A Strategy to Realize Soybean Self-Sufficiency: A System Dynamics Approach (A Study in Central Java Province, Indonesia)

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Abstract

Food self-sufficiency and increased welfare of farmers are targets that must be realized to create food security. In increasing food security, soybean is one of food commodity that has strategic value as a source of protein and functional food. Sources of growth to increase production of soybean are increasing the harvest area and increasing productivity. Increasing productivity can be done by reducing yield loss, improvement of technology and increasing seed quality. The aim of this study is to establish a strategy for the improving of self-sufficiency and increasing farmer's welfare with a system dynamics model in supply chain perspective. The method approach refers to the Supply Chain Management model that started with the identification of relationships between entities involved in the form of causal loop diagrams. The model is depicted in accordance with real system behavior. Model simulation is run with Powersim10 software. Based on simulation results by increasing crop area and productivity, self-sufficiency of soybean can be achieved for the next 14 years on demand condition reach 3,882,718.56 quintals (1 quintal is equal to 100 kilograms) and production 6,061,936.83 quintals with productivity 41.97 quintals per hectares (1 hectares is equal to 10,000 square meters) and 114,444.11 hectares harvested area. At the end of the simulation, per capita income of farmers was IDR 3,068,359.41 and ROI was reached at 1.27.

Keywords
System dynamics, Simulation, Self-sufficiency, Supply chain, Policy

1. Introduction

One of the problems faced by The Government is that agri-food is very important for human being and very complicated to manage the problems (Hisjam and Sutopo, 2017). Self-sufficiency is typically measured as the ratio between total food consumed compared with domestic production (Hubbard, 2013). After the food crisis in 2007-2008, food self-sufficiency becomes the agenda in a number of countries. Some countries sought to buffer their own food to avoid volatility in world food markets (Clapp, 2017). The imbalance between increased population growth and a decrease in food products will result in an increase in food demand (Saputri et al., 2019). Declining of food security can be caused by a decline in food self-sufficiency levels, and the gap between farm and non-farm income can trigger social unrest (Anderson and Strutt, 2014).

Soybeans are one of the strategic food commodities to get more attention from the government in national food policy (Hisjam et al., Tastra et al., 2020, 2012, Kristanti and Guritno 2015, Hasan et al. 2015). Currently the availability of soybeans is still highly dependent on suplly form imports, so that supply and price fluctuations in the international market will have a direct effect on domestic fluctuations (The Ministry of Agriculture, 2015, Nugraha et.al, 2020).

On the national scale, Central Java has the second largest soybean crop in Indonesia after East Java. Until now, soybean production in Central Java has not been sufficient for the people's demand with a percentage of shortage

65% (Department of Agriculture and Plantation Central Java Province, 2017). Dynamics model using simulation studies can also be applied using the sustainability consideration of the supporting of natural resources, as is studied in the furniture industry (Kurniawan et al. 2011, Sutopo 2012). The aim of this study is to formulate alternative policies that can be proposed to the government in an effort to increase soybean production to achieve self-sufficiency and increase farmer's income so that the farmer's welfare in Central Java can be increased.

2. Literature Review

Supply chain management is a network of facilities that produce materials, convert them into semi-finished products and then into finished products, and deliver products to consumers through distribution systems. This includes procurement, manufacturing and distribution (Lee and Billington, 1995).The main goal of supply chain management is to optimize the performance of a link to add as much value to the lowest possible cost. In the configurations of supply chain, factories involve all functions in the acceptance and fulfilment of consumer demand. These functions are the development of new products, marketing, operations, distribution, finance, and customer service (Chopra and Meindl, 2007).

A system is the unity of elements connected through a particular mechanism and bound in a relationship of interdependence. A dynamic model can be seen in terms of productivity factors and sales value. Factors influencing the formation of dynamic models include production, investment value, and resource allocation, either human (farmers) or landowners (Femenia and Gobin, 2011). A simulation is an impersonation of the operation of a process or system in the real world over time (Banks et al., 2005). Simulation involves the generation of an artificial history of a system, and the observation of such artificial history to draw conclusions about the operating characteristics of the real system

There have been several studies related to the achievement of food self-sufficiency by the system dynamics method. Tastra et al. (2012) did research on soybean self-sufficiency through the implementation of synergistic policies. Hasan et al. (2015) has conducted research regarding analysis of soybean production and demand to develop strategic policy of food self-sufficiency. Related study done by Kristanti and Guritno (2016) is showing soybean commodity inventory system model by using simulation method. Research has also been done by Firdaus regarding Self-sufficiency Outlook of Indonesia Soybean on the Era of Trade Liberalization (Firdaus, 2015). Another research by Oktyajati et al. which related to soybean self-sufficiency, is intended to simulate variables that can increase soybean production (Oktyajati et al., 2018, Hisjam et.al, 2020).

3. Methods

The One of the method that can be implemented to improve the production of soybean in Indonesia is by implementing system dynamics approach. The method of system dynamics is initiated by Jay W. Forrester in order to study the dynamic behavior of a system which will be applied in some period (Forrester and Senge, 1980). It is also used to simulate the complex system that has many structures (entities) and interrelated connections among them. Forrester used the system dynamic method to study the behavior of population growth. Nowadays, the system dynamics method has been deployed widespread in areas such as energy and maintenance (Jiao and Han 2014, Liu and Zhaodong 2015).The steps of this research are understanding the system, identify the problem and identify the variable with interviews and study literature. Then model construction and simulation, the steps of model construction are to design the model in the causal loop diagram and then formulate the relationship between the entities into the mathematical model. The next stage describes the stock flow diagram in a computer program using the Powersim Studio Software. Next step are do model verification and validation then analyze the result. Figure1 shows the flow chart of research methods.

4. Data Collection

There are many steps to design simulation model. The first step is creating causal loop diagrams. The second step is to build a mathematical model to formulate a relationship between one parameter to each other. The third step is creating stock flow diagrams using Powersim 10 software. The design of the soybean supply chain model in Central Java is shown in Figure 2. The next step, building a mathematical model to formulate the relationship between the entities.

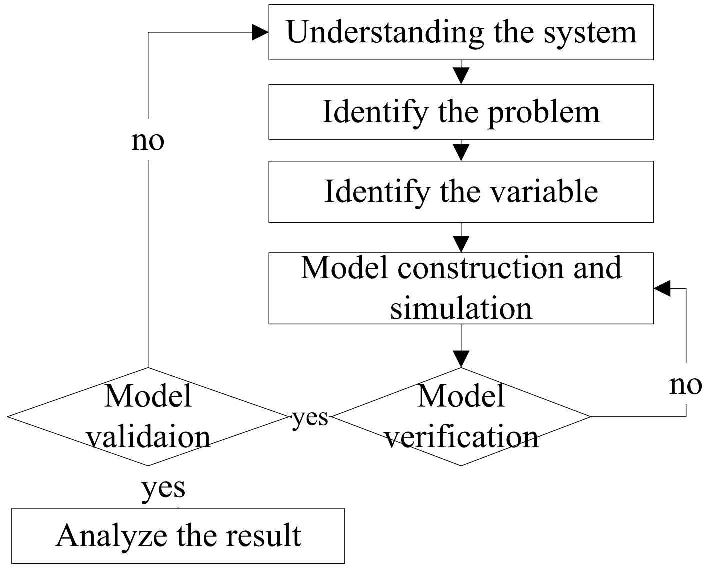

Figure 1: Research Method

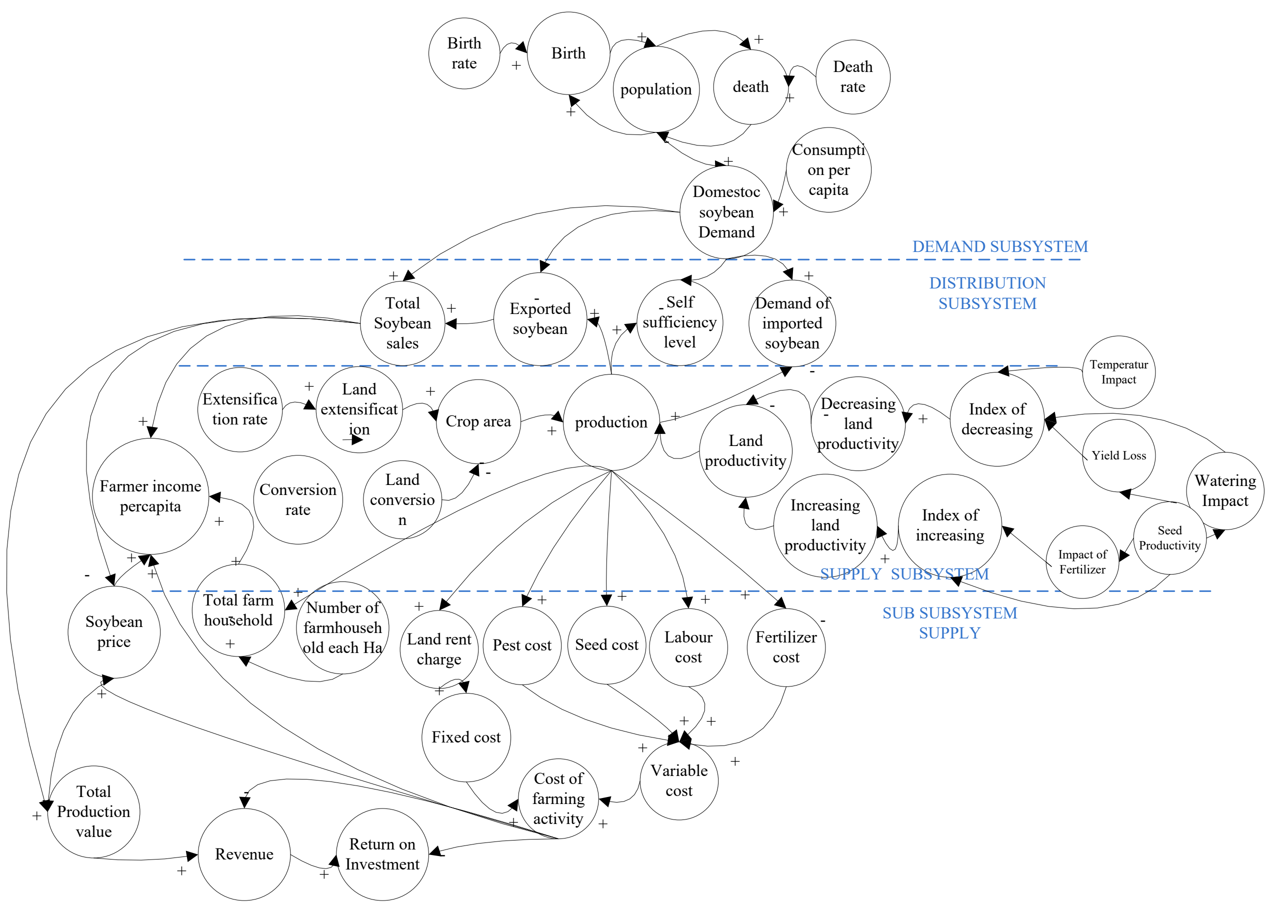

Figure 2: Causal Loop Diagram of Soybean Supply Chain in Central Java Province, Indonesia.

Equations (1) to (4) are mathematical formulation for demand subsystem.

$$D_t = P_t \times K \quad (1)$$

$$P_t = P_{t-1} + \frac{dL}{dt} - \frac{dM}{dt} \quad (2)$$

$$\frac{dL}{dt} = RL \times P_t \quad (3)$$

$$\frac{dM}{dt} = RM \times P_t \quad (4)$$

Equations (5) to (14) are mathematical formulations for supply subsystem

$$Pr_t = Lu_t \times Pv_t \quad (5)$$

$$Pv_t = Pv_{t-1} + \frac{dIPv}{dt} - \frac{dDPv}{dt} \quad (6)$$

$$\frac{dIPv}{dt} = IIPv_t \times Pv_t \quad (7)$$

$$IIPv_t = IP_t \times PB_t \quad (8)$$

$$\frac{dDPv}{dt} = IDPv_t \times Pv_t \quad (9)$$

$$IDPv_t = ITm_t + IW_t + IS_t \quad (10)$$

$$IS_t = PB_t \times LS \quad (11)$$

$$Lu_t = Lu_{t-1} + \frac{dEL}{dt} - \frac{dKL}{dt} \quad (12)$$

$$\frac{dEL}{dt} = RE_t \times Lu_t \quad (13)$$

$$\frac{dKL}{dt} = RK_t \times Lu_t \quad (14)$$

Equations (15) to (20) are mathematical formulations for distribution subsystem.

$$Sw_t = Pr_t \div D_t \quad (15)$$

$$DI_t = D_t - Pr_t \quad (16)$$

$$J_t = Pr_t \quad (17)$$

$$NTPr_t = HP_t \times J_t \quad (18)$$

$$Rv_t = NTPr_t - C_t \quad (19)$$

$$ROI_t = RV_t \div C_t \quad (20)$$

Equations (21) to (31) are mathematical formulations for sub subsystem supply.

$$C_t = FC_t \times Vc_t \quad (21)$$

$$FC_t = SC_t \times PSc_t \times Lu_t \quad (22)$$

$$SC_t = SC_{(t-1)} + \frac{dISc}{dt} \quad (23)$$

$$\frac{dISc}{dt} = IISc_{(t)} + SC_t \quad (24)$$

$$Vc_t = Pc_t + Bc_t + Tc_t + Puc_t \quad (25)$$

$$Pc_t = PcHa \times Lu_t \quad (26)$$

$$Bc_t = BcKg \times QB \times Lu_t \quad (27)$$

$$Tc_t = TcHa \times Lu_t \quad (28)$$

$$Puc_t = PucHa \times PPuc \times Lu_t \quad (29)$$

$$Ipc_t = \frac{[NTPr_t - C_t]}{TP_t} \quad (30)$$

$$TP_t = Lu_t \div TPH_a \quad (31)$$

Where,

$D_t = demand\ in\ period\ t$
$K = consumption\ per\ capita$
$RL = Birth\ rate$
$RM = Death\ rate$
$Rv_t = Revenue\ in\ period\ t$
$ROI_t = Return\ on\ investment\ in\ period$
$C_t = farming\ cost\ activity\ in\ period\ t$
$TP_t = number\ farmer\ in\ period\ t$
$TPHa = number\ of\ farmer\ required\ each\ hectare$
$NTPr_t = production\ value\ in\ period\ t$
$HP_t = Farmer\ cost\ in\ period\ t$
$Pc_t = Pest\ cost\ in\ period\ t$
$Bc_t = Seed\ cost\ in\ period\ t$
$Tc_t = Total\ labor\ cost\ in\ period\ t$
$Puc_t = Fertilizer\ cost\ in\ period\ t$
$PcHa = Pest\ cost\ each\ hectare$
$BcKg = seed\ cost\ per\ kilograms$
$QB = seed\ quantity\ required\ each\ hectare$
$TcHa = Labor\ cost\ each\ hectare$
$PucHa = Fertilizer\ cost\ each\ hectare$
$PPuc = Percentage\ of\ fertilizer\ subsidy$
$Ipc_t = farmer\ income\ percapita\ in\ period\ t$
$J_t = number\ of\ soybean\ sales\ in\ period\ t$
$HL_t = local\ soybean\ price\ in\ period\ t$
$Sc_t = rent\ land\ charge\ each\ hectare\ in\ period\ t$
$PSc_t = percentage\ rent\ land\ in\ period\ t$
$\frac{dISc}{dt} = Increasing\ rent\ land\ in\ period\ t$
$IIS_c index\ of\ increasing\ rent\ land\ charge\ in\ period\ t$

$\frac{dL}{dt} = Number\ of\ birth\ in\ period\ t$
$\frac{dM}{dt} = Number\ of\ death\ in\ period\ t$
$P_t = Number\ of\ population\ in\ period\ t$
$Pr_t = Soybean\ production\ in\ period\ t$
$Lu_t = Crop\ area\ in\ period\ t$
$P_{vt} = Land\ productivity\ in\ period\ t$
$\frac{dIPv}{dt} = Increasing\ land\ productivity\ in\ period\ t$
$\frac{dDPv}{dt} = decreasing\ land\ productivity\ in\ period\ t$
$IIPv = Index\ of\ increasing\ land\ productivity$
$PB_t = Seed\ productivity\ in\ period\ t$
$ITm_t = temperature\ impact\ in\ period\ t$
$IP_t = Fertilizer\ impact\ in\ period\ t$
$IW_t = watering\ impact\ in\ period\ t$
$IS_t = Yield\ loss\ impact\ in\ period\ t$
$IDPv = Index\ of\ decreasing\ land\ productivity$
$\frac{dEL}{dt} = land\ extensification\ in\ period\ t$
$\frac{dKL}{dt} = land\ conversion\ in\ period\ t$
$RE_t = extensification\ rate\ in\ period\ t$
$RK_t = conversion\ rate\ in\ period\ t$
$Sw_t = Self\ sufficiency\ level\ in\ period\ t$
$DI_t = Demand\ of\ imported\ soybean\ in\ period\ t$
$J_t = Soybean\ sales\ in\ period\ t$
$Fc_t = Fixed\ cost\ in\ period\ t$
$C_t = Farming\ cost\ activity\ in\ period\ t$
$Vc_t = Variable\ cost\ in\ period\ t$

The next stage after formulate the relationship between the entities into the mathematical model is describes the stock flow diagram in a computer program using the Powersim Studio Software. Below figure 3 Stock fkow diagram of demand. Figure 4.a and 4.b shows stock flow diagram of Supply and Figure 5 shows Stock Flow Diagram of distribution.

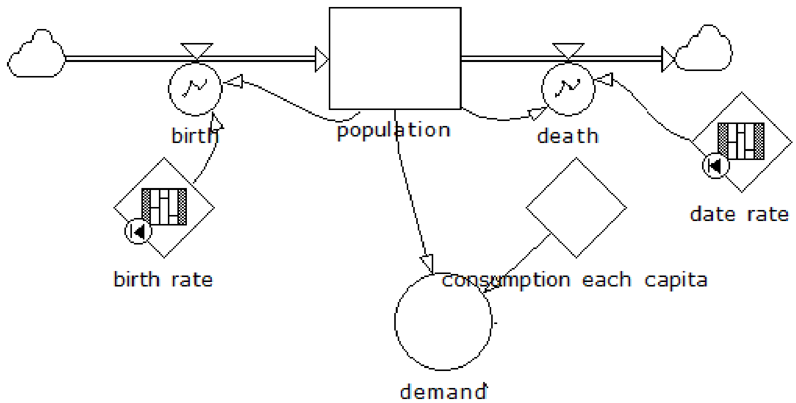

Figure 3. Flow Diagram of Demand Subsystem

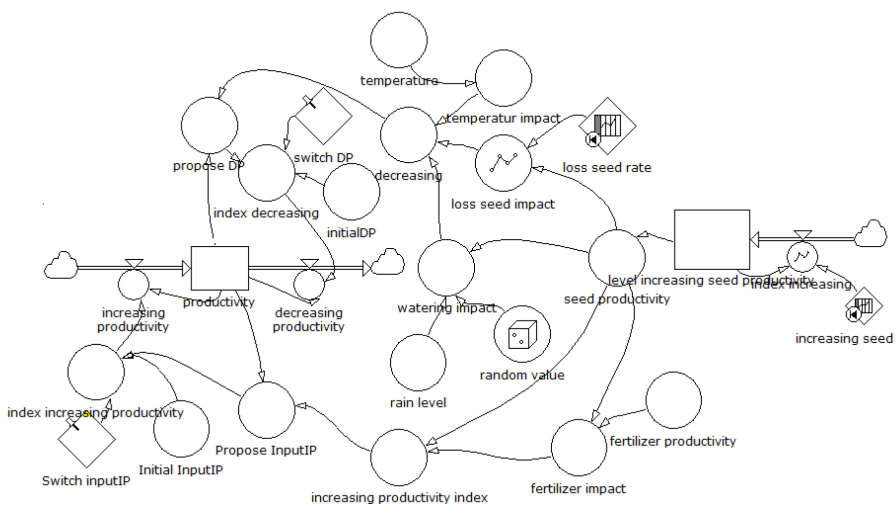

Figure 4.a Flow Diagram of Supply-Productivity Subsytem

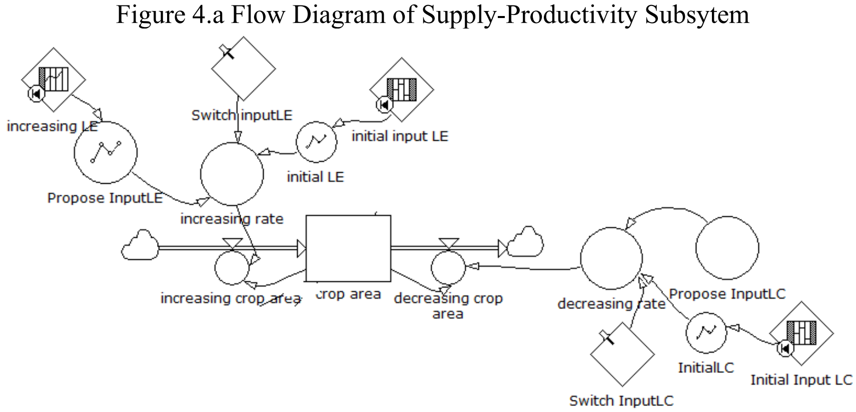

Figure 4.b Flow Diagram of Supply Supply-Crop Area Subsytem

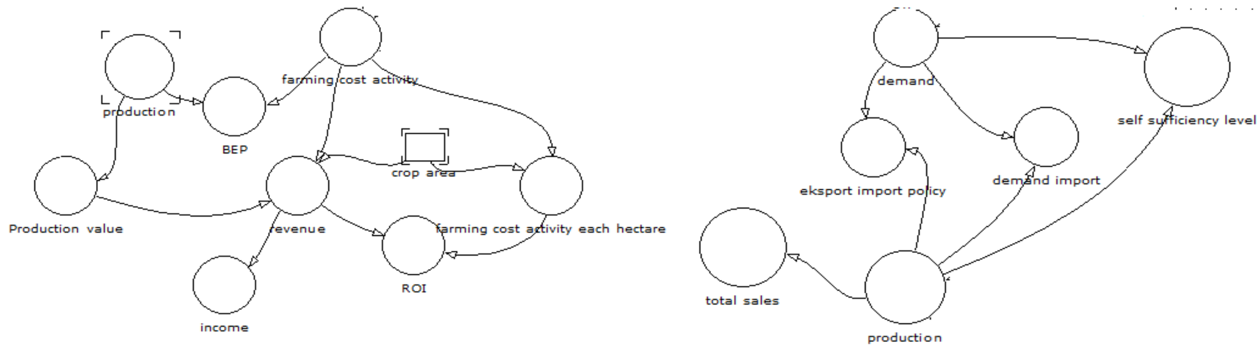

Figure 5. Stock Flow Diagram of Distribution Sub System

Conceptual strategy to achieve self-sufficiency of soybean can be described in Figure 6. Figure 7 shows framework of simulation policy that consist of input needed and output that can be generated. The realization of self-sufficiency in soybeans when local production increases. To increase production, namely by increasing land productivity and increasing land area. To increase the value of farmers' per capita income and ROI, namely by reducing the cost / investment as small as possible, as well as increasing the income or profit.
Framework of simulation policy describe the design of the policy determination, in this design policy as input from the simulation. Policy will affect the system as a whole and have an impact on the response variable. As a key performance indicator in this model is self-sufficiency level, ROI and farmer's income per capita. Five scenario will be done by changing response variables will change the performance of the system.

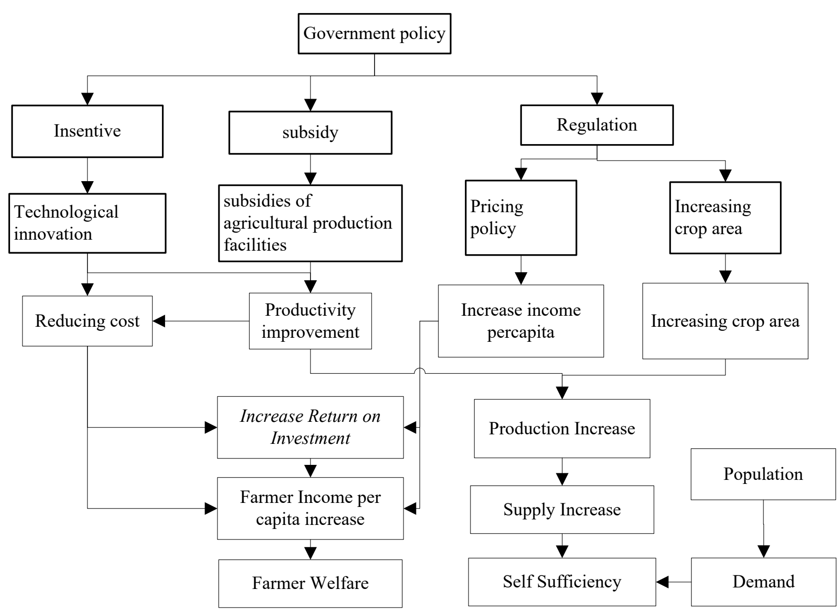

Figure. 6 Strategy to achieve soybean self sufficiency

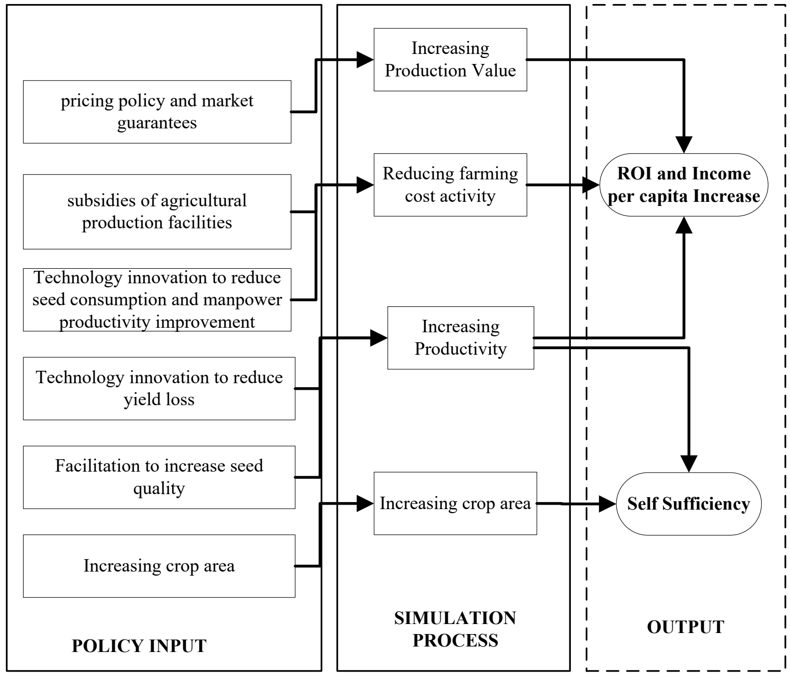

Figure. 7 Framework of simulation policy.

5. Results and Discussion

This model is a simulation model that can be used by the government that has the authority to establish some policy in terms of agriculture and trading of soybean to improve production and farmer welfare. The simulation will be done to analyze the system behavior for the next 20 years and will be done by changing the parameters according to the specified scenario. Scenario I Simulation as initial condition without changing government policy, scenario II Simulation of change policy that responsive to cost of farming activity reduction, scenario III Simulation of change policy that responsive to productivity improvement, scenario IV Simulation of change policy that responsive to increasing of crop area, scenario V Simulation of implementation all policy that response to cost of farming activity reduction, productivity improvement and increasing of crop area. Table 1 shows Simulation Result Achievement of Self Sufficiency Level.

Table 1. Simulation Result Achievement of Self Sufficiency Level

Performance Criteria	Simulation Result Achie.vement of Self Sufficiency Level				
	scenario I	scenario II	scenario III	scenario IV	scenario V
Productivity (quintals / hectare)	30.43	30.43	41.97	30.43	41.97
Crop Area (hectare)	40,580.46	40,580.46	40,580.46	144,444.11	144,444.11
Production (quintals)	1,234,795.37	1,234,795.37	1,703,054.26	4,395,192.62	6,061,936.83
Demand (quitals)	3,882,718.56	3,382,718.56	3,882,718.56	3,882,718.56	3,882,718.56
Self Sufficiency Level (%)	**31.80**	**31.80**	**43.86**	**113.20**	**156.13**

Based on the simulation results of scenario 1 and 2, soybean self-sufficiency will be not achieved in the next 20 years, because scenarios 1 and 2 do not provide policies that affect the increase in supply or production. Scenario 3 results can increase self-sufficiency level of 43.86%. Scenario 3 is a policy scenario in an effort to increase productivity by reducing the value of yield loss and use of quality seeds. With productivity upgrades of up to 41.97 quintals / hectare without any policy towards increasing land area, self-sufficiency cannot be achieved. Scenario 4 shows the achievement of self-sufficiency level 113.20% means that soybean self-sufficiency can be achieved less than 20 years. Scenario 4 is a land acquisition policy with optimization policy of expansion of planting area and policy of price policy of farmers soybean purchase and market guarantee. This means that land expansion efforts can have a significant impact on efforts to achieve self-sufficiency. Soybean self-sufficiency can be achieved by 2035 with condition demand 3,882,718.56 quintals production 4,395,192.62 quintals with productivity 30.43 quintals /hectare and crop area 144,444.11 hectare. Scenario 5 is a scenario that can increase the variables of productivity response and land area so as to increase the level of self-sufficiency significantly. Soybean self-sufficiency can be achieved for next 14 years on demand condition reaches 3,882,718.56 quintals production 6,061,936.83 quintals with productivity 41.97 quintals / hectare and crop area 144,444.11 hectare.

Table 2. Simulation Result Achievement of Faremers Income Per Capita and Return on Investment

Performance Criteria	Simulation Result Achievement of Faremers Income Per Capita and ROI				
	scenario I	scenario II	scenario III	scenario IV	scenario V
Per Capita Income (IDR)	193,674.98	837,235.20	1,429,735.65	915,143.39	3,068,359.41
ROI	0.06	0.35	0.47	0.30	1.27

Table 2 shows Simulation Result Achievement of Faremers Income Per Capita and ROI . The effect of scenarios also impact in per capita income and Return on Investment (ROI). The highest per capita income and ROI values are generated in scenario 5 then scenario 3, 2, 4 and lowest for scenario 1. Simulation result base on scenario 5 are at the end of the simulation period of the 20th year, per capita income of farmers was IDR 3,068,359.41 and ROI was reached at 1.27.

6. Conclusion

This research has identified the relationships between entities involved in the soybean supply chain system captured in the causal loop diagram. From the relationship between entities obtained the conclusion that self-sufficiency of soybeans can be realized if there is an increase in soybean production. Increased soybean production is influenced by land area and land productivity. Farmers' welfare can be measured using the per capita income value of farmers, while the economic analysis of farming is measured by Return on Investment (ROI) scale. Increases in per capita income of farmers and ROI can be achieved if there is a decrease in the cost of agricultural activity and increased value of soybean production. Reducing costs can be achieved if there is an increase in land productivity, the existence of subsidy policies and savings in resource use such as manpower efficiency, reducing the seed consumption. Increasing the value of soybean production can be achieved with the increase of soybean prices at the producer level as well as the increasing number of production. The best scenario to realize self-sufficiency of soybean is by increasing productivity policy, increasing land area, reducing cost of agricultural activity and increasing production value. Further research may considers the sustainability aspect in terms of transportation energy consumption optimization for the distribution of soybean commodities.

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