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Dynamic simulation model of salt supply chain to increase farmers income

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Abstract. The average national salt production is around 2.5 million tons per year has not been able to meet domestic salt demands. One of the factors that caused this was the low incentives received by farmers so that farmers were reluctant to carry out production in the following year. As the main actor in the national salt industry, farmer's welfare needs to be considered to ensure the sustainability of salt production. This study aims to develop a dynamic model of the salt production supply chain by identifying internal and external factors that influence the system. We use system dynamic methods because this framework can model nonlinear equations among variables and can represent feedbacks loop relationships. From the base model simulation results, we developed a scenario to improve the welfare of salt farmers. By using the scenario of land intensification with filtering – threaded technology, geomembrane, and tunnel system, farmer's profits could be increased up to Rp 13,830,300 per ha per season in the shortest dry season.

1. Introduction

The average national salt production is around 2.5 million tons per year has not been able to meet domestic salt demands. Most of the salt production in Indonesia used solar evaporation, so it depends on weather conditions. The shortage of salt production is caused by land limitations, uneven implementation of production technology and low farmer incentives [1-3]. Low farmer incentives make this business less attractive and it can be a threat to the sustainability of salt production [1].

Salt farmers in Indonesia have various incomes depends on landowner status. There are 3 types of landowner status: own land, land rent and profit-sharing land [4]. The highest income is obtained by farmers who own the land, while the lowest income is usually obtained from land with a profit-sharing system [5]. The profit-sharing system is a type of business that divided the incomes 50:50 between the landowner and farmers after reduced production cost [4]. This study aims to model the farmers' income and analyze the factors that have a significant impact on salt production. The model is used to understanding system behavior. From the simulation results analysis of the base model, we provide some scenarios to increase farmers' income.

2. Research method

2.1. Data collection
Primary data such as salt prices, production costs, and farmers' income are obtained from interviews and observations with salt farmers and related government. Secondary data such as imported salt prices and salt demands are obtained from various literary journals. Data is processed to determine the equation in making flow diagrams.

2.2. System dynamic
We use system dynamic methods because this framework can model nonlinear equations among variables and can represent feedbacks loop relationships. To create feedbacks models, it requires domain knowledge and the skill to observe interrelationships between variables [6]. This is can be done through collaboration with multiple stakeholders, who provide different perspectives and knowledge on the problem being addressed [6]. Some stage on building system dynamics models are as follows [7]:

- Problem Articulation: Understanding the system and identifying the issue to be addressed.
- Model Conceptualization: Developing a causal theory about the issue.
- Model Formulation: Building stock flows diagrams of the causal theory.
- Model Validation: Testing the model to assess whether it is fit for the purpose.
- Model Use: Using the model to design and evaluate structural policies to address the issue.

3. Base model development

3.1. Causal loop diagram
The first step in building a dynamic modeling with system dynamics is to make a causal loop diagram (CLD). CLDs describe reality through causalities between variables and how they form a dynamic circular influence [6]. We can observe the system through feedbacks rather than linearly. In this research, the causal loop diagram of the salt supply chain can be seen in Figure 1.

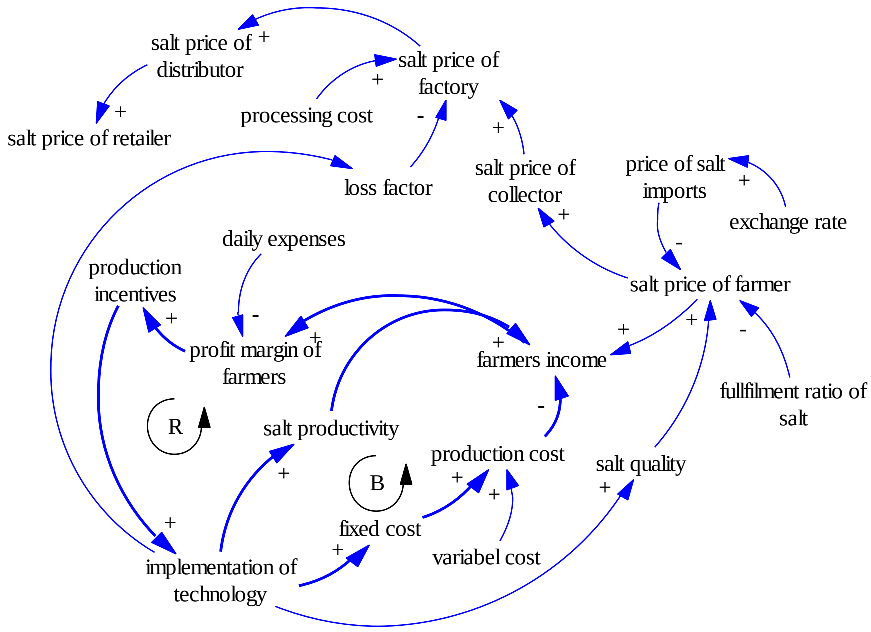

Figure 1. Causal loop diagram of salt supply chain.

There are two feedback loops in the system. Salt prices of farmers have a positive effect on farmers' income [8]. Farmers' income has a positive effect on farmers' profits [8]. Farmers' profits have a positive effect on production incentives (capital) [8]. Production incentives have a positive effect on the implementation of production technology [8]. The implementation of production technology has a positive effect on land productivity and land productivity [9] has a positive effect on farmers' income [8]. This feedback loop is a reinforcing feedback loop. On the other hand, the implementation of production technology has a positive effect on increasing production costs [9] and it has a negative effect on farmers' incomes. This feedback loop forms a balancing feedback loop in the system. Salt price and salt productivity has a significant impact on farmers income, so stakeholders should make a strategy to strengthen these two variable and reduced production cost.

We build several sub-model of flow diagram to break up the complexity of the system.

3.2. Flow diagram of salt price of farmers

The salt price sub-model represents the factors that significantly influence farmers' salt prices. All the factors that make up the farmers' salt price are external factors. Farmers' salt price are strongly influenced by market conditions (supply and demand) and imported salt prices. We conducted a multiple regression analysis of the dependent variable "farmers' salt prices" and two predictor variables "salt fulfillment ratio" and "the price of imported salt" in Indonesia over the past 15 years. Regression analysis results show that the ratio of salt fulfillment and imported salt prices significantly influence the farmer's salt price with an R Square value of 84%.

3.3. Flow diagram of farmers income

The farmers' income sub-model in Figure 2 illustrates the variables that form farmers' income per ha per year. Salt sales and government assistance have a positive effect on farmers' incomes. Production costs such as labor costs, equipment costs, and depreciation costs negatively affect a farmer's income. Profit margin of farmer is obtained from 50% of farmers' income [4]. Some of the salt farmers implement a profit-sharing system with landowners. The profit is used for daily expenses for one year [4]. Production incentives are obtained from a profit margin of farmers reduced daily necessity cost [8]. Profit margin of farmer often not sufficient to fulfill their daily necessity, therefore farmers can't saving for production incentives [4]. This can be a threat to the sustainability of salt production. Hence, the government should be arranged the right policy to increase farmers' welfare.

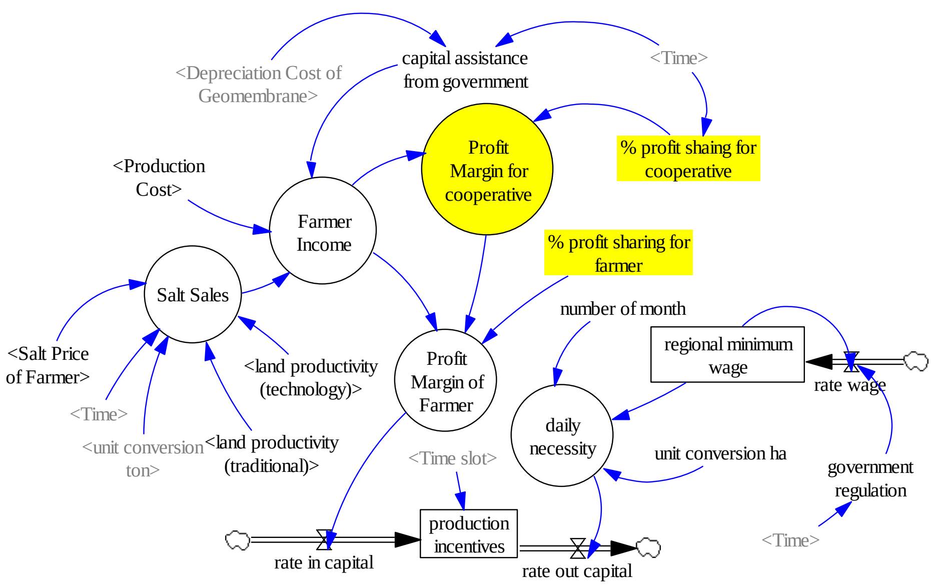

Figure 2. The flow diagram of farmers income.

4. Model validation

Model validation measures whether the model represents the real state of the research object. According to Barlas, system validation can be done in two ways: model validation with a statistic of mean comparison and model validation with the comparison test of amplitude variation or % error variance [9]. 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):

$$E1 = \frac{\bar{S} - \bar{A}}{\bar{A}} \tag{1}$$

$$E2 = \frac{|Ss - Sa|}{Sa} \tag{2}$$

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

In this research, we compare the average simulation results with the original data for the 2007-2018 period. The validation results are summarized in Table 1.

Table 1. Validation of significant variable in the system.

Variable	Avg rate of simulation	Avg rate of Data	E1	Std Deviation of Simulation	Std Deviation of Data	E2
Salt Price of farmer	461	459	0.41%	203	220	7.8%
Price of Imported Salt	465	464	0.13%	164	165	0.51%
Land Productivity	74.93	74.46	0.61%	30.41	38.85	21.73%

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. Comparison graph between the simulation results of the base model and the original data can be seen in Figure 3.

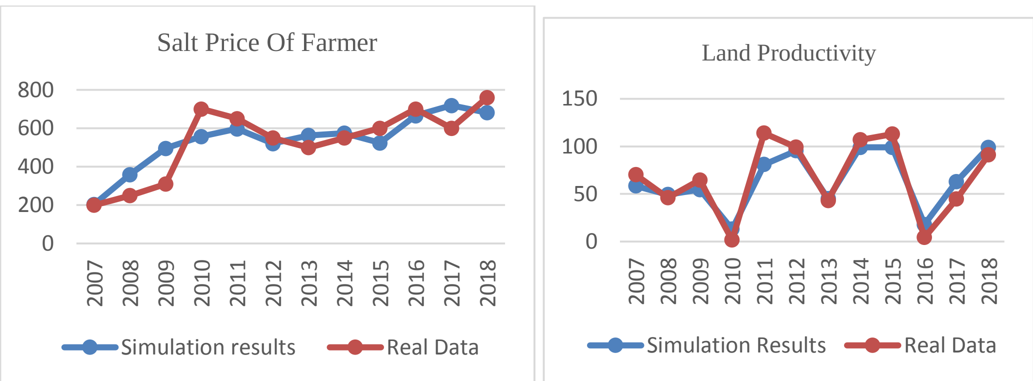

Figure 3. Comparison graph between simulation results and real data.

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5. Results and discussion

5.1. Simulation results of base model

A valid model can be used to analyze system behavior. The simulation results of the base model show the highest profit margin of farmers comes from farmers who implement production technology optimally with the longest dry season as we can see in Table 2. Implementation of production technology such as filtering-threaded and geomembrane significantly impact on land productivity (yield). That technology was implemented massively start from 2011 until now. Therefore, land productivity has increased since 2011 compared to previous years even though the same length dry season. Filtering-threaded technology is a modified evaporation pond by passing water through a series of shallow channels to saturate the water into brine with an additional filtering membrane to purify the water [9,10]. It only requires the cost of land modification when making threads [9]. Geomembrane technology is an improved traditional technology by lining the crystallizers with appropriate plastic membranes [11]. It is commonly used high-density polyethylene (HDPE) [12]. Its costs vary depends on its quality. It has a certain usage period and must be replaced if the usage period runs out. Therefore, farmers must save some of their profits for capital. It is used for purchasing technology that has expired.

Revenue and Cost Ratio obtained from salt sales divided production cost. Implementation of production technology not only increase land productivity but also production cost. However, the impact on increasing land productivity is greater so that salt sales and the average R / C ratio increase. By using technology, farmer's profit increased significantly reaching 21 million in 2018. This could not be obtained in the years before 2011 because of the traditional production process [13].

Table 2. Summarize of simulation results of base model.

Year	Dry Season (month)	Yield (ton/ha)	Salt Prices (IDR/kg)	R/C Ratio	Profit Margin of Farmer (million IDR/ha)
2007	5.3	58.5	204	1.17	0.85
2008	4.6	49.4	359	1.68	3.6
2009	5	54.6	495	2.18	7.3
2010	1.8	13	557	1.45	1.1
2011	5	81	597	2.87	17
2012	5.8	95.4	520	2.51	16
2013	3	45	563	2.02	7.6
2014	6	99	574	2.53	18
2015	6	99	524	2.2	15
2016	1.5	18	665	1.3	2.6
2017	4	63	718	2.46	14.7
2018	6	99	681	2.53	21

From the simulation results of the base model, we can see that if the length dry season only 1 – 2 months, land productivity extremely low as well as farmers' income. Therefore, we provide some scenarios to increase salt production and farmers' income due to unpredictable weather conditions.

5.2. Scenario development

We provide 3 possible scenarios: optimistic scenario, pessimistic scenario, and most likely scenario by changing the parameters of variables that have a significant effect on the system.

- Pessimistic scenario: salt production using traditional technology [13].

- Most-likely scenario: salt production by improving traditional technology using filtering-threaded and geomembrane technology.
- Optimistic scenario: salt production by improving traditional technology using filtering-threaded, geomembrane and tunnel system.

Tunnel is a type of greenhouse that can be used to produce salt in the rainy season. Actually, solar tunnel is commonly used for farming products such as fish to stop of bacteria rate process [14]. In the salt production, it is used to escalate sunlight radiation and to enhance the function of solar collector that's applied as evaporation pond and crystallizer. It can increase brine concentration 1^0 be within 2-3 days at the rainy season. The sample of simulation results after the scenario can be seen in Table 3. In the shortest dry season, the highest profit margins of farmers can be obtained from the optimistic scenario with the optimal application of production technology.

Table 3. Comparison of optimistic, pessimistic and most-likely scenario simulation results.

Scenario	Dry Season (month)	Yield (ton/ha)	Salt Prices (IDR/kg)	R/C Ratio	Profit Margin of Farmer (million IDR/ha)
Pessimistic	1.5	10	1077	0.8	-0.67
Most-Likely	1.5	19	1073	1.4	2.8
Optimistic	1.5	73	939	3	13

6. Conclusion

Land productivity depends on the implementation of production technology. Land productivity has a significant impact on farmers' income so that farmers need to put some efforts to implement the technology, but capital was the main problem for farmers. Therefore, the government should be considered to give assistance to farmers or create policies that facilitate capital loans for farmers with decent profit sharing. In the shortest dry season, land productivity with optimistic scenario can reaches 73 tons/ha and farmer's profits could be increased up to IDR 13,830,300 per ha per year.

Salt prices also influenced the farmers' income, but it depends on external factors. Therefore, the government should make a price policy to protect the price of salt of farmers. It can be addressed for future research.

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