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Development of System Dynamics Model to Increase Salt Fulfillment Ratio

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Abstract

Salt demands in Indonesia have continued to increase over the past decade, while salt production fluctuates and still depends on weather conditions. This makes salt imports tend to increase and salt self-sufficiency is difficult to achieve. Indonesia needs serious efforts to achieve self-sufficiency, both consumption salt and industrial salt. In this study we identify problems that exist in the salt industry and determine the factors that have a significant effect on the system. The national salt production system is represented in a dynamic model using the System Dynamic. We use System Dynamic based on the consideration that this framework offers the ability to combine expert knowledge in the model and the ability to model non-linear behavior that has a significant contribution to the national salt production. System dynamic modeling is also able to associate between variables in a closed causal loop so that actions taken by changing one variable will have an impact on the initial conditions. From the base model simulation results, we developed several scenarios to increase salt fulfillment ratio. To support the sustainability of the salt business, we make a price scenario that supports salt business remains profitable for farmers. To increase salt production, we provide a scenario of increasing productivity through optimal technology implementation. As a result of the two scenarios, total salt production reaches 5 million tons per year. The fulfillment ratio of consumption salt and industrial salt can be achieved.

Keywords: Salt Production; Self-sufficiency; Fulfillment Ratio; Implementation of Technology; Price Scenario

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1. Introduction

Currently national salt production has not been able to meet domestic demands both in quantity and quality. The increasing population and the pace of industrial growth have resulted in national salt demand continuing to increase. Salt demands in 2004 were around 2.9 million tons, increasing to 3.6 million tons in 2014 [1]. Based on the data from Marine and Fisheries Ministry [1], national salt production in 2014 reached 2.19 million tons. This indicates that Indonesia has not been able to maintain its salt production. Around 1.8 million tons or about 85% of national salt were produced by farmers, and the rest was produced by the government through PT Garam. With a national salt production average capacity of 2.5 million tons, Indonesia's share is less than 1% [2] compared to the world's main producer of salt.

In Indonesia, salt is classified into consumption salt and industrial salt. The classification is based on the chemical content required by each user. Consumption salt requires a minimum NaCl content of 94%. Industrial salt in the regulation of the Minister of Industry No. 88 of 2014 is used as raw material in the production process in the chemical industry, various industries food, pharmaceutical industry, petroleum industry, leather tanning industry and water treatment. Most industrial salt is used by the Chlor Alkali Plant (CAP) industry which requires salt with a minimum NaCl level of 96%. The food industry needs salt with a minimum NaCl level of 97% [3]. The amount of consumption saltd demands around 20% and 80% is the demands for industrial salt. The demands for industrial salt requires high specifications (NaCl levels more than 95%) reached 60% of the total industrial salt demands. Unfortunately, the demand for industrial salt with high quality specifications which could be met by domestic production was only around 31% [3].

In addition to the low-quality problems, several problems in national salt production include:

- Most of the salt is produced by farmers with a small scale of ownership of land between 0.5-1 ha, so the quality of the salt produced varies. This relatively small and scattered land ownership also causes difficulty in developing large-scale salt land to pursue business efficiency [3].
- The application of salt production technology is not optimal so that the production process still depends on weather and climate conditions.
- The high loss rate of around 20-30% during the processing stage further causes the price of local salt to be less competitive than imported salt [4].

Dharmayanti *et al* (2013) develop a salt production model that compares the results of production before and after a self-sufficiency policy. In this study salt production was influenced by land productivity, salt area and number of harvest days [5]. Salt production rose after there was a self-sufficiency policy with the existence of a Community Salt Business Empowerment Program (PUGAR). Salt self-sufficiency can be achieved by increasing the implementation of geomembrane technology and thread filters to all farmers and reducing salt consumption per capita. However, the current conditions for both scenarios are not enough to maintain national salt production. There are several other factors that indirectly affect salt production. One of these factors is the price of salt. Prices that are too low will make farmers lose their passion to continue salt production sustainably while prices that are too high will burden consumers. Determination of salt prices at the farm level is often below the government's basic price so that it harms farmers [6,7]. Marine and Fisheries Ministry said that one of the factors not achieving salt production of 3.3 million tons in 2015 was the development of salt prices that were less profitable for farmers [8]. Therefore, to give a complete picture of the national salt industry we must consider the price factor.

In this study, we developed a salt production model by adding other variables that had a significant effect on salt production. We use dynamic system modeling to describe the national salt industry system. We use System Dynamic based on the consideration that this framework offers the ability to combine expert knowledge in the model and the ability to model non-linear behavior that has a significant contribution to the national salt production. The results of the study are expected to provide a broader picture of national salt production. The results of the simulation analysis of the base model will provide several alternative scenarios to increase the salt fulfillment ratio in Indonesia, both consumption salt and industrial salt.

2. Literature review

2.1. National salt production

During 2004-2010, the salt production of farmers ranged from 1.1 to 1.37 million tons. This is because salt production has not implemented production technology. The salt production process uses the solar evaporation method, so the production period depends on the length of the dry season. Salt production is carried out by evaporation of seawater to a certain degree of density then crystallizing brine in crystallization ponds. In this way, the time needed for sea water evaporation reaches 22-30 days. The land of salt ponds is grounded so it is prone to seepage of sea water into the soil. With this condition, the land productivity is low around 40-60 tons / ha and salt quality is low with NaCL levels between 80-90% [9]. Since 2011, Marine and Fisheries Ministry held a Community Salt Business Empowerment Program (PUGAR). This program provided an introduction of production technologies such as geomembrane and filter thread technology. This program fosters farmers actively participating in the stages of planning, managing land and sea water, providing production facilities and infrastructure, as well as the selection and utilization of the right technology according to location [1].

The results of production technology implementation through the PUGAR, land productivity has increased to 80-120 tons / ha / year. National salt production increased to 2 million tons in 2012 and 2.8 million tons in 2015 [3]. With these conditions, Indonesia can already be self-sufficient in consumption salt. However, in the extreme weather conditions such as in 2010 where a wet dry season occured due to La Nina, salt production dropped to 30 thousand tons. Extreme weather also occurred in 2013 and 2016 where the dry season lasted for only about 2 months, so salt production was only able to reach 1.1 million tons in 2013 and 137 thousand tons in 2016 [1].

Until now, Indonesia has not been able to be self-sufficient in industrial salt. This is because the amount of production that fluctuates and the quality of salt still varies. Indonesia needs serious efforts to achieve salt self-sufficiency starting from the increase in the implementation of production technology [10, 11], improving the skills and knowledge of farmers, as well as the efficiency of salt distribution [12].

2.2. System dynamic

System dynamics (SD) is a method to analyze and design a policy for complex system. It can be used as an approach for modeling and simulation of complex system. Sterman describes system dynamics as an aid to learning and understanding complex systems [13]. He emphasizes how the system dynamics modeling process consists of tools to elicit mental models of systems, procedures to create formal models based on the mental models, computer simulations of the formal models, and applications of the findings of the simulations to improve understanding of the system.

The development of a dynamic system model is carried out in several stages including [14]: (1) problem identification, (2) consensus construction of a concept model, (3) construction of a formal model, (4) model analysis and validation, (5) policy analysis and design.

3. Base model development

The initial development stage of dynamic simulation is to determine the variables that have a significant effect on the system. These variables are arranged into a causative relationship that represents the real system. The advantages of dynamic system models are able to associate variables in a feedback loops so that actions taken by changing one variable will have an impact on the initial conditions. The Causal Loop Diagram of the national salt production is shown in Fig. 1.

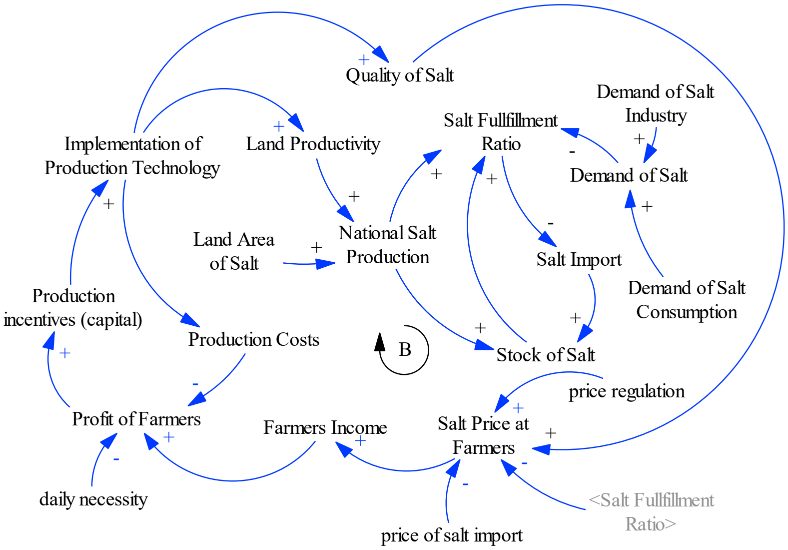


Fig. 1. Causal Loop Diagram of Salt Production System.

Implementation of production technology has a significant effect on land productivity [10, 11] and salt quality [3]. Land productivity and land area of salt affect salt production [5]. Salt requirements consist of the demand for consumption salt and industrial salt [3]. Production and salt requirements affect the salt fulfillment ratio in Indonesia. The fulfillment ratio that has not been met will be overcome by importing salt. The salt fulfillment ratio, quality of salt, price regulation and price of imported salt have an effect on salt prices at farmer [4, 6]. Salt price at farmer affects the farmers income. Profit of farmers are derived from farmers' income minus production costs and daily necessity [3]. Profit of farmers is used for incentives for salt production in the following period. In the CLD it can be seen that the price of salt has an indirect effect on national salt production. The main causal loop on the model is as follows: implementation of production technology → land productivity → national salt production → salt fulfillment ratio → salt prices at farmer → farmers income → profit of farmers → production incentives (capital) → implementation of production technology.

3.1. Production sub model

The flow diagram of national salt production can be seen in Fig. 2. Salt production is divided into two, salt production by farmers and production by the government through PT Garam. Salt production is influenced by land productivity and the productive land area of salt cultivation [5]. Salt production by farmers has a high loss rate of around 10-25% during the further processing [3]. The productive land area is influenced by land expansion and land conversion. Land productivity is influenced by technology implementation [10, 11] and number of harvest days [5]. In this model land productivity is divided into two, namely productivity before the existence of technology and productivity after there is production technology through the PUGAR program. The number of harvest days is influenced by the length of the dry season [5]. The variable “Total Salt Production on Farm” is the total production of salt at harvest, while the variable “Farmers Salt Production” is the amount of production minus Loss Factor during the processing. Salt production is divided into 3 based on its quality. Q1 quality salt is used as industrial salt raw material and the remainder is used as consumption salt raw material.

3.2. Demand sub model

Salt demands are divided into 2 (two) types, namely consumption salt and industrial salt. Based on the data from the Ministry of Industry, the need for food industry salts from 2004 to 2017 grew by an average of 8.5% per year. The

CAP and pharmaceutical industries grew by an average of 4.5% per year. The fish salting industry grew by an average of 4.5% per year, and the non-CAP industry grew by an average of 3.75% per year [1]. The average of per capita salt consumption is 3 kg / year.

Consumption salt demands consists of household demands and the fish salting industry. Salt for the food industry was initially included in consumption salt demands, but since 2014 Food Assorted Salt has been categorized into industrial salt according to Minister of Industry Regulation No. 88 / M-IND / PER / 10/2014. Industrial salt demands consist of CAP industry, food industry and NON CAP industry (oil, textile, soap etc.). The flow diagram of salt demands can be seen in Fig. 3.

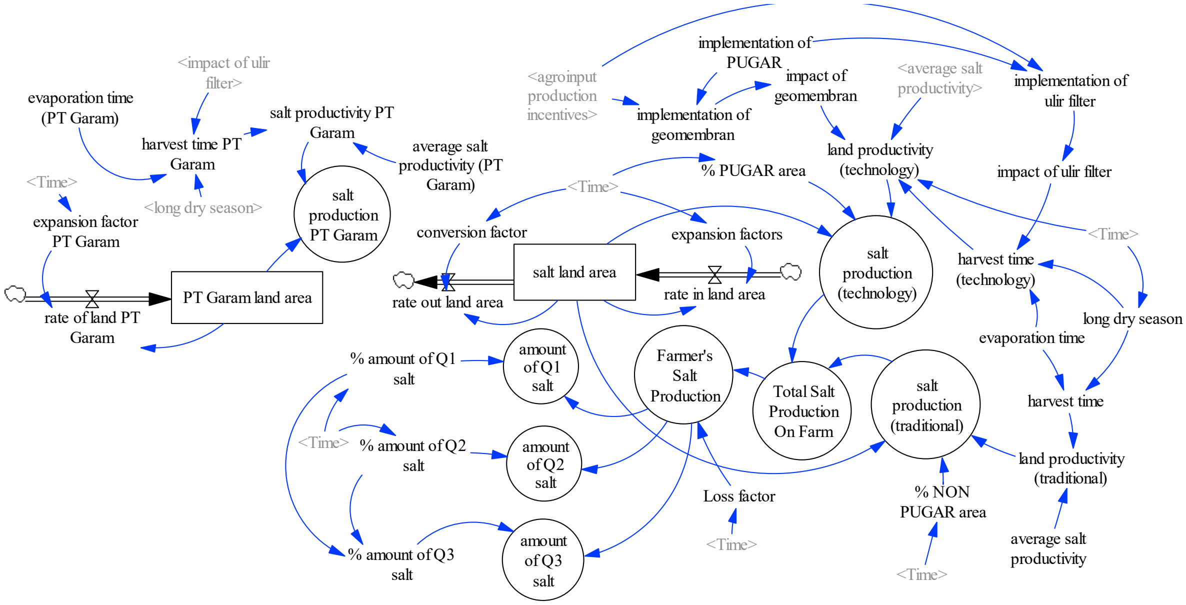


Fig. 2. The Flow Diagram of Salt Production System.

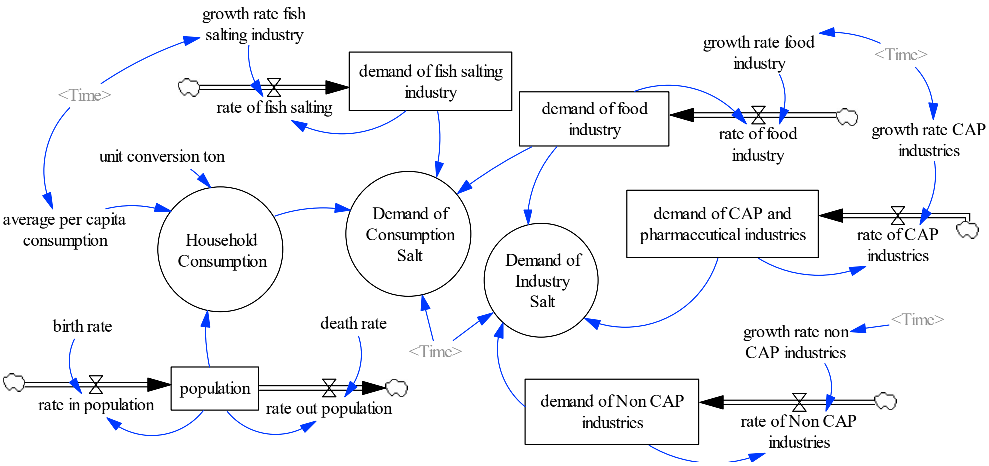


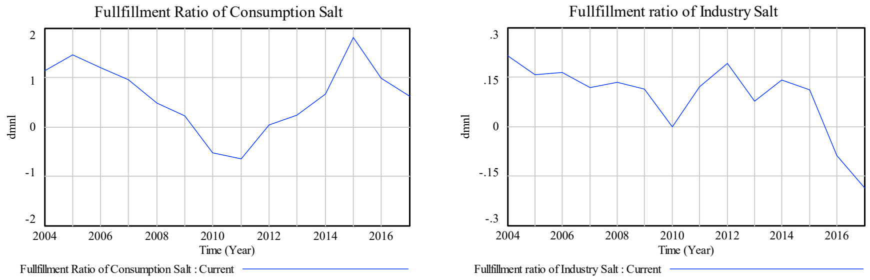
Fig. 3. The Flow Diagram of Salt Demands.

3.3. Fulfillment ratio sub model

The demand for the CAP industry which has a highgrade standard, with a minimum NaCl level of 96% (adbk), a maximum water content (b / b) of 2.5%, and a maximum Calcium (Ca) of 0.1% cannot be met by domestic salt production. Salt production from PT Garam is intended for the leather tanning industry, various foods, salting fish, and medicine. Approximately 44% of salt produced by PT Garam competes with farmer's salt as a raw material for iodizing salt industry [3].

The simulation results of salt fulfillment ratio is shown in Fig. 4. The fulfillment ratio of consumption salt in 2004-2007 was reached and began to decline in 2008 because of the increasing demand, but production remained and dropped dramatically in 2010. The consumption salt consumption ratio began to be met because the PUGAR program was implemented and reached 2.5 million tons of production in 2015.

The average salt produced by PT Garam is used as industrial salt by 56% of the total production or around 168 thousand tons. The quality of Q1 salt from farmers is around 30-50% of the total production, so the fulfillment ratio of industrial salt is very far from self-sufficiency. The simulation results in Fig. 4(b) show that the fulfillment ratio of industrial salt averages around 15%, while 85% is achieved from import. This is in accordance with the data in the Marine and Fisheries Ministry where the demand for industrial salt is mostly met by the supply of imports, especially for the CAP industry and pharmaceuticals at 83.54% [1].

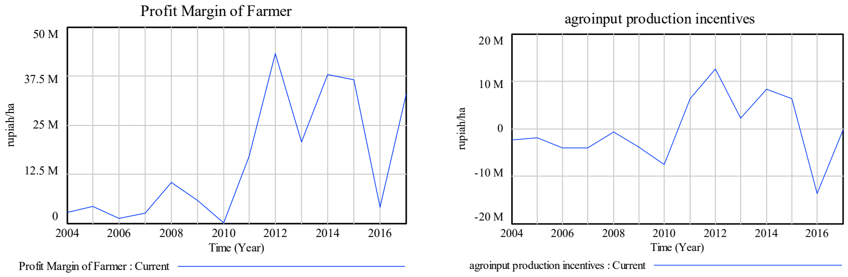


(a) (b)

Fig. 4. (a) Simulation Results of Consumption Salt Fulfillment Ratio, (b) Simulation Results of Indutrial Salt Fulfillment Ratio.

3.4. Farmer's income sub model

The farmer income submodel represent the income obtained by salt farmers per ha per year. Farmer income is influenced by land productivity per ha and salt prices at the farm level. The income of salt farmers is used for daily expenses in one year [4]. The profit margin of farmers are derived from farmers' income minus production costs and added assistance from the government. Production incentives are obtained from profit margin of farmer minus the costs of daily necessities. Production incentives are used as capital for production costs the following year. Simulation results of farmer income sub model can be seen in Fig. 5.



(a) (b)

Fig. 5. (a) Simulation Results of Profit Margin of farmer, (b) Simulation Results of production incentives.

4. Model validation

Model validation is done to test whether the model represents the real state of the research object. According to Barlas [14], system validation can be done in two ways, namely model validation with a statistic of mean comparison and model validation with the comparison test of amplitude variation or % error variance where the model is considered valid if mean comparison (E1) ≤ 5% and error variance (E2) ≤ 30%. Mean comparison and error variance are defined in Eq. (1) and (2):

$$E1 = \frac{\bar{S} - \bar{A}}{\bar{A}} \quad (1)$$

$$E2 = \frac{| Ss - Sa |}{Sa} \quad (2)$$

Where :

- $\bar{S}$ = the average rate of simulation
- $\bar{A}$ = the average rate of data
- Ss = the standard deviation of simulation
- Sa = the standard deviation of data

We provide the average rate of simulation results, average rate of data, standard deviation of simulation, and standard deviation of data in Table 1 and Table 2 to determine the Error Rate and Error Variance of salt production and salt demand.

Table 1. Error Rate Determination.

Variable	Average of Simulation	Average of Data	Error Rate	% Error Rate
Farmer’s Salt Production	1049141.97	1066924.80	0.016	1.6%
PT Garam Salt Production	235484.86	226529.05	0.0395	3.95%
Demand of Consumption Salt	1415545.96	1411560.88	0.0028	0.28%
Demand of Industrial Salt	2014196.07	2012538.70	0.00082	0.082%

Table 2. Error Variance Determination.

Variable	Standard Deviation of Simulation	Standard Deviation of Data	Error Variance	% Error Variance
Farmer’s Salt Production	647773.58	645785.46	0.0030	0.3%
PT Garam Salt Production	117299.64	109217.11	0.074	7.4%
Demand of Consumption Salt	171061.42	171398.17	0.0019	0.19%
Demand of Industrial Salt	387526.76	389388.57	0.0047	0.47%

From the comparison results of average test and standard deviation, it can be seen that each value of E1 ≤ 5% and each value of E2 ≤ 30%, so the model can be said to be valid. We also conduct unit parameter testing and structural model testing through the Vensim application. Test results show that the unit parameters and structure models are valid.

5. Results discussion

The simulation results from the base model show that salt production still fluctuates and is influenced by climatic conditions. On the other hand, technology that can produce salt in the rainy season has been found, for example tunnel systems or prism house. Utilization of these technologies has not been implemented by farmers because of limited capital. From the simulation results, farmers' income is only enough to meet their daily needs. Salt prices at the farm level are often under the government's basic pricing [6]. Therefore, price protection is needed for farmers so that the salt business can provide decent benefits. In order to manage uncertainties both caused by nature and the trading system of the commercial business, various efforts are needed to protect farmers. Institutionally, cooperatives are needed to be able to help implement basic price policies by participating in salt procurement activities for the purposes of national stock and the general market [7]. To overcome uncertain weather conditions, it is expected that all farmers implement year-round salt production technology through a tunnel system or a prism house. Capital assistance can be provided through institutions such as cooperatives [7, 12]. Capital assistance from cooperatives is provided with a profit-sharing system. To get a decent profit for farmers, salt price protection is needed. Institutions such as cooperatives are expected to become farmers' salt absorbers according to government prices [7, 12]. Institutions such as cooperatives are important factors that must be sought by the government.

In this study, we developed a two-step scenario to increase the salt fulfillment ratio. The first scenario is the Basic Salt Pricing Scenario. The second scenario is land intensification through an optimal implementation of production technology.

We propose Basic Salt Pricing Scenario to ensure a reasonable business profit for farmers and capital borrowers (cooperatives). Based on the results of interviews with farmer groups in Sumenep, the price of salt that is beneficial for farmers who have implemented production technology throughout the year is a minimum of IDR 1000 / kg per 2018. This is because the production costs increase to install the tunnel system. On the other hand, imported salt prices averaged USD 0.05/kg in the last five years, an increase in the price of imported salt influenced by the exchange rate of the rupiah. Over the past decade, the increase in the exchange rate of the rupiah against the dollar of 3.5% per year. To anticipate the effect of imported salt prices on local salt, the imposition of import salt import duties needs to be considered [15]. Thus the price of local salt is expected not to fall. The basic price of Q1 salt in 2004 was IDR 150 / kg and in 2010 it was IDR 750 / kg until now. The increase in base prices is based on production costs which also increase from year to year. In this basic price scenario, we assume an increase in the salt base price of 3.5% per year to equal the increase in imported salt. At the end of the simulation, the basic price of salt reached IDR 1563 / kg in 2031. This was done to anticipate the increase in production costs due to the influence of inflation. By taking strategic steps through empowering cooperative institutions and pricing, the second scenario can be implemented.

The second scenario is increasing salt production by implementing production technology optimally. To increase salt production can be done through production technology throughout the year by implementing prism houses/tunnel system and water bunker. In this scenario, evaporated brine can be stored in a water bunker and harvested every time through a prism house. The function of the prism house is to crystallize salt in the rainy season. Crystallization ponds are equipped with geomembranes to accelerate crystallization and reduce impurities. The pond is designed with a thread filter system to accelerate evaporation. By using this technology, land productivity increases to 200 tons / ha / year [11]. The use of geomembrane, filter thread and proper cultivation techniques can improve the quality of salt to Q1, so that the demands of industrial salt can be achieved.

The simulation results from these two scenarios, total salt production reaches 5 million tons per year. The fulfillment ratio of consumption salt rose and began to be fulfilled in 2022. With a proportion of 65% of PT Garam salt production and 70-80% of farmer's salt production intended for industrial salt, the fulfillment ratio of industrial salt can be achieved. Besides increasing productivity, the use of geomembranes, filter threads, and training to farmers can increase the number of first quality (Q1) salts to reach 70-80%. With the opportunity to produce throughout the year, the productivity of the land increases and the income of farmers increases beyond the production cost.

6. Conclusion

System understanding is required as a basic foundation in developing system dynamics model. System dynamics is an appropriate method for dynamic studies and policy analysis especially on developing model and scenarios to improve national salt production and farmers' income as the method can consider internal and external factors as well as nonlinear relationships among factors. Once we have a valid model, we can modify the structure of a valid model dan modify the parameters to improve the system performance.

The price of salt has an indirect effect on national salt production. Therefore, to increase salt production sustainably the price factor must be given special attention. Institutional empowerment such as cooperatives that are able to assist farmers in providing capital loans and absorbing salt according to the base price are very important points. The role of the institution will be able to improve the position of weak farmers. With assistance from cooperatives, farmers can implement production technology optimally.

In further research, it is necessary to study more about the formation of basic salt prices in order to compete with imported salt. The formation of a base price is influenced by various factors that can be modeled separately. The price model can be analyzed to find suitable policy alternatives in order to compete with imported salt.

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