extensification initiatives will adversely affect small-scale farmers, the majority of whom are not prosperous, and exacerbate environmental deterioration. Consequently, it is preferable to prioritize intensification over extensification. The concept of intensification is inherently linked to the utilization of environmentally detrimental fertilizers that exacerbate greenhouse gas emissions [90]; however, this issue can be alleviated by technological advancements [91] and the efficient management of non-renewable resources. Moreover, this has ramifications for the Government's initiatives to elucidate the concept of intensification, encompassing not just the planting index and productivity that reflect output components but also the processes or methods employed to attain that output.

Finally, this study acknowledges its limitations, which include a focus on only three core food commodities and one major plantation commodity in Indonesia. Although these commodities contribute to Indonesia's agricultural structure, the diversity of other commodities that reflect Indonesia's food and plantation diversification should not be overlooked. Refining just a few commodities has ramifications for simulation results, which cannot represent all of

the dynamics on agricultural land and plantations, necessitating more research into a more extensive range of commodities. Furthermore, this study's limitations stem from the translation of satellite image interpretations to actual field conditions, such as rice fields, where the image only interprets the land as producing rice but does not describe how productive the land is. Field investigations in different parts of the island of Java revealed that certain rice crops were unproductive. One of the causes is that the land is degrading and requires urgent conversion into another land cover. However, the area is still classified as rice fields, which suggests that, while rice fields are declining in this location, the actual rate of decrease may be far more extensive than what data can represent. In this sense, this sheds light on merging system dynamics approaches with field validation at specific locales.

6. Conclusions

This article examines the dynamics of agricultural land cover changes, emphasizing policy interventions to balance the dual role of this sector in achieving Indonesia Emas 2045. The analysis indicates that the food security issue is becoming increasingly intricate, as by 2045, only Java Island is projected to have a rice surplus, while also contending with significant land development pressures. The status of agricultural land as sacrificed land remains unchanged outside of Java. Despite signs of food diversity, this shift represents a transient transformation towards urbanized land that highlights the precarious aspects of food security in Indonesia. Conversely, in non-food agricultural commodities like palm oil, the role of palm oil cultivation is identified as a contributor to land cover alterations, resulting in the acquisition of both primary and non-primary forest areas in Kalimantan and Maluku-Papua. This indicates that based on the persistent dual role of the agricultural sector, the complexity of land usage in achieving Indonesia Emas 2045 will intensify, as it encompasses not only food security but also economic growth and environmental concerns.

The model's results regarding several development targets, based on both moderate and optimistic scenarios, demonstrate substantial results in promoting production; however, they are less effective in illustrating the extreme degree of land change at a national level, which seems to be influenced by the limitations of the commodities examined in detail. Nevertheless, this study illuminates collaborative interventions centered on productivity and land variables. Extensification is crucial in areas experiencing substantial development pressures, such as Indonesia's Western Region, due to limited land availability for transfer; thus, intensification should be emphasized to improve agricultural output. Similar priorities should be established in Eastern Indonesia because alterations jeopardize further conservation areas. Due to the inequity in land tenure fairness between major businesses and rural populations, land cover change must be addressed. Therefore, while land expansion is still possible, agricultural output must begin to rise to mitigate the depletion of other productive land.

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Appendix A. Land Reclassification from 23 to 7 Land Cover Classes

No.	Land Cover Class	Code	Model Class
1	Primary dryland forests	2001	1 Primary Forest
2	Primary mangrove forests	2004	1 Primary Forest
3	Primary swamp forest	2005	1 Primary Forest
4	Secondary dryland forests	2002	2 Non-Primary Forests
5	Secondary mangrove forests	20041	2 Non-Primary Forests
6	Secondary swamp forests	20051	2 Non-Primary Forests
7	Plantation forests	2006	2 Non-Primary Forests
8	Paddy	20093	3 Rice fields
9	Plantation	2010	4 Plantations
10	Dryland farming	20091	5 Agriculture
11	Mixed dryland farming	20092	5 Agriculture
12	Pond	20094	5 Agriculture
13	Settlements	2012	6 Settlements
14	Transmigration	20122	6 Settlements
15	Airports/ports	20121	6 Settlements
16	Shrub	2007	7 Others
17	Swamp bush	20071	7 Others
18	Savanna/grassland	3000	7 Others
19	Open ground	2014	7 Others
20	Mining	20141	7 Others
21	Water bodies	5001	7 Others
22	Swamp	20011	7 Others
23	Cloud	2500	7 Others

Appendix B. Policy Intervention Scenarios in Each Region in Indonesia

Policy	Baseline	Scenario 1—Moderate		Scenario 2—Optimistic	
		2030	2045	2030	2045
Sumatra					
Rice Productivity Target	4.86 tons/ha	5	5.1	5	5.1
Rice Planting Intensity Target	1.239/year	1.01	1.01	1.01	1.01
Cassava Productivity Target	26.68 tons/ha	29	30	29	30
Corn Productivity Target	5.62 tons/ha	5.8	6	5.8	6
People's Palm Oil Productivity	2.7 tons/ha/year	3	3.2	3	3.2
Private Palm Oil Productivity	3.4 tons/ha/year	3.7	4	3.7	4
Replanting of Smallholder Oil Palm Plantations	3 periods	3.5	3.5	3.5	3.5
Replanting Private Oil Palm Plantations	4 periods	4.5	4.5	4.5	4.5
Minimal Agricultural Land	12,000,000 ha			12,000,000	12,000,000
Minimum Rice Field Land (LP2B)	1,900,000 ha			1,900,000	1,900,000
Transfer of Plantation Increase Function	100%			70%	50%

Policy	Baseline	Scenario 1—Moderate		Scenario 2—Optimistic	
		2030	2045	2030	2045
Jawa					
Rice Productivity Target	5.75 tons/ha	5.85	6	5.85	6
Rice Planting Intensity Target	1.572/year	1.59	1.6	1.59	1.6
Cassava Productivity Target	22.41 tons/ha	26	27	26	27
Corn Productivity Target	5.57 tons/ha	5.8	6.1	5.8	6.1
People's Palm Oil Productivity	0.8 tons/ha/year	1	1	1	1
Private Palm Oil Productivity	1.4 tons/ha/year	1.6	1.8	1.6	1.8
Replanting of Smallholder Oil Palm Plantations	2 periods	2	2	2	2
Replanting Private Oil Palm Plantations	4 periods	4	4	4	4
Minimal Agricultural Land	4,500,000 ha			4,500,000	4,500,000
Minimum Rice Field Land (LP2B)	3,200,000 ha			3,500,000	3,500,000
Transfer of Plantation Increase Function	100%			70%	50%
Kalimantan					
Rice Productivity Target	3.4 tonnes/ha	3.9	4.25	3.9	4.25
Rice Planting Intensity Target	1.7/year	0.7	0.7	0.7	0.7
Cassava Productivity Target	14.62 tonnes/ha	29	32	29	32
Corn Productivity Target	4.61 tons/ha	4.8	5	4.8	5
People's Palm Oil Productivity	2.3 tons/ha/year	2.5	3	2.5	3
Private Palm Oil Productivity	3.7 tons/ha/year	4	4.5	4	4.5
Replanting of Smallholder Oil Palm Plantations	3 periods	3.5	3.5	3.5	3.5
Replanting Private Oil Palm Plantations	4 periods	4.5	4.5	4.5	4.5
Minimal Agricultural Land	7,800,000 ha			7,800,000	7,800,000
Minimum Rice Field Land (LP2B)	650,000 ha			650,000	650,000
Transfer of Plantation Increase Function	100%			70%	50%
Sulawesi					
Rice Productivity Target	4.71 tons/ha	5	5.5	5	5.5
Rice Planting Intensity Target	2.3/year	0.57	0.3	0.57	0.3
Cassava Productivity Target	22.16 tonnes/ha	24	27	24	27
Corn Productivity Target	4.9 tonnes/ha	5.1	5.3	5.1	5.3
People's Palm Oil Productivity	2.1 tons/ha/year	2.3	2.5	2.3	2.5
Private Palm Oil Productivity	2.7 tons/ha/year	2.9	3.1	2.9	3.1
Replanting of Smallholder Oil Palm Plantations	3 periods	3	3	3	3
Replanting Private Oil Palm Plantations	4 periods	4	4	4	4
Minimal Agricultural Land	4,600,000 ha			4,600,000	4,600,000
Minimum Rice Field Land (LP2B)	1,500,000 ha			1,500,000	1,500,000
Transfer of Plantation Increase Function	100%			70%	50%

Policy	Baseline	Scenario 1—Moderate		Scenario 2—Optimistic	
		2030	2045	2030	2045
Bali-Nusa Tenggara					
Rice Productivity Target	4.76 tons/ha	4.9	5	4.9	5
Rice Planting Intensity Target	0.94/year	0.8	0.85	0.8	0.85
Cassava Productivity Target	11.8 tons/ha	13	17	13	17
Corn Productivity Target	4.31 tonnes/ha	4.5	4.7	4.5	4.7
People's Palm Oil Productivity					
Private Palm Oil Productivity					
Replanting of Smallholder Oil Palm Plantations					
Replanting Private Oil Palm Plantations					
Minimal Agricultural Land	2,500,000 ha			2,500,000	2,500,000
Minimum Rice Field Land (LP2B)	580,000 ha			580,000	580,000
Transfer of Plantation Increase Function	100%			70%	50%
Maluku—Papua					
Rice Productivity Target	3.76 tons/ha	3.85	4	3.85	4
Rice Planting Intensity Target	0.9/year	1	1.2	1	1.2
Cassava Productivity Target	18.25 tons/ha	19	19.25	19	19.25
Corn Productivity Target	3.02 tonnes/ha	3.25	3.5	3.25	3.5
People's Palm Oil Productivity	1.3 tons/ha/year	1.5	1.75	1.5	1.75
Private Palm Oil Productivity	3.8 tons/ha/year	4	4.25	4	4.25
Replanting of Smallholder Oil Palm Plantations	2 periods	2.5	3	2.5	3
Replanting Private Oil Palm Plantations	3 periods	3.3	3.5	3.3	3.5
Minimum Primary Forest Land	25,000,000 ha			25,000,000	25,000,000

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