The Development of System Dynamics Model to Increase National Sugar Fulfillment Ratio

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Abstract**—Sugar is one of the basic needs for people and industries that currently still continues to be a problem due to lack of domestic production. There are 11 refined sugar factory companies with an installed capacity of 5 million tons. However, there is an idle capacity of refined sugar factory about 46%. In 2013, an estimated domestic market demand of crystal sugar was around 2.8 million tons, while total production of farmers and sugar factory was only 2.7 million tons. This could pose a risk of a surge in sugar prices at retail level. Without adequate protection, cane farmers and sugar factories in Indonesia will be harmed in the long run. We need to achieve self-sufficiency in sugar production by conducting land intensification and expansion in all parties starting from smallholder, government, and private industry. Therefore, we developed a set of system dynamics simulation models to increase the fulfillment ratio of sugar. System dynamic is a computer-aided framework to develop policy analysis and design. We utilized system dynamics framework based on consideration that this framework can accommodate the internal and external factors that have significant contribution to sugar fulfillment ratio. Based on the simulation results, the fulfillment ratio can be increased by conducting land expansion and intensification. With land expansion of around 40,000 ha per year for 15 years, government harvested area would be around 606,617 ha in 2030. Fulfillment ratio after land expansion and intensification would be greater than 1 starting from 2020.**

Index Terms**—Demand; Production; Simulation Dynamics; Sugar; System.**

I. Introduction

National sugar stock is estimated to continue to decrease in 2014. To overcome this problem, based on the Technical Coordination Meeting at the end of 2013, it was agreed that the Government commissioned BULOG to add reserves of 350,000 tons of sugar stocks [1]. BULOG may gather sugar from domestic production or imports, either in the form of white crystal sugar or refined sugar consumption. Domestic sugar supply can be obtained from state-owned sugar mills (PTPN / RNI) and the private sector through the processing of domestic sugar cane. While sugar for food and beverage industry are supplied by manufacturer of refined sugar, which is the raw material obtained from sugar imports. Indonesian sugar market in total was around 5.7 million tons in 2012, which is 3 million tons for the consumption and 2.7 million tons for the food and beverage. Sugar demand growth per year reached 8.77%, while production growth decreased 1.73% per year [2]. Import of raw sugar processed is required to meet the needs of the food and beverage industry.

There are 11 refined sugar factory companies with an installed capacity of 5 million tons. There is idle capacity of refined sugar factory about 46 percent. For domestic crystal sugar, it has yet to fully be met by domestic production of crystal sugar. In 2013, an estimated domestic market needs crystal sugar of 2.8 million tons, while production of farmers and sugar factory only 2.7 million tons. This could pose a risk of a surge in sugar prices at the retail level. The problem is, the price of sugar in the international market is still far lower than the cost of domestic production of sugar crystals. Without adequate protection, cane farmers and sugar factory in Indonesia will be harmed in the long run and stop producing sugar. It is necessary for gradual changes in line with the achievements of the sugar mill revitalization program. With the condition of refined sugar price (import) much lower than the domestic price, refined sugars will easily seep into crystal sugar consumption market.

Several studies related to sugar productivity have been carried out. As harvest is almost totally mechanized, and cane deterioration becomes more rapid, farmers have the incentive to follow the schedules imposed by the mill [3]. Farmers with common equipment or encouraging contracting arrangements may lead to solve problems between farmers and contractors, which will impact on cane flow regularity and cane quality [4]. Modelling of logistic chains has already been carried out in the sugar industry, to investigate the matching harvest capacity to mill crushing capacity [5]. This model describes the paths followed by cane consignments and the machinery used from fields to mill, with the aim of pinpointing potential bottlenecks and their impact on the supply chain. A modelling approach has been developed to simulate on a weekly basis the planning and operation of mill supply throughout the season [6]. The model compares weekly and total sugar production for a season as well as focuses on the simulation of logistic chains, and enables the impacts of technological and structural changes on daily harvest and transport capacities to be assessed.

Based on the above problems and studies, we need to achieve self-sufficiency in sugar production by conducting land intensification and expansion in all parties starting from smallholder, government, and private industry. The development of sugar industry must be integrated from plantations, processing, marketing, as well as distribution systems that must be supported by all stakeholders.

II. Literature Review

A. Sugar Productivity

Sugar is one of the basic needs for people and industries that currently still continue to be a problem due to lack of domestic production, while the need continues to increase. There are about 8 refined sugar mills which are not producing optimally (capacity utilization around 40% - 60% in 2008) [7]. The rapid development of sugar demand and the relatively unbalanced production make Indonesia as a sugar importer for both raw sugar and industrial sugar (refined sugar). Sugar demand is divided into two categories [8], direct consumption and indirect consumption. Direct consumption represents the amount of sugar consumed without going through the industrial processing, for example directly used as a sweetener tea or coffee. While indirect consumption represents the amount of sugar consumed in the form of processed food, such as bread, cakes, finished drinks, snacks, and so on.

Currently, the average yield of sugarcane is only 7%. In general, there are several factors that affect the declining performance of the sugar industry sector [9] those are: 1) the decrease in sugarcane plantations, sugar cane land was only 400,000 ha; 2) a decrease in land productivity, the productivity of land was around 6 tonnes/ha. This decrease occurred due to the absence of many regular rejuvenation of sugarcane crop and the low quality of seed as a result of fluctuations in national sugar prices and the absence of concern to increase the yield of sugarcane; 3) the decrease in efficiency of sugar factories, due to old equipment that causes production process be degraded. These factors are the dominant cause of declining national production.

B. System Dynamics

System dynamics is a computer-aided framework to develop policy analysis and design. It can be applied to dynamic problems arising in complex social, managerial, economic, ecological systems, as well as any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality. This framework begins with defining problems dynamically, proceeds through mapping and modeling stages, to steps for building confidence in the model and its policy implications. There are five essential steps to modeling that are characteristics of all successful modeling efforts such as depicted in Figure 1 [10].

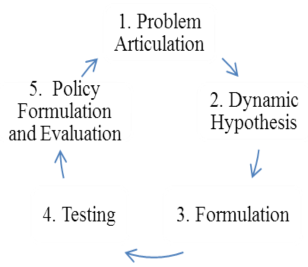

Figure 1: Sterman's Five-Step in Developing System Dynamics Model [10]

Step 1: Problem articulation: in this step, we need to find the real problem, identify the key variables and concepts, determine the time horizon and characterize the problem dynamically for understanding, and designing policy to solve it.

Step 2: Dynamic hypothesis: modeler should develop a theory of how the problem arose. In this step, we need to develop causal loop diagram that explains causal links among variables and convert the causal loop diagram into a flow diagram. Causal loop diagrams capture the feedback loops within the system while flow diagrams provide a description of the structure of the system. This flow diagram consists of some variables such as depicted in Table 1.

Table 1
System Dynamics Variables

Variable	Symbol	Description
Level	□	A quantity that accumulates over time, change its value by accumulating or integrating rates
Rate	⧗	Changes the values of levels
Auxiliary	○	Arise when the formulation of a level's influence on a rate involves one or more intermediate calculations, often useful in formulating complex rate equations, used for ease of communication and clarity

Step 3: Formulation: to define system dynamics model, after we convert the causal loop diagram into flow diagram, we should translate the system description into the level, rate and auxiliary equations. We need to estimate some parameters, behavioral relationships, and initial conditions. Writing equations will reveal gaps and inconsistencies that must be remedied in the prior description. The basic structure of a formal system dynamics model is a system of coupled, nonlinear, first-order differential (or integral) equations such as depicted in Equation (1):

$$\frac{d}{dt} x(t) = f(x,p) \tag{1}$$

where: x = a vector of levels (stocks or state variables), p is a set of parameters, and f is a nonlinear vector-valued function.

Step 4: Testing: the purpose of testing is comparing the simulated behavior of the model to the actual behavior of the system. In the testing phase, the modeler must ensure that the model has "dimensional consistency" – the relationships among the units in the levels, rates, and auxiliary variables and constants must make sense.

Step 5: Policy Formulation and Evaluation. Once modelers have developed confidence in the structure and model behavior, we can utilize it to design and evaluate policies for improvement. The interactions of different policies must also be considered, because the real systems are highly nonlinear, the impact of combination policies is usually not the sum of their impacts alone.

III. Model Development

To increase national sugar fulfillment ratio, we developed demand, land area, sugar production (supply), and fulfillment ratio sub models. These submodels are required as the inputs for the fulfillment ratio model.

A. Demand Submodel

Figure 2 represents the flow diagram of national sugar demand. As we can see from Figure 2, total demand for sugar is the summation of industry and household demand. Household demand is influenced by national population and direct consumption. Meanwhile, industry demand depends on indirect consumption and national population. Direct consumption varies between 8.7 kg/people/year and 11.3 kg/people/year. While sugar indirect consumption varies between 5.7 kg/people/year and 12.2 kg/people/year. In 2005-2010, the total consumption of sugar in Indonesia increased by an average of 6% per year [11].

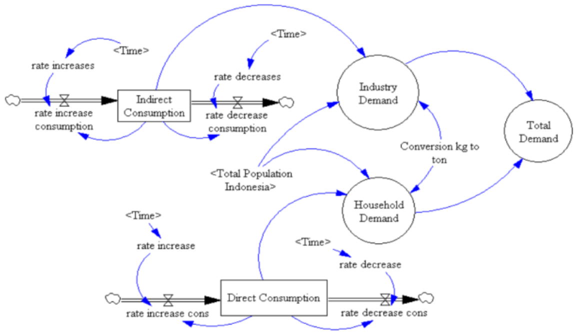

Figure 2: The Flow Diagram of Sugar National Demand

We classified indirect and direct consumptions as level variables based on the consideration that there will be a constant inflow and outflow yields a rising accumulation of dynamic system behavior. The equation of “Indirect Consumption”, “Direct Consumption”, and demand for sugar can be seen in Equation (2) to (6).

$$\textit{Indirect consumption} = \int \textit{rate increase indirect cons.} - \textit{rate decrease indirect cons.} \quad (2)$$

$$\textit{Direct consumption} = \int \textit{rate increase direct cons.} - \textit{rate decrease direct cons.} \quad (3)$$

$$\textit{Industry demand} = \textit{indirect consumption} * \textit{total population} * \textit{converstion kg to ton} \quad (4)$$

$$\textit{Household demand} = \textit{direct consumption} * \textit{total population} * \textit{converstion kg to ton} \quad (5)$$

$$\textit{Total demand} = \textit{industry demand} + \textit{household demand} \quad (6)$$

Sugar national demand has grown with the average growth rate of around 4.26% per year as seen in Figure 3. The rapid growth of sugar demand occurred within the year 2008-2013, due to the growth in household consumption and industry demand.

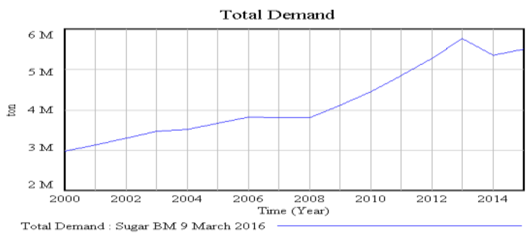

Figure 3: Demand for Sugar

B. Land Area Submodel

This submodel is developed to determine cane land area owned by the government, smallholder, and the private sector. The flow diagram of cane land area can be seen in Figure 4.

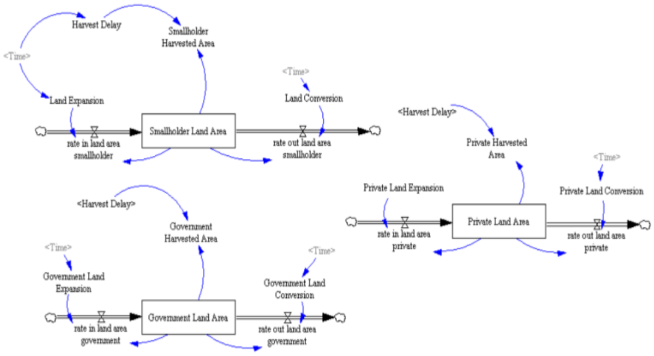

Figure 4: The Flow Diagram of Sugarcane Land Area

As we can see from Figure 4, cane land area depends on land expansion and land conversion. The equation of Smallholder Area can be seen in Equation (7) to (11).

$$\textit{Harvest Delay} = \textit{IF THEN ELSE}\ (\textit{Time} > 2007, 0.016, 0) \quad (7)$$

$$\text{Land Expansion} = \text{IF THEN ELSE (Time} < 2013, 0.05, 0.011) \quad (8)$$

$$\text{Rate in land area smallholder} = \text{land expansion} * \text{smallholder land area} \quad (9)$$

$$\text{Rate in land area smallholder} = \text{land expansion} * \text{smallholder land area} \quad (10)$$

$$\text{Smallholder Land Area} = \int \textit{Rate in land area smallholder} - \textit{Rate out land area smallholder} \quad (11)$$

Based on the simulation results, cane land area owned by the government in 2015 was around 88,861 ha; smallholder was around 268,155 ha; and private sector was around 123,504 ha.

C. Sugar Production (Supply) Submodel

Figure 5 represents the flow diagram of sugar production. As we can see from Figure 5, sugar production is influenced by cane production and actual rendement. Cane production depends on cane yields and harvested area. Cane yields are influenced by seed, fertilizer, crop rotation, rainfall, temperature, humidity, altitude, and adequacy of water, pH (potential of Hydrogen) of soil, pest and disease that may attack [12]. Previous study stated that the increase of 1 unit rainfall would decrease the value of rendement by 0.645%, the increase of temperature by 1 unit will raise the yield of 0.016%, the increase in humidity by 1 unit will increase the yield of 0.659% and the increase of solar radiation of 1 unit will increase rendement of 0.102% [13]. Another study state that the provision of organic fertilizer compost bagase can improve soil fertility [14]. The equation of smallholder yields can be seen in Equation 12.

$$\text{Smallholder Yields} = \text{IF THEN ELSE(Time} = 2014, 71, \text{IF THEN ELSE(Time} = 2015, 72, \text{Impact of Altitude} + \text{Impact of Climate} + \text{Impact of Irrigation} + \text{Impact of PH Soil} + \text{Impact of Seed} + \text{Impact of Fertilizer} + \text{Impact of Crop Rotation} - \text{pest and disease attack))} \tag{12}$$

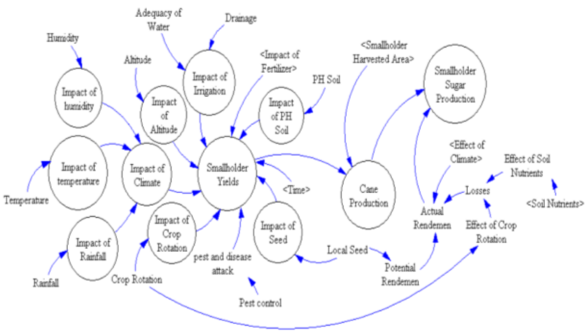

Figure 5: The Flow Diagram of Sugar Production

Based on the simulation results, the average cane yields productivity of government was around 64.6 tons/ha, government sugar production in 2015 was around 426,872 tons; the average cane yields productivity of smallholder is around 76.7 tons/ha, and smallholder sugar production in 2015 was around 1,361,638 tons; meanwhile, the average cane yields productivity of private sector is around 81.8 tons/ha, and private sector sugar production in 2015 was around 755,222 tons.

D. Sugar Fulfillment Ratio

Sugar fulfillment depends on sugar production and demand as seen in Figure 6.

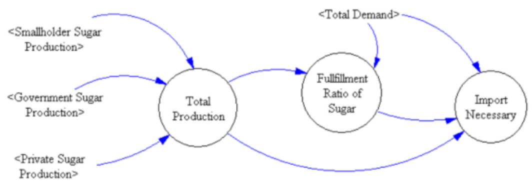

Figure 6: The Flow Diagram of Sugar Fulfillment Ratio

The equation of sugar fulfillment ratio is provided in Equation 13.

$$\text{Fullfillment ratio of Sugar} = \text{Total Production/ Total Demand} \tag{13}$$

The fulfillment ratio of sugar was around 46.2% in 2015 as seen in Figure 7.

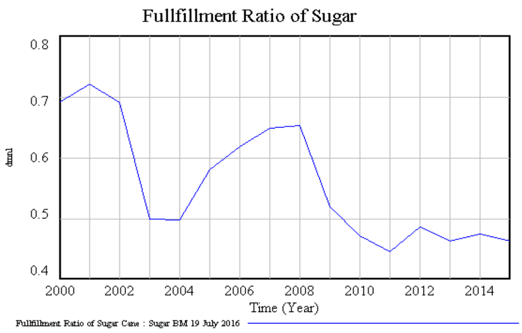

Figure 7: Sugar Fulfillment Ratio

IV. Model Validation

Model validation is required to check the model accuracy. A model will be valid if the error rate is less than 5% and error variance is less than 30% [15]. We validate demand, land area, productivity and production submodel. The Error rate and error variance are defined in Equation (14) and (15).

$$ErrorRate = \frac{\left|\bar{S} - \bar{A}\right|}{\bar{A}} \tag{14}$$

$$ErrorVariance = \frac{\left|Ss - Sa\right|}{Sa} \tag{15}$$

where $\bar{S}$ = the average rate of simulation
$\bar{A}$ = the average rate of data
S_s = the standard deviation of simulation
S_a = the standard deviation of data

Data used in this research is obtained from Central Bureau of Statistics and The National Socioeconomic Survey.

Error rate of some variables of sugar model are depicted as follows:

1. Error rate "Sugar Demand" = $\frac{[4,177,076 - 4,147,685]}{4,147,685} = 0.007$
2. Error rate "Land Area of Private Sector" = $\frac{[101,971 - 101,100]}{101,100} = 0.0086$
3. Error rate "Yields Productivity of Private Sector" = $\frac{[81.83 - 81.11]}{81.11} = 0.089$
4. Error rate "Sugar Production of Private Sector" = $\frac{[671,116 - 664,572]}{664,572} = 0.009$

Meanwhile, the error variance of some variables of sugar model are depicted as follows:

1. Error variance "Sugar Demand" = $\frac{[902,288 - 976,402]}{976,402} = 0.08$
2. Error variance "Land Area of Private Sector" = $\frac{[13,942 - 16,675]}{16,675} = 0.16$
3. Error variance "Yields Productivity of Private Sector" = $\frac{[10.24 - 8.52]}{8.52} = 0.20$
4. Error variance "Sugar Production of Private Sector" = $\frac{[105,095 - 103,750]}{103,750} = 0.013$

Based on the above calculation, all the error rates are less than 5%, and error of variance is less than 30% which means that our model is valid.

V. Scenario Development

Scenario development is designed to increase the fulfillment ratio of national sugar through land expansion and intensification.

A. Land Expansion

The potential area of land expansion for sugar cane is still very wide in some provinces [16]. Ministry of Environment and Forests will allocate land expansion of around 600,000 hectares for sugarcane plantations [17, 18]. There is a potential area of 124,000 hectares in Madura suitable for sugar cane development [19].

This area of 600,000 hectares will be used for the long-term scenario. We assume that land expansion will be done gradually from the year 2016 - 2030, so that the land expansion will be conducted for 15 years or 40,000 ha per year. The flow diagram of sugar land expansion can be seen in Figure 8.

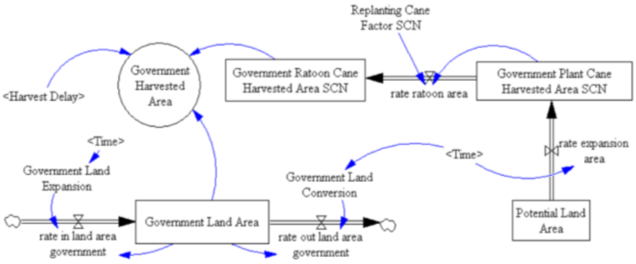

Figure 8: Sugar Land Expansion

The equation of Government Harvested area after land expansion can be seen in Equation (16) to (18).

$$\text{Government Harvested Area} = \text{GovernmentLandArea} + \text{Government RatoonCaneHarvestedAreaSCN} - ((\text{Government Land Area} + \text{Government Ratoon Cane Harvested Area SCN}) * \text{Harvest Delay}) \quad (16)$$

$$\text{Harvest Delay} = \text{IF THEN ELSE}(\text{Time} > 2007, 0.016, 0) \quad (17)$$

$$\text{Goverment Land Area} = \int \textit{Rate in land area goverment} - \textit{Rate out land area goverment} \quad (18)$$

With this land expansion, government harvested area would be around 606,617 ha, as seen in Figure 9.

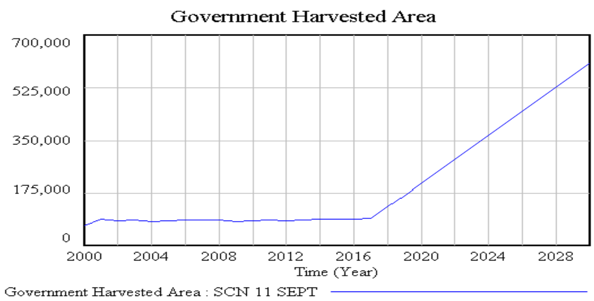

Figure 9: Land Expansion Scenario

B. Land Intensification

Land intensification can be done through:1)balanced fertilization with the composition of ZA 800 kg/ha + SP-36 100 kg/ha + KCl 100 kg/ha [11]; 2)Adequacy of water; 3)the implementation of ratoon system: new varieties of sugarcane are the result of crossbreeding with previous sugarcane as well as the improvement of soil and irrigation. In order for Indonesia to reduce the dependence of raw sugar (raw sugar) imports, it is recommended to use the Unloading Ratoon program that dismantles old sugar cane and replaced with new seeds, so that the productivity of sugarcane per hectare increases and the problem of shortage of sugarcane supply during this time can be slightly overcome [20]. The flow diagram of cane land intensification can be seen in Figure 10. The equation of land intensification can be seen in Equation (19) to (21).

$$\text{Government Plant Cane Yields SCN} = \text{Impact of Altitude} + \text{Impact of Climate} + \text{Impact of Crop Rotation Gov Area} + \text{Impact of Fertilizer Gov Area} + \text{Impact of Irrigation Gov Area} + \text{Impact of New Improved Seed SCN} + \text{Impact of Soil Gov Area} \quad (19)$$

$$\text{Government Cane Production} = (\text{Government Yields} * \text{Government Harvested Area}) + (\text{Government Plant Cane Harvested Area SCN} * \text{Government Plant Cane Yields SCN}) \quad (20)$$

$$\text{Government Sugar Production} = \text{Actual Rendemen Gov Area} * \text{Government Cane Production} \quad (21)$$

Based on the simulation results and projection in 2030, the government production is projected to be 5.98 million tons (after land expansion and intensification); smallholder production is projected to be 2.67 million tons (after land intensification); and private production is projected to be 1.27 million tons (after land intensification).

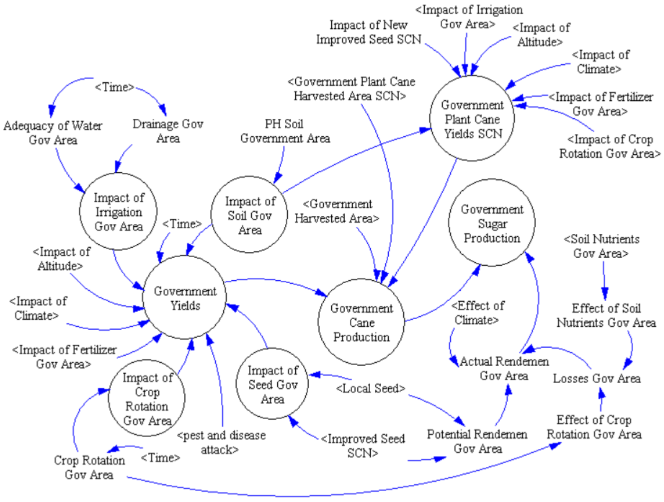

Figure 10: Cane Land Intensification

C. Sugar Fulfillment Ratio After Land Expansion and Intensification

This scenario is made to check sugar fulfillment after land expansion and intensification. Based on the simulation result, the sugar fulfillment ratio would be greater than 1 starting from 2020, which means that we can fulfill national demand as seen in Figure 11.

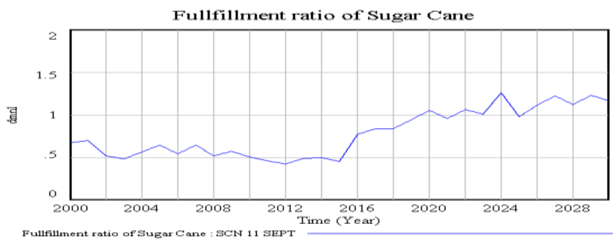

Figure 11: Sugar fulfillment Ratio after Land Expansion and Intensification

VI. CONCLUSION

The demand for sugar is the summation of industry and household demand. Household demand is influenced by national population and direct consumption. Meanwhile, industry demand depends on indirect consumption and national population.

Sugar production is influenced by cane production and rendement. Cane production depends on cane yields and harvested area. Cane yields are influenced by seed, fertilizer, crop rotation, rainfall, temperature, humidity, altitude, adequacy of water, pH (potential of Hydrogen) of soil, pest and disease that may attack. Balanced fertilization, irrigation management, crop rotation, the implementation of ratoon system, the use of high-quality seed are required to improve cane productivity.

Sugar fulfillment ratio depends on sugar production and demand. With the land expansion of around 40,000 ha per year for 15 years, government harvested area would be around 606,617 ha in 2030. Fulfillment ratio after land expansion and intensification would be greater than 1 starting from 2020.

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