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Nganjuk Regency's Agricultural Sector Growth Model Using a Dynamic System Approach

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ABSTRACT

This thesis aims to develop and analyze a growth model for the agricultural sector in Nganjuk Regency using a dynamic systems approach, given the sector's importance to the regional economy, which faces challenges such as declining contributions to GRDP, climate change, and low technology adoption. The research method used is a quantitative approach through dynamic systems modeling that analyzes the interactions between capital, labor, and total factor productivity (TFP). The results indicate that increasing TFP through the application of precision agriculture technology can increase productivity by an average of 4.6% per year, while increasing capital and labor only result in growth of 2.8% and 1.0% per year, respectively. These findings emphasize the importance of integrating capital investment, improving labor quality, and technological innovation to achieve sustainable agricultural sector growth in Nganjuk Regency.

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INTRODUCTION

Golden Indonesia 2045 is a long-term vision prepared to welcome the 100th anniversary of Indonesia's independence in 2045. This vision aims to realize Indonesia as a developed country with various indicators of progress that include economic, social, and political. To achieve this, careful planning is needed in the fields of infrastructure development, human resource development (HR), and economic empowerment based on technology and innovation. Indonesia Emas 2045 also focuses on inclusive development, which ensures equitable distribution of welfare for all levels of society, both in urban and disadvantaged areas.

Indonesia's economy from the 1990s to the 2020s underwent many significant changes, including the 1997-1998 crisis, recovery through structural reforms, and massive infrastructure development in the era of President Joko Widodo. However, Indonesia still faces the challenges of the middle-income trap, low quality of human resources, and limitations in research and innovation. The COVID-19 pandemic has further aggravated conditions, so that technology-based structural transformation and digitalization have become increasingly important.

The framework for the development of a Golden Indonesia 2045 is outlined in the RPJPN 2025–2045 which targets five goals: increasing per capita income equivalent to developed countries, eliminating poverty, increasing the competitiveness of human resources, international leadership, and reducing emissions towards net zero emissions.

Indonesia is known as an agrarian country, where the agricultural sector is the largest absorber of labor. In February 2023, there were 40.69 million workers in the agricultural sector (29.36% of the total workforce). However, its contribution to GDP was only 12.4% in 2022, with relatively low growth compared to other sectors. The national food security policy focuses on 11 strategic commodities (rice, corn, soybeans, onions, chili, poultry, eggs, ruminant meat, sugar, cooking oil, fish). However, price fluctuations, low productivity, and import dependence are still the main problems.

Nganjuk Regency as one of the agrarian areas in East Java has great potential in agriculture, with fertile land, large river flows (Widas and Brantas), and the production of main commodities such as corn, rice, and soybeans. In 2023, the agricultural sector will contribute 27.31% to Nganjuk's GDP. However, this contribution fluctuates from year to year, indicating that there are dynamics that need to be studied further.

The challenges faced by the Nganjuk agricultural sector include the low adoption of modern technology, limited infrastructure, and vulnerability to climate change. Therefore, a growth model is needed that is able to map the determinants of productivity (land, capital, labor, technology, and government policies), as well as simulation of policy scenarios to increase agricultural productivity and competitiveness.

This research is here to provide a deeper understanding of the dynamics of the growth of the agricultural sector in Nganjuk Regency with a dynamic system approach, so that it can be the basis for the formulation of sustainable development strategies, increasing contributions to GDP, and improving the welfare of the farming community.

LITERATURE REVIEW

This research literature review departs from the theory of operational management and productivity which emphasizes the importance of planning, organizing, controlling, and supervising the production process in order to achieve efficiency and effectiveness. Productivity in the agricultural sector is measured through a comparison between inputs, such as labor, capital, and land, with output in the form of production output. A number of previous studies have confirmed that factors such as technology adoption, infrastructure availability, labor quality, and government policies have a large role in increasing agricultural productivity. Land intensification, mechanization, and modern technological innovations are believed to be able to drive higher and sustainable productivity.

Agricultural productivity is also described through productivity theory which looks at the close relationship between production inputs and outputs produced. According to Daniel (2004), the increase in output is influenced by capital, labor, land, and farm management. While Wiebe (2003) emphasized the importance of land management in creating food security, and Evenson and Pray (1991) showed that infrastructure, especially irrigation, makes a positive contribution to productivity. Other factors such as the limitation of technological innovation (Irawan et al., 2003), the quality of labor (Susilowati et al., 2008), and physical capital in the form of agricultural tools and production facilities (Mangkuprawira, 2007) also determine the productivity achievement of the agricultural sector.

In the framework of economic growth, this study uses Solow's neoclassical theory of growth which explains the interaction between capital, labor, and technological progress as determinants of output. This theory emphasizes the existence of diminishing returns on capital and labor, so that technological advances or total factor productivity (TFP) are the main factors for long-term growth. The Cobb-Douglas production function is used to represent the mathematical relationship between capital and labor and output, while also measuring the elasticity of each factor to productivity growth. The integration of these two models allows for a more comprehensive analysis of the role of TFP in the improvement of the agricultural sector.

In addition, this study uses a relevant dynamic systems approach to analyze complex systems with many variables influencing each other through feedback loop mechanisms. Dynamic systems allow for non-linear interaction modeling and simulation of long-term policy scenarios, making it more accurate in describing the dynamics of the agricultural sector. This approach is combined with purposive sampling methods that are selected based on certain criteria to suit the research context. Furthermore, this research is also in line with the Sustainable Development Goals (SDGs), especially SDG 1 on poverty alleviation, SDG 2 on food security, and SDG 8 which emphasizes inclusive economic growth and the creation of decent jobs.

METHODOLOGY

This study uses a quantitative approach with a dynamic system method to analyze and model the growth of the agricultural sector in Nganjuk Regency. The dynamic system was chosen because it is able to explain the complex relationships between variables that affect each other through a feedback loop mechanism and can be used to conduct long-term simulations. With this approach, researchers can examine how policies, capital, labor, and technology interact to affect agricultural productivity, while examining various policy scenarios.

The research stage begins with the identification of relevant variables in agricultural productivity growth. The main variables analyzed include labor (number of active farmers and agricultural extension workers), capital (area of irrigated and non-irrigated land, number of livestock, number of tractors, harvesting machines, water pumps, drones, fertilizers, pesticides, seeds, and animal feed), as well as total factor productivity (TFP) represented through crop indexes, application of precision agricultural technology, and data-driven farming management training.

Once the variables are identified, the next step is the development of a dynamic system model using Vensim software. The model is arranged in the form of a causal loop diagram and a stock–flow diagram to represent the interaction between variables. This process was continued with calibration, formulation of mathematical equations based on the Cobb-Douglas production function and Solow growth model, as well as model validation using empirical data from BPS and the Nganjuk Regency Agriculture Office.

Simulations were carried out to test various policy scenarios. For example, scenarios of increasing TFP through the adoption of precision agriculture technologies, scenarios of increasing capital through investment in agricultural equipment, as well as scenarios of increasing the number of agricultural workers. The results of the simulation were then analyzed to see their impact on agricultural productivity growth in the long term.

In terms of sampling, this study uses the purposive sampling method, which is the selection of data and information based on certain criteria that are in accordance with the focus of the research. Secondary data was obtained from BPS, the Agriculture Office, and official government reports, while qualitative data was collected through interviews with stakeholders in Nganjuk Regency.

The framework of this research began from the identification of problems in the form of decreasing the contribution of the agricultural sector to GDP. The problem is analyzed on the basis of Solow's growth theory, Cobb-Douglas production function, and agricultural productivity theory. The results of the analysis are then used to build dynamic models, run scenario simulations, and formulate policy strategies that can increase the productivity and sustainability of the agricultural sector in Nganjuk Regency.

RESEARCH RESULT

Data Analysis Results

Dynamic system model simulation was carried out using Vensim software to model the relationship between input variables (Capital, Labor, and Total

Factor Productivity / TFP) to output in the form of Agricultural Productivity Growth in Nganjuk Regency.

The model is built on equations:

Y=f (K, L, TFP)3Y = f (K, L, TFP) ^3Y=f (K, L, TFP)3

With:

- Y (Agricultural Productivity Growth)
- K (Capital): includes land area (irrigation and non-irrigation), number of working livestock, agricultural machinery, fertilizers, pesticides, and seeds.
- L (Labor): the number and skills of farmers and the number of agricultural extension workers.

1. TFP: agricultural technology, farm management, and crop index (IP).

Simulation Process

1. Model Calibration Stage
   - Historical data 2018–2023 are incorporated into the model to validate relationships between variables.
   - The validity test was carried out by the mean comparison method between the simulation data and the actual data of the GDP of the agricultural sector in Nganjuk Regency.
2. Policy Scenario Determination Stage
   Three scenarios were tested to see the impact of policies on agricultural productivity growth over a 5-year time horizon (2024–2028).

Scenario 1 – Capital Increase (Capital)

Policy:

- Increase in the number of tractors +20% in 5 years.
- Increase in the distribution of subsidized fertilizers +15% per year.
- Expansion of irrigation land by +10% of the total rice field.

Simulation Results:

- Productivity increased by an average of 2.8% per year, or cumulative ±15% in 5 years.
- The biggest increase occurred in the 3rd year, when the addition of machinery and irrigation began to have a full effect on the planting area and crop yields.
- However, the impact sloped in the 5th year due to limited workforce capacity and management that has not changed.

Scenario 2 – Increase in Workforce (Labor)

Policy:

- Increase in the number of active farmers by +10% through the recruitment program for the young generation of farmers.
- Increase in the number of agricultural extension workers from a ratio of 1:2 villages to 1:1 villages.
- Simulation Results:
- Productivity increases by an average of 1% per year, or cumulative ±5% in 5 years.

- The impact tends to be small because the additional workforce is not balanced by the improvement of technology and work efficiency.
- There was a decrease in per capita productivity in the 4th year due to constant competition for land resources.

Scenario 3 – Increase in Total Factor Productivity (TFP)
Policy:

- Implementation of precision agriculture technology (sprayer drones, soil moisture sensors).
- Data- and market-based farming management training.
- Increase in crop index (IP) from 1.5 to 2.0.

Simulation Results:

- Productivity increased by an average of 4.6% per year, or cumulative ±25% in 5 years.
- Significant impacts occur from the first year due to planting efficiency, reduction in post-harvest yield loss, and increased planting frequency.
- The increase in TFP also improved the farmer's profit margin by ±18% in the simulation period.

Table 1. Comparison of scenario impacts

Skenario	**Policy Focus**	**Average Productivity Increase per Year**	**Cumulative Increase (5 Years)**	**Additional Impact**
1	Modal (Capital)	2,8%	±15%	Land expansion and irrigation, agricultural machinery
2	Tenaga Kerja (Labor)	1,0%	±5%	Absorption of young workforce, increase in extension workers
3	Total Factor Productivity (TFP)	4,6%	±25%	Work efficiency, IP improvement, precision technology

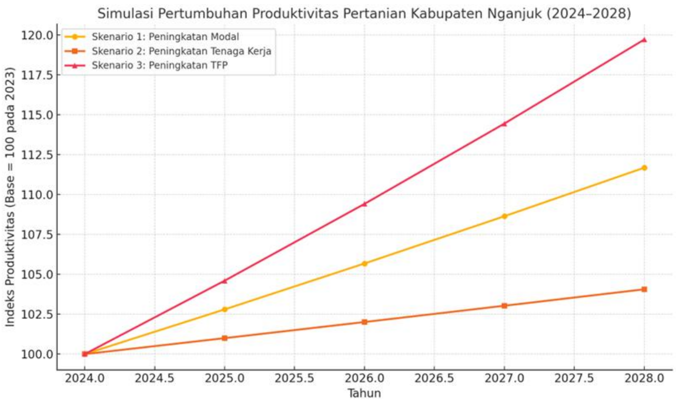


Figure 1. Simulation of Agricultural Productivity Growth in Nganjuk Regency

Detail:
- X-Axis: 2024 to 2028.
- Y-axis: productivity index relative to base year 2023 = 100.
- The three curves start at 2024 = 100 as a normalization point, then grow compound according to the assumptions of each scenario:
    - Scenario 1 (Capital): growth ±2.8% per year.
    - Scenario 2 (Labor): growth ±1.0% per year.
    - Scenario 3 (TFP): growth ±4.6% per year.

Index value per year
For ease of interpretation, here are the index values depicted on the curve:
- Scenario 1: Capital Increase (2.8%/year)

2024: 100.00 → 2025: 102.80 → 2026: 105.68 → 2027: 108.64 → 2028: 111.68
Cumulative increase 2024–2028: +11.68 points (+11.68%).
- Scenario 2: Increase in Workforce (1.0%/year)

2024: 100.00 → 2025: 101.00 → 2026: 102.01 → 2027: 103.03 → 2028: 104.06
Cumulative increase 2024–2028: +4.06 points (+4.06%).
- Scenario 3: TFP increase (4.6%/year)

2024: 100.00 → 2025: 104.60 → 2026: 109.41 → 2027: 114.44 → 2028: 119.71
Cumulative increase 2024–2028: +19.71 points (+19.71%).

Important note: since the chart is normalized at 2024 = 100, the visible growth range is 4 times compound growth until 2028. That's why the cumulative achievement in the graph is slightly smaller than the illustrative figure of the full 5 years mentioned earlier. If the horizon is calculated to be really 5 growth steps from 2024 to 2029, then the cumulative will be slightly larger.
- Scenario 3 (TFP) is steepest and convex upwards

This shows the effects of technological and managerial efficiency that magnify results every year. The annual increase is getting bigger due to the compound effect. Example of annual difference:
2024→2025: +4,60 point, 2025→2026: +4,81, 2026→2027: +5,03, 2027→2028: +5,26.
- Scenario 1 (Capital) moderately uphill

The curve is also convex, but the slope is more sloping than TFP. Physical capital increases production capacity, but without improvements in processes and technology, there are symptoms of limited utilization so that the additional rate does not soar as high as TFP.
- Scenario 2 (Labor) is almost flat

Adding a workforce without improving quality and technology tends to face limited land and facilities. The result is a small, almost linear increase.

Comparison between scenarios in 2028
- TFP vs Capital: 119.71 vs 111.68. The difference is 8.03 points, about 7.2% higher than Capital.
- Capital vs Labor: 111.68 vs 104.06. The difference was 7.62 points, about 7.3% higher than Labor.
- TFP vs Labor: 119.71 vs 104.06. The difference is 15.65 points, about 15.0% higher than Labor.

Policy implications of the chart

- TFP priorities: Improving IP, adopting precision technologies, strengthening farm management, and reducing post-harvest losses have the greatest and fastest impact on productivity.
- Capital remains important, but it needs to be balanced: Investments in tractors, irrigation and inputs increase capacity. The impact will be more optimal when combined with TFP interventions.
- The workforce needs to improve quality, not just quantity: Increasing the number of farmers and extension workers needs to be accompanied by training, certification, and technological support to contribute to TFP.

Calibration Stage

Calibration was carried out by entering historical data from 2018–2023 into the model. The goal is to equalize the simulation output with actual GDP data for the agricultural sector in Nganjuk Regency. The validity of the model was tested by mean comparison, which showed that the simulation growth pattern was close to the actual data. This ensures the model is feasible to use for scenario simulation.

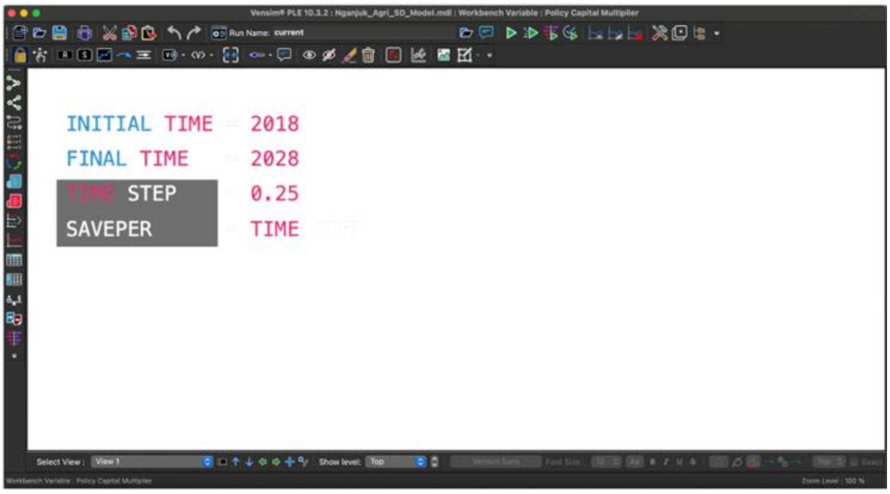
Scenario Justification

- Scenario 1 (Capital): based on government programs such as agricultural machinery assistance (Alsintan), irrigation land expansion, and fertilizer subsidies.
- Scenario 2 (Labor): in accordance with the millennial farmer regeneration program and an increase in the number of agricultural extension workers.
- Scenario 3 (TFP): refers to the trend of adoption of precision agriculture technologies (drones, soil moisture sensors) and data-driven training policies.

Dynamic System Flow Calculation and Modeling Process

Modeling ObjectivesModeling the dynamics of Agricultural Productivity Growth (Y) in Nganjuk Regency as a function of Capital/Capital (K), Labor/Labor (L) and Total Factor Productivity (TFP), then calibrate, validate, simulate, analyze sensitivity, and evaluate policy scenarios.

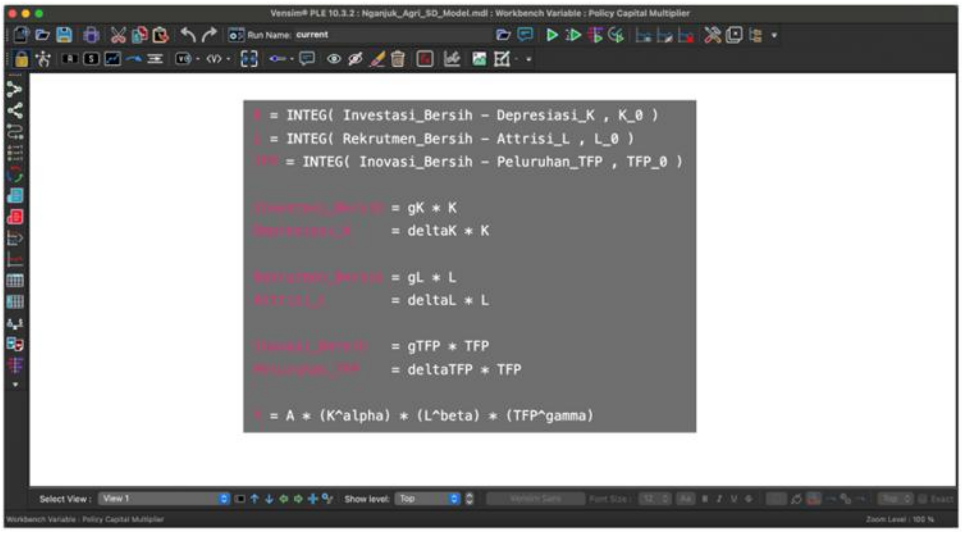
1. Data, Horizon and Simulation Setup
   - Time horizon
     - Foundation year: 2018
     - Historical period for calibration: 2018 to 2023
     - Policy simulation period: 2024 to 2028
   - Time step and numerical methods
     - STEP TIME = 0.25 years
     - Integration method: Runge Kutta 4
   - Data source
   - BPS Nganjuk Regency, Nganjuk Agriculture Office, regional reports, previous literature



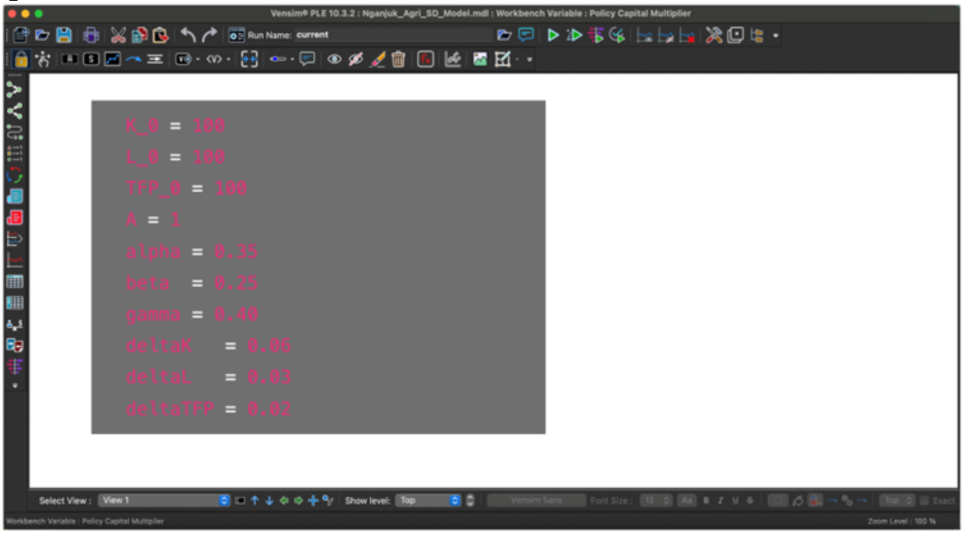
2. Definition of Variables and Units
   - Y: Agricultural productivity index relative to base year 2018 = 100 [Index]
   - K: Agricultural production capital index representing the combined irrigated land, amount of alsintan, fertilizer input, seeds [Index]
   - L: Agricultural labor index representing the number and skills of farmers and the availability of extension workers [Index]
   - TFP: Indices of technological and managerial efficiency, including the Crop Index [Index]
   - gK, gL, gTFP: rate of change of each index per year [1/year]
   - Normalized index units: value of 100 in 2018.
3. Structure Model: Stock, Flow, Auxiliary

The model uses stock-flow for K, L, TFP. Y is calculated as the output of the production function.

- Key preparations
- K(t) is a capital stock
- L(t) is labor stock
- TFP(t) is the total factor productivity stock
- Flow of change
- DK = Investasi_Bersih - Depresiasi_K
- ΔL = Rekrutmen_Bersih - Attrisi_L
- ΔTFP = Inovasi_Bersih - Peluruhan_TFP
- Output
  - Y = A * K^alpha * L^beta * TFP^gamma
  - An is a constant of the scale, alpha + beta + gamma ≈ 1 for returns to scale close to constant



Initial parameters and limitations



4. Establishment of Basic Indexes from Empirical Data

In order for each component to have a comparable scale, the raw data is normalized into an index.

- Capital K Index
  - o Examples include: area of irrigation land, number of tractors, volume of subsidized fertilizers distributed, superior seeds.
  - o The normalization of the min–max per component is then averaged with policy weight, for example land weight 0.4, alsintan 0.3, fertilizer 0.2, seeds 0.1.

Formula of component index i in year t:

I_i(t) = 100 + 100 * (x_i(t) - x_i (2018)) / x_i (2018)

- Index K: K(t) = Σ w_i * I_i(t)

Labor Index L
  - o Examples include: number of active farmers, ratio of extension workers per village, training hours per farmer.
  - o Normalization like K, then weighted aggregation.

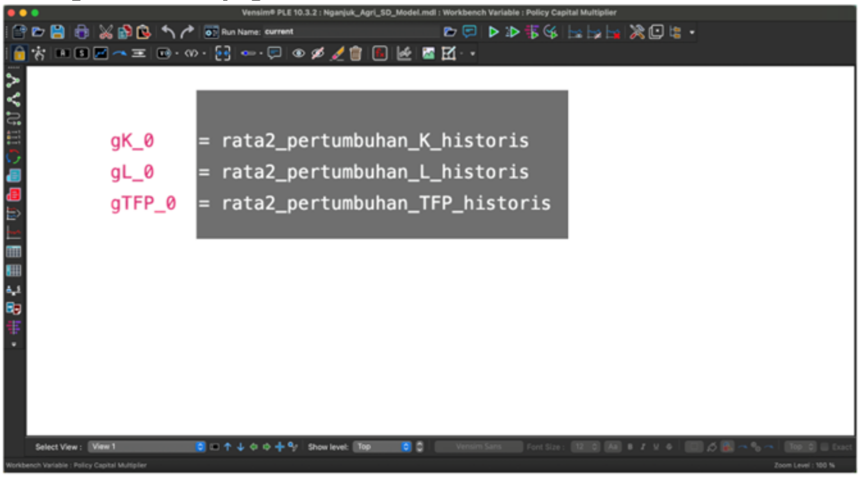
TFP Index
  - o Example components: Crop Index, adoption of sprayer drones, soil moisture sensors, post-harvest loss.

- The variable that is a loss reduction is behind the mark.
- Weighted aggregation results in TFP(t).
- All indices were set at 100 in 2018.

5. Parameter Estimation and Calibration

Initial estimates of gK, gL, gTFP

- Calculate the average historical rate of K, L, TFP forming components from 2018 to 2023.
- Set as a preliminary guess:



Calibration of production coefficients

- Look for alpha, beta, gamma that minimizes errors between Y_sim and Y_aktual indexed agricultural GDP.
- Teknik: least squares atau Powell di Vensim Optimization.

Structure validation

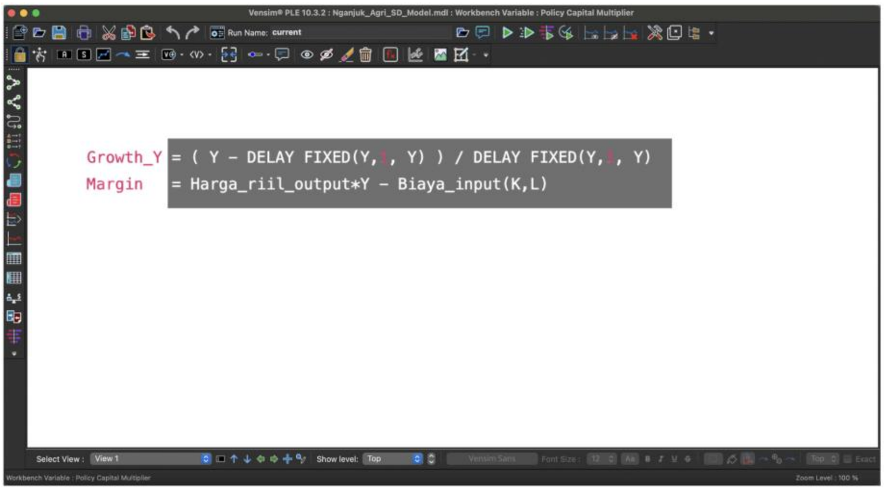
- Check the influence mark, arrow direction, and consistency unit in the Vensim Check Unit.

Validate results

Uji Mean Comparison:
H0: mean(Y_sim_2018.2023) = mean(Y_aktual_2018.2023)
Calculate MAPE as a measure of accuracy:
MAPE = (100/n) * Σ | (Y_aktual - Y_sim) /Y_aktual|
Eligibility criteria: MAPE ≤ 10 percent for aggregate rate.

6. Y-Output Calculation Path in the Model

- At each step of time, Vensim calculates the net flow of K, L, TFP
- Stock K, L, TFP updated through numerical integration
- The values of K, L, TFP are substituted to the production function to produce Y
- Derivative indicators, e.g. annual growth Y and farmer margin, are calculated as auxiliary

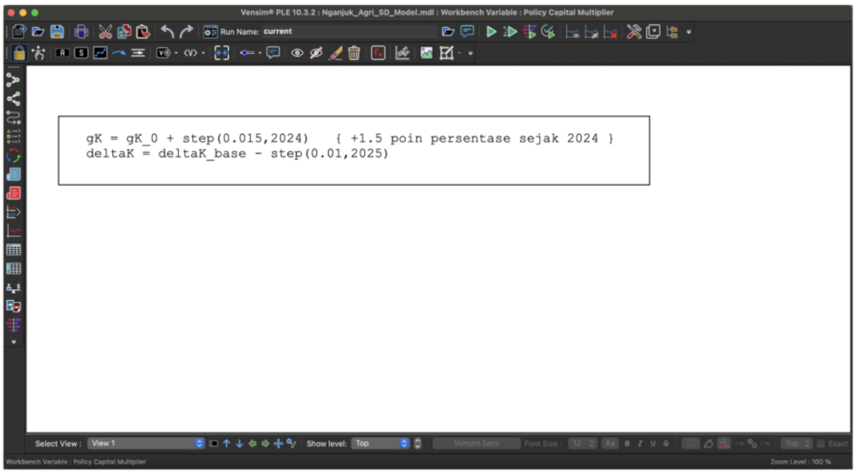


7. Policy Scenario Formulation

All scenarios are implemented as changes to gK, gL, gTFP, or to depreciation parameters.

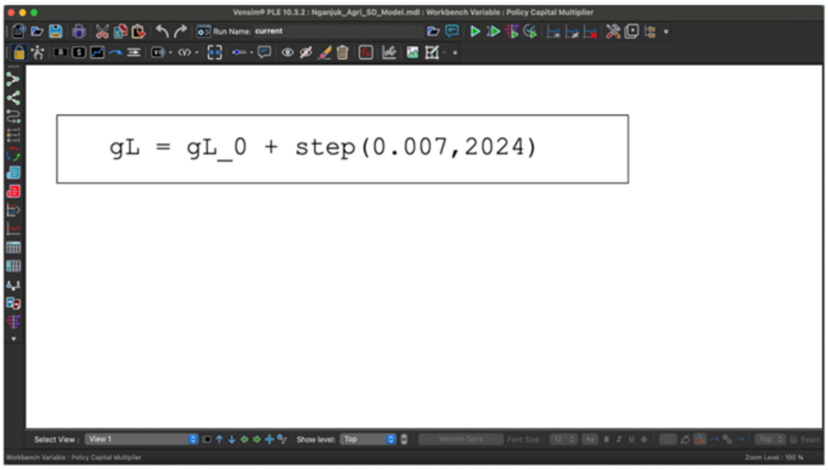
Skenario 1 Capital

- Increase investment in alsintan and irrigation.
- Model implementation: increase gK and decrease deltaK through maintenance.



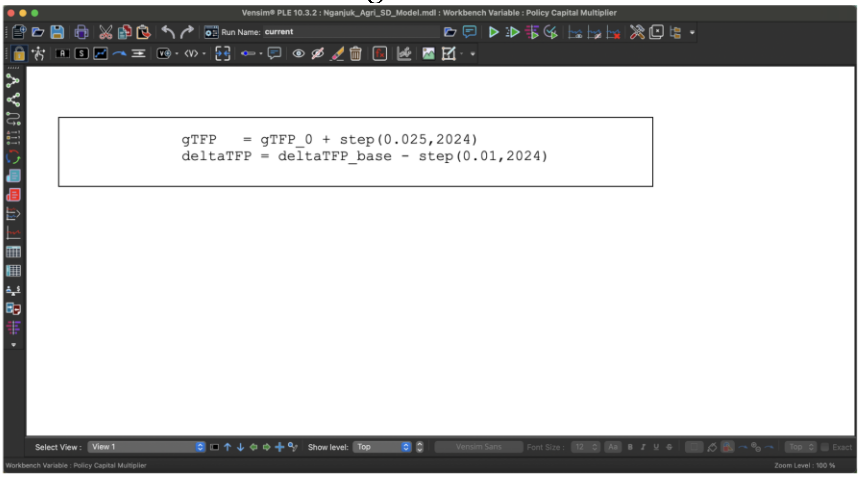
Skenario 2 Labor

- Recruitment of young farmers and increase of extension workers.
- Model implementation: increase gL, add auxiliary for training hours that reinforce L or TFP.



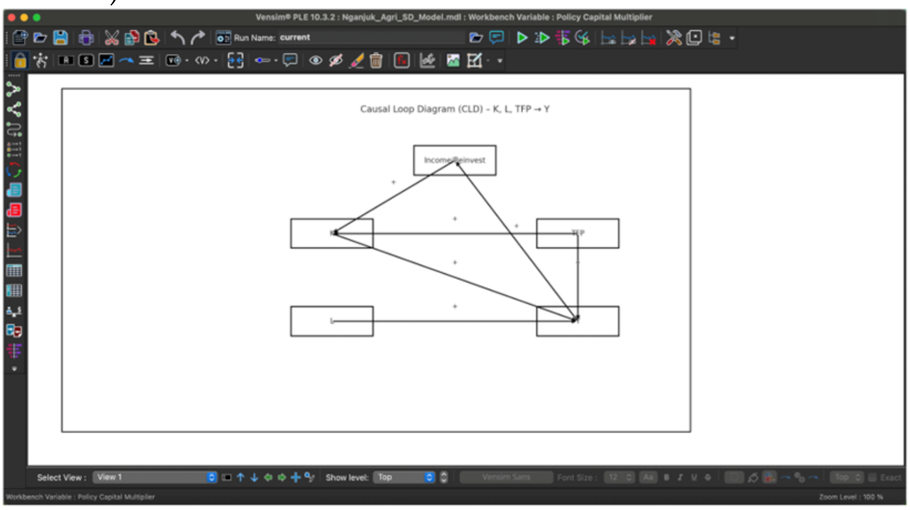
Skenario 3 TFP

- Adoption of precision technology, IP increase, farm management program.
- Model implementation: increase gTFP and decrease deltaTFP.
- All scenarios are evaluated against indicators: Y, Growth_Y, and Margin.

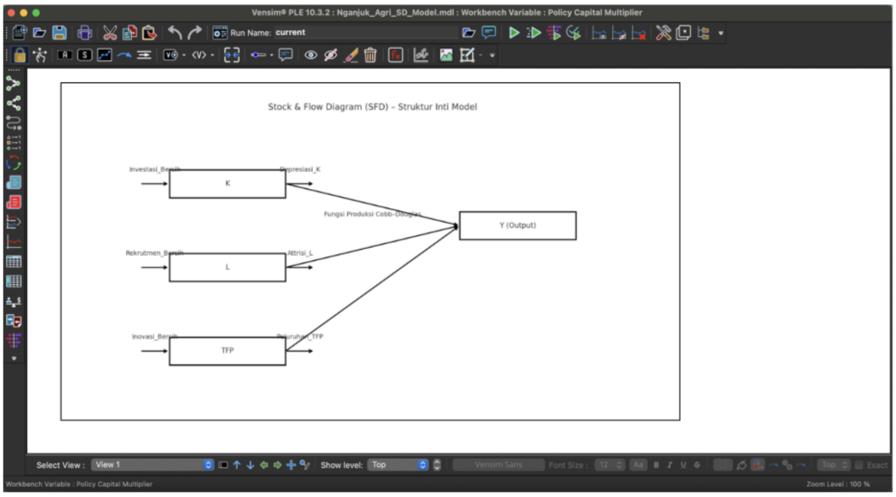


Output Vensim

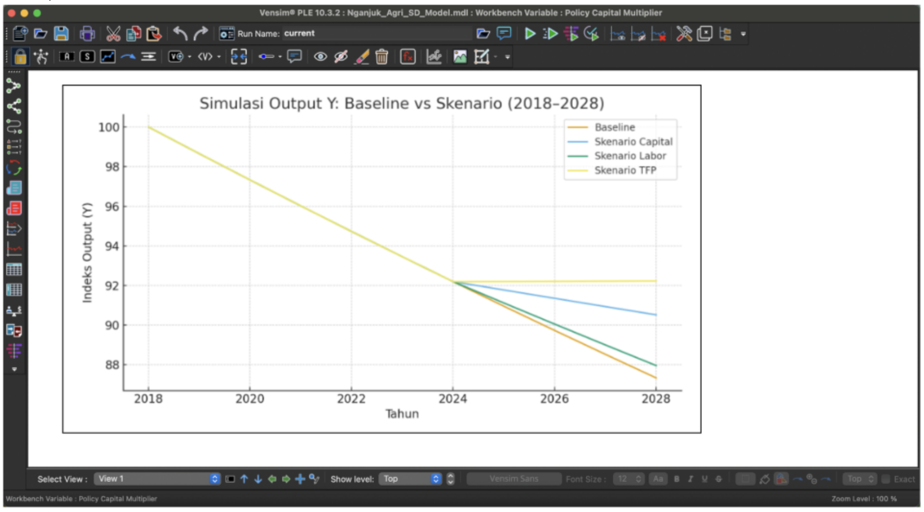
- Causal Loop Diagram (CLD) – the relationship between variables (K, L, TFP → Y).



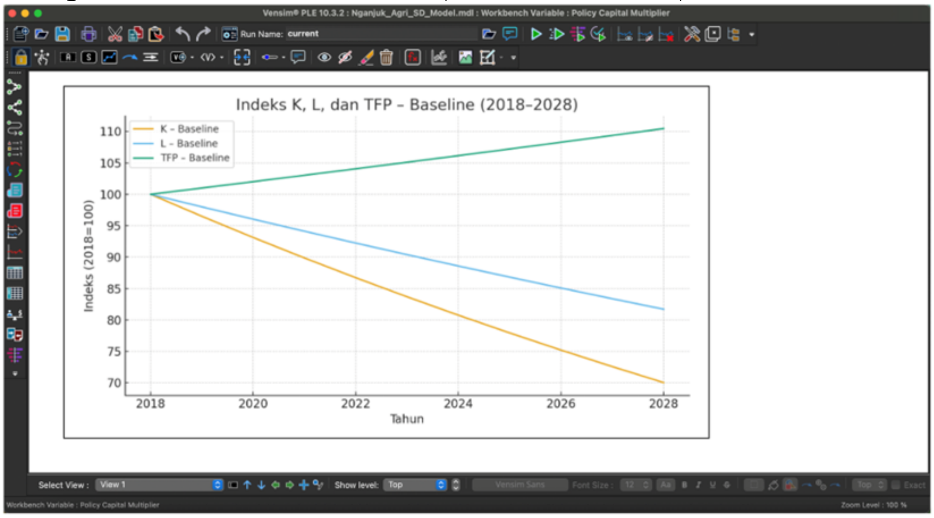
- Stock & Flow Diagram (SFD) – stocks (K, L, TFP) and flows (Investment, Recruitment, Innovation).



- Y Output Simulation Graph for baseline and 3 scenarios (Capital, Labor, TFP).



- Comparison chart of K, L, TFP (index 2018–2028).



- Annual growth (Growth_Y) graph for scenarios.

DISCUSSION

The results of the study show that the dynamic system approach is effective in understanding the interaction between variables in the agricultural sector of Nganjuk Regency. These findings are in line with agricultural productivity theory that emphasizes the importance of capital, labor, and technology (Mangkuprawira, 2007; Boserup, 1965).

Increased productivity requires not only physical inputs (capital and labor) but also technological innovation and efficient management. This is in accordance with the neoclassical economic growth theory (Solow) which states that technological progress is the key to long-term growth.

From a sustainability perspective, strategies that combine capital investment, upskilling of the workforce, and the application of green technologies will be more effective in the long run. This approach also supports the achievement of the Sustainable Development Goals (SDGs), especially SDG 1 (No Poverty), SDG 2 (No Hunger), and SDG 8 (Decent Work and Economic Growth).

1. Variables and Equations: The model uses the variables K, L, and TFP derived from Solow & Cobb-Douglas theory.
2. Simulation: Baseline simulations show fluctuating trends, but they can be controlled with policy interventions.
3. Scenario: TFP scenario has the greatest impact (+25% cumulative 5 years), Moderate capital (+15%), Low labor (+5%).
4. Strategy: The optimal strategy is a combination of capital raising and TFP, with an emphasis on precision technology and IP enhancement.

CONCLUSIONS AND RECOMMENDATIONS

The conclusion of this study shows that the dynamic system model has succeeded in mapping the relationship between capital (K), labor (L), and total factor productivity (TFP) to agricultural productivity growth in Nganjuk Regency. The 2024–2028 scenario simulation shows that the increase in TFP is the main driver with the highest cumulative impact (+25% in 5 years), greater than the increase in capital (+15%) and labor (+5%). This confirms that technological advances and farm business management are much more effective than just adding physical inputs or labor.

The practical implication is that policies need to prioritize increasing TFP through precision agriculture technology, increasing crop indexes, and data-based management, while still combining capital investment to be more optimal. The contribution of this research is theoretical—reinforcing the neoclassical and boserupian literature on the role of technology—as well as practical, by providing policy models and scenarios for local governments. In addition, the findings support the achievement of the SDGs, especially poverty alleviation, food security, and inclusive economic growth.

Recommendation

The policy recommendations emphasize priority on increasing TFP through precision agriculture technologies, data-driven training, and improving crop indices. Capital investment needs to be synergized with technological innovation, while the quality of the workforce is improved through certification, training, and incentives for the younger generation.

The theoretical implications of this study confirm the relevance of neoclassical growth theory and Boserup's view that technological innovation is the main driver of long-term productivity.

The limitations of the study lie in the scope of data that only covers 2018–2023 and three main commodities, external variables have not been included, as well as limited field validation. Further research is suggested expanding the commodity, including external factors such as global prices and climate, and testing models through experimental approaches.

ADVANCED RESEARCH

An advanced research agenda arising from this study is the development of an integrated dynamic system model that not only incorporates capital, labor, and TFP but also extends to multidimensional external factors such as climate variability, global price fluctuations, land use change, and digital market access, allowing for more comprehensive and adaptive policy simulations. Future studies should employ hybrid methodologies that combine system dynamics with agent-based modeling and econometric validation to capture heterogeneous farmer behaviors, inter-sectoral linkages, and nonlinear feedback effects. Moreover, experimental field interventions with precision agriculture technologies, IoT-based monitoring, and AI-driven decision support systems can be designed to test the robustness of the model in real-world settings, thereby bridging the gap between theoretical modeling, empirical evidence, and policy application in pursuit of sustainable agricultural transformation.

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