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Integrated Nuclear-Renewable Energy System for Industrialization in West Nusa Tenggara Province, Indonesia: Economic, Potential Site, and Policy Recommendation

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ABSTRACT

Industrialization on renewable energy is needed to begin to avoid dependence on fossil fuels. West Nusa Tenggara (NTB) Province has the potential for the development of bioethanol which is integrated with the Small Modular Reactor (SMR) nuclear reactor. Through this study, the economics of sugar- ethanol plant and SMR reactors was calculated, as well as development schemes supported by policy recommendations will be presented. This study uses cash flow modelling from a sugar-ethanol plant and SMR to determine the economics of the project. The potential site is mapped by using scoring method to obtain the best location. The SMR reactor can operate with Internal Rate of Return (IRR) of 9%, Net Present Value (NPV) USD 2,325,347,181, and payback period 13 years. The sugar-ethanol plant has IRR of 12.6%, NPV 441,278,716, and payback period of 10 years. The appropriate locations for the construction of the SMR reactor are in Bima and Dompu districts, based on mapping analysis both locations have potential for future development.

Keywords: Small Modular Reactor, Sugar, Ethanol, Economics, Mapping, Policy
JEL Classifications: P28, P48, Q48

1. INTRODUCTION

Industrialization has an important role in driving national economic growth, between economic growth and manufacturing has a significant correlation (Gerring et al., 2022; Haraguchi et al., 2019; Usman and Balsalobre-Lorente, 2022). This theory related to Caldor's Law that (1) manufacturing is an engine of economic growth, (2) manufacturing growth is able to increase productivity in manufacturing through dynamics and statistical scales, and (3) manufacturing productivity can cause rapid productivity growth in other economic sectors (Alexiou and Tsaliki, 2010; Di Meglio and Gallego, 2022). The impact of Covid-19 pandemic has slowdown in the economic growth 2020 between -0.4% and 1%. In 2021, Based on Ministry of National Development Planning the Government of Indonesia assigned its economic growth in 2024 based on the National Long-Term Development Plan (RPJMN) was 5.4-5.7% (Ministry of National Development Planning, 2021). This economic growth will certainly affect the massive increase in energy consumption patterns. Economic growth and energy consumption become an inseparable part. Economic growth is driven by industrialization, urbanization, and transportation infrastructure which influenced by energy consumption such as oil and coal. The rise in energy consumption is accompanied by rapid economic growth. The rise of energy consumption will accelerate economic growth because energy is an element in economic growth and the relation between both of those variables are related (Waheed et al., 2019; Woldemedhin et al., 2022).

Crude oil production in Indonesia continues to decline from year to year. In 1996 Indonesia's oil production was 548,648,300 barrels. In 2020 Indonesian oil production was only half of oil production in 1996, which was arround 258,420,000 barrels, down 3% annually (Indonesian Statistics, 2018; SKK Migas, 2020). There is no balance between the discovery of new oil sources and oil exploitation activity. The fuel consumption continues to increase by 2.5% every year which impacts national compulsory to diversify its energy resources (British Petroleum, 2019).

The Government is committed to improve the renewable energy mix as enshrined in Government Regulation No. 79 of 2014 which concern to The National Energy Policy that in 2025 the goals of energy mix for new renewable energy are 23%. The government has also set mandatory biodiesel and bioethanol for transportation and manufacturing as fuel. In 2025 the government is targeting mandatory biodiesel mandatory by 25-30% for all sectors, while for bioethanol 20% for several sectors such as the Public Service Obligation (PSO) & non-PSO for transportation sector and industry. Maulidia et al. in her article stated that the implementation of mandatory fuel has many obstacles, among others the causes are such as mandatory program is still unclear, availability fossil fuel subsidies, bureaucratic processes, and limited institutional capacity (Maulidia et al., 2019).

To encourage the use of renewable energy it needs a study about the policy framework and development scheme for renewable energy implementation. The development of renewable energy is also to encourage industrialization in eastern Indonesia, especially in the West Nusa Tenggara (NTB) Province. The NTB Province had experienced negative economic growth several times. The NTB Gross Domestic Product (GDP) relied on the agriculture sector and the mining and quarrying sector, where GDP growth in this dominant sector is volatile every year. Ditambah dampak covid-19 PDRB NTB mengalami negative di quarter II – IV 2021. In addition, the impact of COVID-19 on NTB's GDP was negative in the second to fourth quarter of 2021 (Bank of Indonesia, 2022, 2019). Those two sectors has a major role in regional income. To reduce the income dependency from the natural resource sector, the concept to be developed is constructing a new factory based on renewable energy that will be able to improve the NTB economy while realizing the mandate of PP No. 79/2014. The concept is increasing the renewable energy mix through the production of energy-based ethanol from a 300 MW small modular reactor (SMR) nuclear power plant.

Mignacca and Localtelli defined that SMR is the latest version of nuclear reactor generation which has a power plant design of up to 300 MW (Mignacca and Locatelli, 2020). Its Components and systems can be fabricated at the place where the reactor is produced and transported to the installation site. While Zohuri and Vujic showed their research that SMR is a safer, simpler, and standardized reactor compared to current reactors (Vujić et al., 2012; Zohuri, 2019).

Increasing ethanol production will push the use of renewable energy mix higher. Indonesia is a world sugar-producing country, where in 2018 Indonesia was the 16th largest sugar producer in the world with total production 2,200,000 tons (United States Departement of Agriculture, 2020). By looking at this opportunity, it is suitable for the development of sugarcane-based ethanol. One example of a successful country using ethanol from sugarcane is Brazil. Mączyńska et al. research shows that the use of renewable energy in Brazil has reached 42%, where 18% is bioenergy fuel derived from sugarcane (Mączyńska et al., 2019).

The greater profits are obtained if the construction of an ethanol plant is integrated with sugar production. Based on Liang et al. study there is an additional profit by 12% if the factory operates only by producing sugar and 42% of the profit when the factory operates by producing sugar and ethanol products (Liang et al., 2012). Ethanol production is obtained from sugarcane processing residual products, namely molasses, so the factory gets additional revenue from ethanol sales. By using an integration scenario between sugar and ethanol production, the issue of food security for energy production can be overcome. Greene et al. shows his report that the residual heat from SMR can be used for processing in biorefinery, so that the utilization of heat from the integration between SMR and biorefinery can be more optimal (Greene et al., 2009). Previous research conducted a study on the integration of SMR with renewable energy based microgrid, technologically SMR has the potential to replace fossil fuels. However, little research on the integration of SMR and renewable energy due to the lack of an SMR market and systematic investigation (Michaelson and Jiang, 2021).

This study examines the economics of sugar-ethanol plant and SMR as an energy source that will supply to the plant. On the other hand, it also conducts potential site analysis to determine the potential site for SMR and sugar-ethanol plant. So that it needs a comprehensive policy strategy to accelerate its implementation. Land availability is one of the keys to the successful development of this ethanol-based renewable energy for sugarcane commodity. Critical land has the potential to be used as sugar cane production. Based on Statistics Indonesia, NTB has a potential critical land area of 444,409 ha (Statistic Indonesia, 2013). The land is spread both inside and outside of the forest area. Critical land within the forest area can be managed with existing Social Forestry schemes (Village Forests, Community Forests, Community Plantation Forests, Customary Forests, and Forestry Partnerships) where the potential area of social forestry land in Indonesia is 12,700,000 ha (Fitri Nurfatriani and Alviya, 2019).

By calculating the cost of electricity generation from SMR and the production cost of a sugar-ethanol plant, the operational feasibility data of the plant will be obtained from this study for the implementation of renewable energy program. The development scheme for the use of new renewable energy can improve the energy mix in the future through recommendations based on economic analysis of the plant. The plant operational feasibility analysis is the initial foundation in developing the policy framework. The integration of policies that have been formed is important to maximize positive impacts on society. The outputs from the economic calculations and policy implementation schemes in this study can later be used as a reference in decision making.

1.1. Long History Indonesian Nuclear Policy

Indonesia currently has three nuclear research reactors. Indonesia's first reactor was built in Bandung in 1960 and named TRIGA Mark II. Then Indonesia rebuilt its second research reactor in Yogyakarta in 1979 and was named the Kartini Reactor. In 1987 Indonesia rebuilt a multipurpose reactor with a capacity of 30 MW. Indonesia has a long history of plans to build a nuclear power plant. Since 1970 the government has conducted a pre-feasibility study for the first time for a nuclear power plant project. Until 1996 a study on the proposed site for the construction of a nuclear power plant was completed, and it was planned that the first reactor would be operational in 2020 to provide electricity for the Java-Bali system.

Public acceptance of nuclear power plants is a very important indicator. The construction of a nuclear power plant in Indonesia has become a political issue and currently, the construction of nuclear power plants still faces public opposition (Sugiawan and Managi, 2019). One of the causes of low public acceptance of nuclear power plants is the impact of nuclear disaster. Therefore, policymakers need to focus on changing public attitudes towards nuclear energy. Kim et al. demonstrated that several cases of nuclear disasters in the world, especially in Fukushima, reduce public acceptance of nuclear energy in the world. In 2016, the support for the construction of nuclear power plants reached 77.53% (Kim et al., 2013). Wisnubroto et al. did the survey which indicated that the Fukushima incident in 2011 yielded less support at only 59.7% in general and only 35% for Bangka Belitung. This was due to opposition from several local Non-Governmental Organizations which refuse the nuclear power plants program (Wisnubroto et al., 2019).

1.2. Integrated Sugar-Ethanol Plant and SMR

The integration between facilities which provide several forms of services such as electricity, heating, cooling, and some chemical products could be regarded as polygeneration. Similarly, nuclear energy can be integrated with new renewable energy sources and form a nuclear-renewable hybrid energy system (Redfoot et al., 2022; Rubio-Maya et al., 2011; Suman, 2018). Table 1 illustrates examples of integration between nuclear energy and renewable energy and the corresponding outputs. There are several key points to note in the integration of nuclear energy with new renewable energy sources which is an increase in component costs and additional risks associated with system integration. A substantial initial investment is required since the process involves combining two energy-producing sources.

1.3. Sugar-Ethanol Production

During a bioethanol process, sugar cane that has been processed in the pre-treatment stage (cleaning, unloading, and breaking) is extracted using a mill. At this stage, sugar cane is separated between the juice and the bagasse. Warm water is typically added during the imbibition process to increase sugar recovery. This milling process requires a steam turbine and therefore will consume more energy. The juice is subsequently evaporated to produce a sucrose solution. This solution is then concentrated in a vacuum pan to increase the sucrose content and produce crystalline sucrose. In the next process, raw sugar is produced by repeatedly centrifuging sucrose crystalline to increase the productivity of raw sugar. By-products from sugar production are subsequently fermented and distilled to produce ethanol at 95% content. To be used as fuel, it is dehydrated until an ethanol level of 99.3% is reached (Dias et al., 2015; Nichols and Bothast, 2008).

Table 1: Examples of Integrated Nuclear-renewable Systems (Suman, 2018)

Energy sources		Possible outputs
Nuclear	Wind	Electricity, hydrogen
Nuclear	Solar	Electricity, heat
Nuclear	Biomass	Electricity, biofuels
Nuclear	Geothermal	Electricity, heat
Nuclear	Wind and Natural Gas	Electricity, chemical product, synfuel

1.4. Production Economics

Ethanol could be produced from several feedstocks, such as starchy, sugary, and other materials that contain cellulose. Several studies (Table 2) demonstrated that the highest productivity of ethanol was produced from sugar cane and sugar beet feedstock products because they contain sugar and starch content.

Table 2 illustrates that sugar cane has the highest productivity value per hectare. Furthermore, a by-product from sugar production in the form of molasses is produced and could be processed into ethanol. From an economic standpoint, a sugar factory integrated with ethanol production will yield higher profit margins (Table 3).

2. METHODS

This study was conducted to examine the economic calculation of the plant, determine the most suitable location and formulate the appropriate implementation policy (Figure 1). The economic

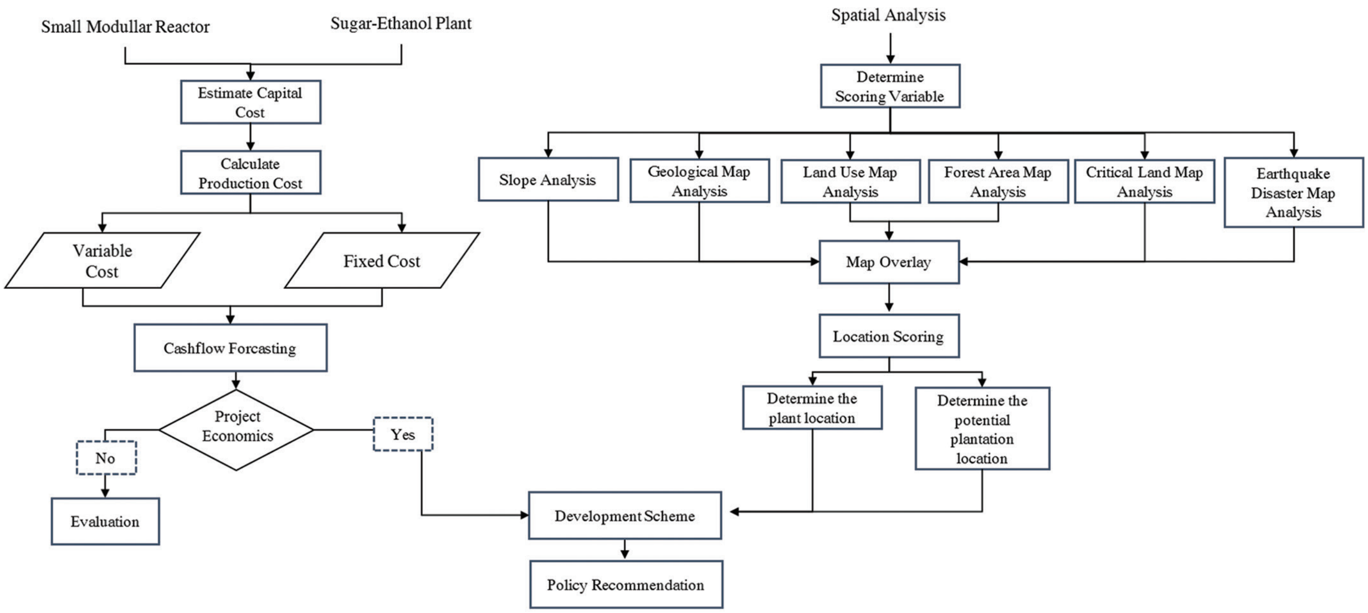
Table 2: Productivity from Various Feedstock Sources (Budimir et al., 2011; Nichols and Bothast, 2008; US Department of Agriculture, 2006)

Commodities	Ethanol conversion factor (litre/ton)	Ethanol conversion factor (litre/ha)
Corn	371.23	1,295
Sugar cane	73.71	6,500
Sugar beets	93.74	6,270
Molasses	262.332	547,75
Raw sugar	551.812	-
Refined sugar	532.98	-

Table 3: Profit Comparison from Various Feedstock (Liang et al., 2012)

Project (USD)	Sugar product only	Sugar combined with ethanol fuel	Ethanol product only
Total cost	7,608	7,395	6,102
Ethanol fuel product income	-	1,268	8,876
Sugar product income	11,412	10,937	-
Molasses income	428	-	-
Total income	11,840	12,205	8,876
Profit	4,232	4,810	2,774

Figure 1: Research flowchart



calculation of the plant was carried out on two plants, namely the sugar-ethanol plant and SMR with a capacity of 300 MW. The calculation of the economic feasibility requires the constituent costs in the production of products from the plant and compilation of cash flow which was carried out to determine the plant operating profit or loss using the existing parameters.

2.1. Sugar-Ethanol Plant and SMR Capital Cost

Capital cost plays a significant role in the SMR cost structure, constituting 50-75% of the total cost (Mignacca and Locatelli, 2020). Both the capital costs for the sugar-ethanol plant and the SMR are calculated based on the benchmark from the existing plant. The approach used to estimate capital cost is to use sixteenth rules and the Chemical Engineering index to adjust the time of plant construction (Richard Turton et al., 2012) (Table 4).

$$\frac{C_a}{C} = \left(\frac{A_a}{A_b}\right)^n \quad (1)$$

Note:
A = Equipment cost
C = Purchased cost
n = Cost exponent.

The capital costs of SMR ranges from 2,100 USD/KWe to 3,500 USD/KWe and may even be higher (Nian and Zhong, 2020). Capex is obtained from two funding sources, that are equity and debt. Based on financial modelling, debt is to be paid within 30 years for an SMR and 20 years for a sugar-ethanol plant. Repayment of debt is subject to the principle of compound interest, hence there are two costs that must be returned, namely principal amount and interest payment. The following Table 5 illustrates the financial parameters used in financial modelling:

Table 4: Capital cost estimation

Plant benchmark	Capacity	Capital cost (1,000,000 USD)
SMR		
SMART - Korea (2015)	100 Mwe	497, (Kessides and Kuznetsov, 2012)
CAREM - Argentina	27 Mwe	860, (Delmastro et al., 2004; Kessides and Kuznetsov, 2012)
Sugar-ethanol plant		
Fincha Sugar (1998)	110,000 ton/year	132, (Schmidt et al., 2018)
Kessen Sugar (2015)	153,000 ton/year	297, (Schmidt et al., 2018)

Table 5: Financial parameters

Parameters	Value
Equity to debt ratio	40:60
Interest rate	3.74%
Depreciation period	50 years
Return on debt period	30 years for SMR and 20 years for sugar-ethanol plant
Operating life	50 years for SMR and 30 years for sugar-ethanol plant
Construction period	4 years both for SMR and sugar-ethanol plant

After determining financial parameters, weighted average cost of capital (WACC) was calculated to determine the economic basis of the project.

2.2. Assessing the Production Costs

Production costs consist of fixed costs and variable costs (Table 6). The benchmarks used to describe the two types of costs are as follows:

In several studies stated that the calculation of energy balance during fuel processing uses an assumption of 4.9% uranium enrichment with fuel burn up of 60 GWd/tU (Hussein, 2020; International Atomic Energy Agency, 2002a, 2002b). To determine the energy used in uranium enrichment, a Separative Work Unit (SWU) was calculated using a spreadsheet equation as follows (K. T. Brown, 1977; Lamarsh and Baratta, 2001; Rothwell, 2018) (Table 7):

$$SWU = P(2xp-1)\ln\left(\frac{xp}{1-xp}\right) + W(2xw-1)\ln\left(\frac{xw}{1-xw}\right) - F(2xf-1)\ln\left(\frac{xf}{1-xf}\right) \quad (2)$$

Note:
P = Mass of product (enrichment uranium)
W = Mass of waste
F = Mass of feedstock
Xw = Assay of waste
Xp = Assay of product
Xf = Assay of the feedstock.

The sugar price refers to the auction price conducted by the company to the distributor with the highest retail price of Rp. 12,500.00 (Minister of Trade, 2018). The selling price of sugar increases in line with an average increase in inflation of 4.67% (an average of 10 years of inflation) (Bank of Indonesia, 2020). The price of uranium was determined using an escalation in price of 0.5% per year (Trading Economics, 2020). The price of electricity was determined using the electricity generation cost in NTB province, equivalent to USD 19.18 cent per kWh (Minister of Energy and Mineral Resources, 2019) with an escalation benchmark of electricity prices at 2% per year (Nuryanti et al., 2015). In terms of variable costs, adjustments were made using the Chemical Engineering Plant Cost Index to estimate costs from the year the cost base was used (McAloon et al., 2000).

Cash flow forecast based on Zong (Nian and Zhong, 2020) and (Mignacca and Locatelli, 2020) was carried out for a lifetime of 50 years for the SMR and 30 years for the sugar-ethanol plant. Construction of the plant was determined based on (Rath and Morgan, 2020) and was assumed for 48 months for an SMR with

Table 6: Fixed cost determination

Fixed costs	
SMR	
O&M (USD/Kwh)	0.01182, (Boarin and Ricotti, 2014)
O&M escalation (per year)	1%, (Komanoff, 1982)
Depreciation rate (per year)	6%
Sugar-ethanol plant	
O&M	3% from capex
Depreciation rate (per year)	6%

Table 7: Variable cost determination

Variable costs	
SMR	
Natural uranium consumption (tU/year)	55
Uranium price (USD/kg)	25, (Trading Economics, 2020)
Uranium price escalation (% per year)	0.5, (Du and Parsons, 2009)
Conversion cost (USD/kg U	8.6, (Pannier and Skoda, 2014)
Enrichment cost (USD/SWU)	105.33, (Pannier and Skoda, 2014)
Fabrication cost (USD/kg UO2)	295.57 (Pannier and Skoda, 2014)
Transport and storage (USD/KgHM)	132.4 (Pannier and Skoda, 2014)
Disposal (USD/Kg)	228.61, (Ko and Gao, 2012)
Reactor decommissioning cost (USD/kWe)	411.5, (Khattak et al., 2018)
Project management (USD/kWh)	0.0417, (Nuclear Energy Agency, 2016)
D&D (USD/kWh)	0.034 (Nuclear Energy Agency, 2016)
Site restoration (USD/kWh)	0.0056 (Nuclear Energy Agency, 2016)
Sugar-ethanol plant	
Sugar production	
Sugar cane Feedstock (tonne/year)	1,715,383.5
Sugar cane price (USD/tonne)	34
Electric consumption for sugar production - 15 USD/kWh (kwh/year) (Suman, 2018)	25,730,753
Labour (USD/kg)	0.0272, (US Department of Agriculture, 2006)
Chemical (USD/kg)	0.003, (US Department of Agriculture, 2006)
Materials and supplies (USD/kg)	0.0123, (US Department of Agriculture, 2006)
General and administrative (USD/kg)	0.0226, (US Department of Agriculture, 2006)
Ion exchange column regeneration and GAC (USD/litre ethanol)	0.02, (Rein, 2008)
Ethanol production	
Electricity	
Fermentation and distillation – 0.188 USD/litre ethanol, (kWh/year) (Khatiwada and Silveira, 2009)	3,230,083
Dehydration – 0.199 USD/litre Ethanol, (kWh/year) (Khatiwada and Silveira, 2009)	3,418,504
Effluent treatment process – 0.0840 USD/litre ethanol, (kWh/year) (Khatiwada and Silveira, 2009)	1,435,592
Lighting and facilities – 0.139 USD/litre ethanol, (kWh/year) (Khatiwada and Silveira, 2009)	2,386,672
Molecular sieve for dehydration – (USD/litre ethanol)	0.088, (Bhatia, 2014)
Enzyme (USD/litre ethanol)	0.0935, (Sandra T. Merino and Joel Cherry, 2007)
Denaturant (USD/litre ethanol)	0.017, (US Department of Agriculture, 2006)

a capacity factor of 90-95%. The construction of a sugar-ethanol plant takes 3 years with a production of 95% of the total capacity. The SMR refuelling based on (Rowinski et al., 2015) is substituted every 36 months with additional cost of storing used fuel once every five years (Ko and Gao, 2012).

2.3. Potential SMR Site Investigation

The plant's potential site could be determined using several methods, one of which is the ranking method, where, according to (Abudeif et al., 2015), the criteria are ranked based on certain preferences. Arc Gis 10.2 software was used to analyse the site location. In the initial stage of determining the potential sites, analysis of the regional geology of the construction area was carried out, using IAEA report as the benchmark (International Atomic Energy Agency, 1984). Further analysis was conducted by overlaying several maps, namely distribution of community settlements maps, land status maps, earthquake-prone areas maps, contour maps, and imagery. The following are indicators used in site assessment (Table 8):

After determining the criteria for location mapping, the data used for mapping, namely geological maps, slope maps, building maps, earthquake hazard maps, and forest area maps, were prepared. The data were subsequently overlaid with each other based on criteria and parameters according to (Susiati et al., 2015) and the results of the intersection were tabulated in Table 9:

The minimum score was set at 104. A site with a score of lower than 104 could be categorized as unfit for plant construction, whereas a site with a score higher than 104 could be categorized as feasible or considered as a prospective plant site.

3. RESULTS AND DISCUSSIONS

Both the sugar-ethanol plant and the SMR must operate profitably at the same time because these two plants constitute an integrated system. To determine the economic aspects of the operations of the SMR and the sugar-ethanol plant, an economic analysis is needed. Energy and mass balance is the basis for conducting an economic analysis of the project. The results of the economic calculation based on the results of cash flow modelling during the factory operation are presented as follows.

3.1. Techno-economics Aspect

Capital cost plays a significant role in the electricity generation process using nuclear energy. The calculation demonstrated that the estimated capital expenditure with a capacity of 300 MW for the Small Modular Reactor – Presurrized Water Reactor (SMR-PWR) is approximately USD 2.26 billion with the capital cost per kWe of USD 7,559 USD per KWe. These estimates are considered within reasonable range when compared to two existing SMR-PWR reactors in Korea and Argentina. Nevertheless, a further benchmark with other SMR capital costs calculation that have been operated needs to be carried out. Based on Nian and Zong, the capital cost of an SMR varies from USD 2100 per KWe to USD 5,000 per KWe, with the possibility of reaching USD 9,000 per kWe. In comparison, the KLT-40S SMR reactor has a capital cost of USD 3,314 per kWe, while the HTR-PM is at USD 3,270 per kWe, and the Hualong One SMR is at USD 3,500 per KWe. Energy balance calculation using 4.9% Uranium enrichment and 60 Gwd/tU burn-up required a natural Uranium (U_3O_8) feed up to 58 tU. (John R. Lamarsh, 1983) demonstrated that the conversion process from U_3O_8 to UF_6 caused Uranium loss of 0.5%, resulting in the UF_6 to reach 55.2 tU. The results of the calculation on the enrichment process required 34,549 kg of SWU energy.

The economic calculation (Figure 2) demonstrated that the capital cost holds the largest proportion with a percentage of 65.9%. Based on calculations by (Antony et al., 2017), who calculated the levelized cost of hydrogen production using nuclear reactors, capital costs are the largest component at 71% including debt as component. O&M costs constitute 28.9% of the overall cost, while decommissioning cost stands is at 2.85% and front end and back end fuel cycle cost at 2.5%. The Straight line depreciation simulation was used to calculate depreciation costs per year in the next 50 years and in the 50th year the SMR operations would have a salvage value of USD 51,557,359.

Figure 2: Cost breakdown of SMR electricity generation

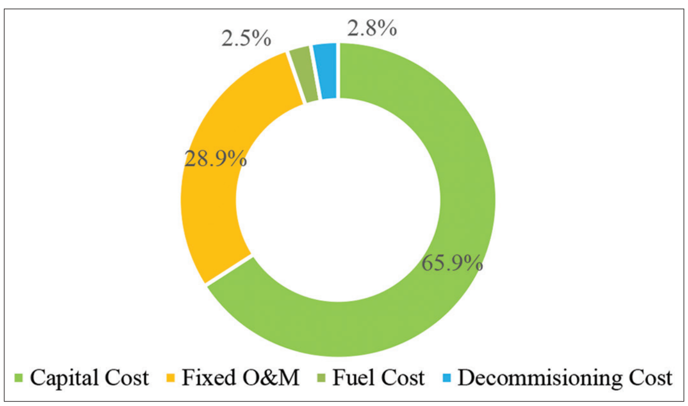


Table 8: Plant site criteria

Criteria	Reference
Distance to settlements and public facilities	The first zone is within a radius of 1 km from the facility, no permanent settlements and other facilities are allowed. The second zone is at a radius of 5 km from the facility and the third zone is at a radius of 20 km from the facility (Khattak et al., 2017).
Slope	<12%, (Damoom et al., 2019)
Proximity to petrochemical plants	5 km, (Damoom et al., 2019)
Distance to potential cooling water	<32 km, (Damoom et al., 2019)
Land use status	Must be outside the protection zone, (Damoom et al., 2019)
Distance to fault zone	40 km, (Eluyemi et al., 2020a)
Seismicity	Low earthquake risk, (Abudeif et al., 2015)
Subsurface soil	Soil layers do not have a significant response to seismic activity, (Abudeif et al., 2015)

Table 9: Weighting and Rating Parameters (Baskurt and Aydin, 2018; Eluyemi et al., 2020b; Susiati et al., 2015)

Parameter	Weight	Criteria	Score
Fault zone distance	10	>40 km	3
		Radius 25-40 km	2
		Radius 25 km	1
Earthquake hazard	8	Very high	5
		Low	3
		Moderate	2
		High	1
		Very high	0
Seismicity (magnitude)	8	<6	5
		6 – 7.5	3
		>7.5	0
Availability Cooling water	8	<10 km	4
		10-20 km	3
		20-30 km	2
		>30 km	1
Lithology	8	Igneous rock	4
		Metamorph	3
		Sediment	2
		Alluvial	1
Distance to settlement	6	Radius >20 km	3
		Radius 20 km	2
		Radius 5 km	1
Land cover	6	Empty land	3
		Bushes	2
		Plantation	1
		Forest cover	0
Slope	4	< 12.5°	4
		12.5° – 15°	3
		15° – 25°	2
		25° – 45°	1

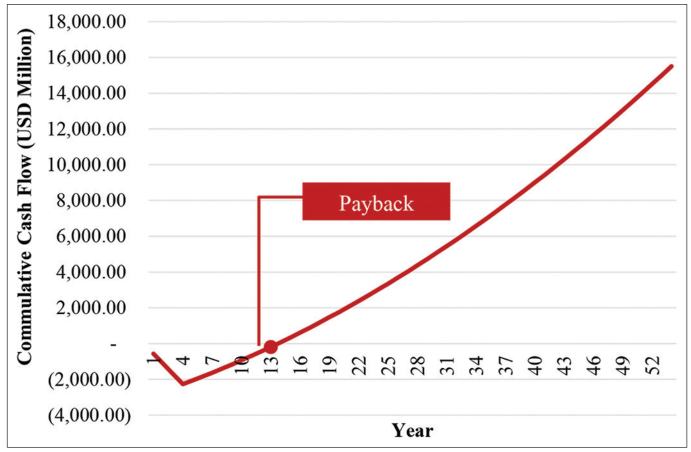
Table 10: Site scoring results for SMR

Indicators	Weight	SMR 1	Value	SMR 2	Value
		Score		Score	
Fault zone	10	3	30	2	20
Earthquake hazard	8	2	16	2	16
Seismicity	8	5	40	5	40
Cooling water	8	4	32	4	32
Lithology	8	4	32	4	32
Settlement distance	6	3	18	2	12
Land condition	6	3	18	3	18
Slope	4	4	16	4	16
Total			202		186

The current price of electricity generation in NTB is USD 19.18 per kWh and the annual average revenue obtained is USD 666,672,249. Therefore, 50 years of operation would generate an IRR of 9% and NPV of USD 2,325,347,181, where the WACC calculation result is at 5.17%. The SMR operation would achieve a payback period of 13 years (Figure 3) after the SMR is operating commercially. The SMR payback period typically ranges between 13-15 years according to (Mario D. Carelli and Daniel T. Ingersoll, 2015).

The levelized cost calculation resulted in the generation cost for SMR of 13.5 cents USD per kWh. As a comparison, SMR reactors operating in Russia, such as ABV PWR type, have generation cost of 12 cents USD per kWh, according to (Mario D. Carelli and Daniel T. Ingersoll, 2015). Other reports by (Nuclear Energy

Figure 3: SMR Payback period



Agency and OECD, 2016) indicated that SMR generation costs may reach 20 cents USD per KWh. When compared to other existing power plant levelized costs in Indonesia, IESR report (IESR, 2019) demonstrated that power plants using natural gas fuel has a levelized cost of approximately 6.69 cents per kWh, coal mine mouth at USD 5.01 - 7.31 cent per kWh, coal subcritical at USD 6.11 - 8.41 cent per kWh, supercritical coal at USD 5.77 - 8.05 cent per kWh, ultra-supercritical coal at USD 5.83 - 8.38 cent per kWh, onshore wind at USD 7.39 - 16.1 cents per kWh, solar at USD 5.84 - 10.28 cent per kWh, geothermal at USD 4.56 - 8.7 cents per kWh, and biomass at USD 4.68 - 11.4 cent per kWh. The comparison indicated that the cost of SMR is way higher than other power plants because of its expensive development cost.

Ethanol production is targeted at 17,100 KL per year and 177,635 tons of sugar per year with a capacity factor of 95%. Ethanol production is expected to meet the energy mix target in NTB Province with productivity of 52.2 tons/ha of sugar cane and 5.41 tons/ha of sugar (Directorate General of Estate Crops, 2018). Based on the mass balance calculation, one ton of sugar cane produce 40 kgs of molasses and an area of one hectare produces 2.9 tons of molasses. Therefore, in one hectare there is a potential molasse of 547.75 l (1 tonne of molasse can produce 262.33 litre of ethanol). The estimated cost of capital for sugar capacity is USD 411,996,493.

The plant operates by producing white crystal sugar and ethanol. The by-products of sugar production, in the form of molasses, would become feedstock for ethanol production. Hence, there are two revenue sources from the plant operation, namely white crystal sugar and ethanol. Figure 4 illustrates the calculation results of the cost of producing sugar and ethanol. The variable cost of sugar production constitutes the highest cost at 76.41%. This is due to the high need for feedstock cane. The price of cane plays a key role in regulating the amount of sugar production costs. In Figure 4 shows that the variable costs of sugar production consist of energy costs (4.3%), labour costs (4.3%), chemical costs (0.5%), material and supplies (2%), general and administrative costs (2%), feedstock costs (82.9%), and granular activated carbon costs (2.4%). On the other hand, the variable costs for ethanol production include energy costs (43%) and chemical costs (57%).

The selling price of sugar and ethanol products are the driving factors in increasing company profits. With a reference price of Rp. 12,500.00, the reference ethanol price is Rp. 10,244.00 and the parameter of average inflation over the past 10 years is 4.67%, generating an IRR of 12.6% and NPV of USD 441,278,716, where the WACC calculation result was at 6.68%. Figure 5 illustrates that the company payback period is 10.06 years. With an operational period of 30 years, based on the results of calculations using the straight-line depreciation method, at the end of the operational year, the factory has a salvage value of USD 64,376,761.

Integration between SMR and the sugar-ethanol plant could operate economically if the development cost of SMR is more economical. This integration concept would not succeed if only one of the plants is economical. For future development, the SMR could be opted as an alternative diversified energy. Up to date, SMR is still on progress for commercial development.

3.2. Potential Site for Plant Development

An integrated plant consisting of a sugar-ethanol plant and an SMR must carry out strict procedures in determining the location of the factory. To anticipate the occurrence of nuclear accidents that impact on society and the environment, early mapping needs to be conducted. Locating potential sites is an initial step before proceeding with more detailed field studies. Mapping is carried out using available data to determine a safe zone to set up a nuclear reactor.

Figure 4: Cost breakdown of sugar and ethanol production

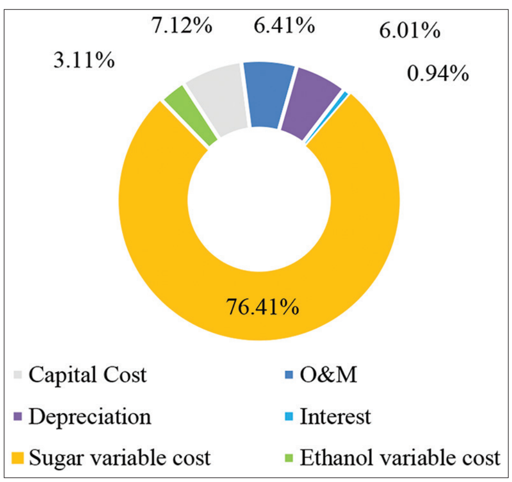
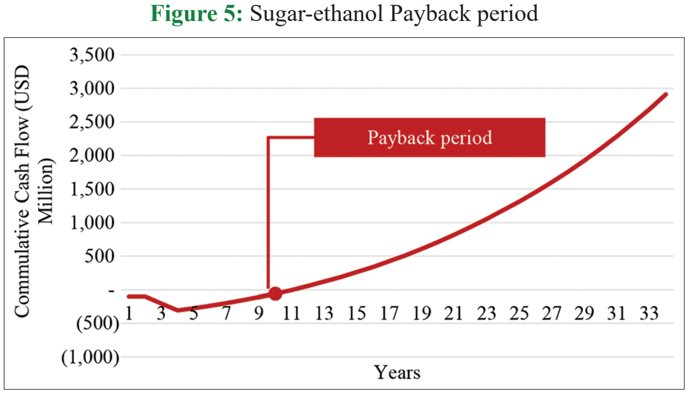


Figure 5: Sugar-ethanol Payback period



Potential locations for the SMR and sugar-ethanol plant have been identified at two locations in Bima and Dompu District. Figure 6 demonstrates the analysis result of the fault zone in the northern part of NTB Province. The map was also overlaid with seismicity in NTB Province. To analyse the potential of an earthquake, it was overlaid with an earthquake hazard index map issued by the National Disaster Management Agency. The best scoring site is a factory with a fault location of more than 40 km. Based on an analysis using the buffer feature in Arc Gis, SMR 1 is located outside the fault zone. However, SMR 2 is in 25 km radius fault zone. In terms of earthquake hazard levels, the two SMR sites have a moderate level of earthquake potential. Numerous earthquakes occurred all at magnitude scale of less than 6.0 (Figure 6).

The potential sites for the construction of nuclear reactors must in proximity to water sources, which would be used for the reactor cooling system. Both the locations of SMR 1 and SMR 2 are located on the shoreline, making it easier to obtain water for cooling process. The preferable lithology for nuclear reactor sites is composed of stable and hard rock structures (Damoom et al., 2019). In Figure 3, SMR 1&2 are located in areas with igneous rock structures such as andesite, breccia, tuff, and volcanic ash. Land slope modelling (Figure 7) demonstrates that the two reactor locations are in the slope of 0-12.5^{o}. Reviewed on the land use (Figure 8), the two potential lands are outside of forest area with no vegetation cover. Land acquisition would be easier when the site is within the APL area not covered by forest and there are no settlements at potential locations of SMR 1 within a radius of 5 km and 25 km. However, at the potential location of SMR 2, there are several settlements within a radius of 25 km. The following Table 10 summarizes the total score for the potential SMR 1 and 2 sites:

Table 10 shows that both potential locations have scores above the eligibility threshold. The potential location of SMR 1 has a higher score due to several factors such as the location of the fracture and the distance of the settlements (Figure 9).

3.3. Policy and Development Scheme

The key to the success of this development program is the availability of land and vacant land is available in the NTB Province for the development of sugar cane commodities. The scheme developed is using degraded land for sugar cane plantations. Critical land in NTB is located in both forest and non-forest locations, both of which could be used to grow sugar cane. If the development of sugar cane plantations is on critical land whose status is included in the forest area, it can be aligned with the existing government program, namely the Social Forestry program. Based on the Indicative Map and the Social Forestry Area (PIAPS) of the Ministry of Environment and Forestry, NTB Province has a potential land area of 281,760 ha (Ministry of Environment and Forestry, 2019)and the land area needed to produce ethanol is 14,000 ha. Figure 10 illustrates the potential of social forestry land and critical land that could be used for the development of sugar cane commodities. The critical land is located in the forest and non-forest zone, and there is also land that is included in PIAPS. Sugar cane commodity development can

Figure 6: Fault, seismicity, and earthquake hazard index (Indonesian National Board for Disaster Management, 2020; Meteorology, Climatology, and Geophysical Agency, 2020)

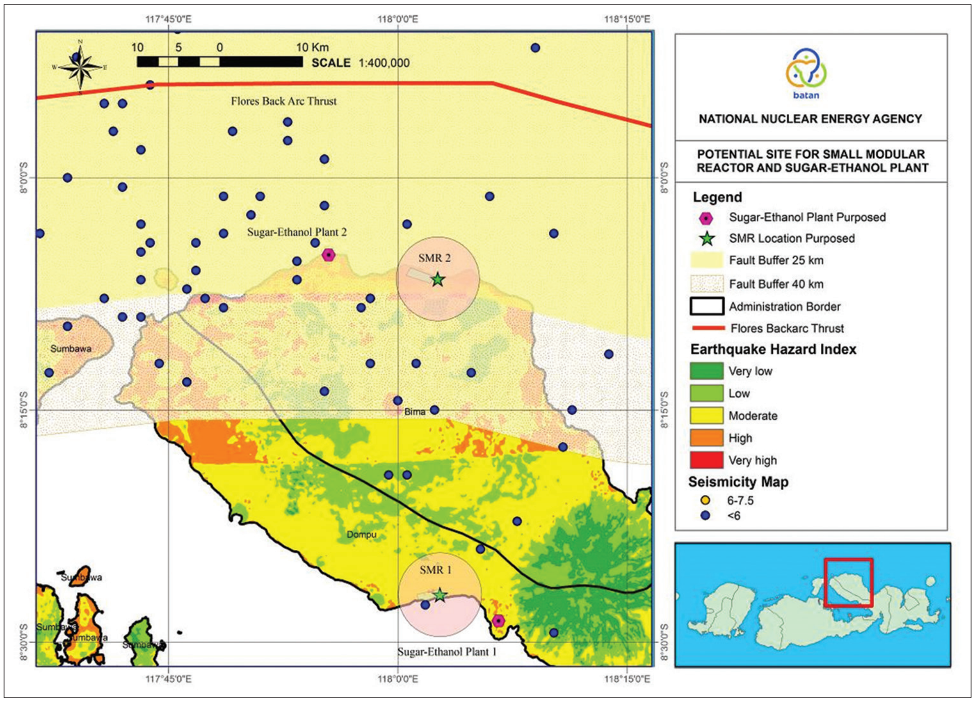
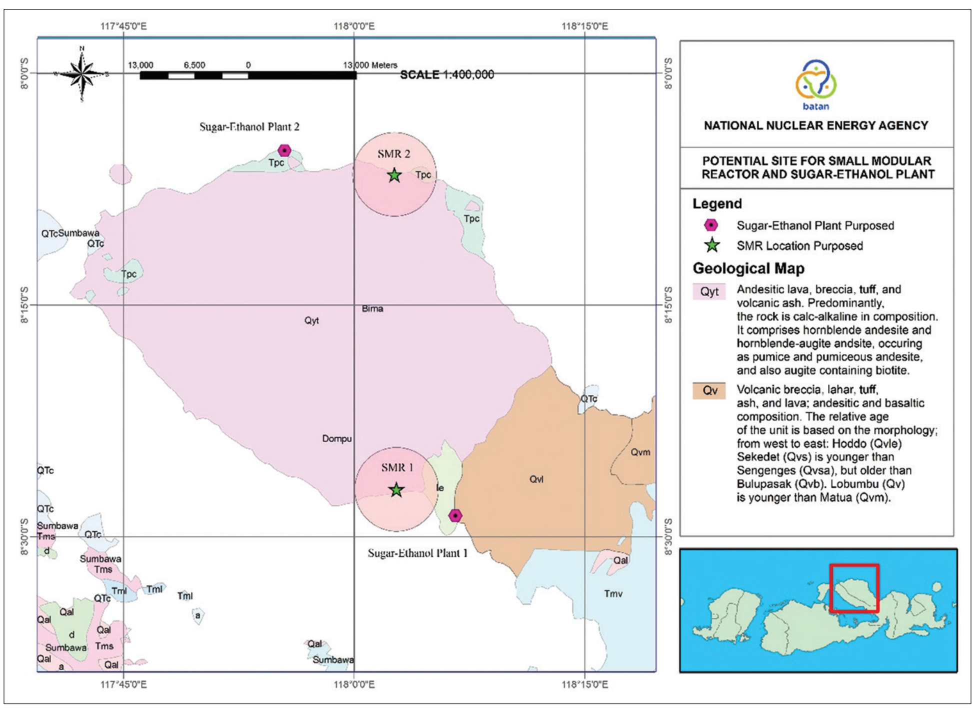


Figure 7: Fault, seismicity, and earthquake hazard index (Indonesian National Board for Disaster Management, 2020; Meteorology, Climatology, and Geophysical Agency, 2020)



be done on forest and non-forest land. For land in the forest area category, social forestry schemes are allowed to be carried out.

In developing this scheme, the implementation could not be undertaken by the Indonesian government alone. The involvement of a state-owned company or investors that provide funds for the development of factories and commodities are necessary. In addition, another support is also needed from farmers as land tenants and local governments. State-owned enterprise companies that could participate in this scheme include PT. Perkebunan Nusantara (PT. PN).

Figure 11 illustrates a business process policy implementation scheme where PT. PN or a private company with farmer association collaborate to develop sugar cane commodity. PT. PN or the private company has the duty to manage commodity products and provide

Figure 8: Slope map analysis

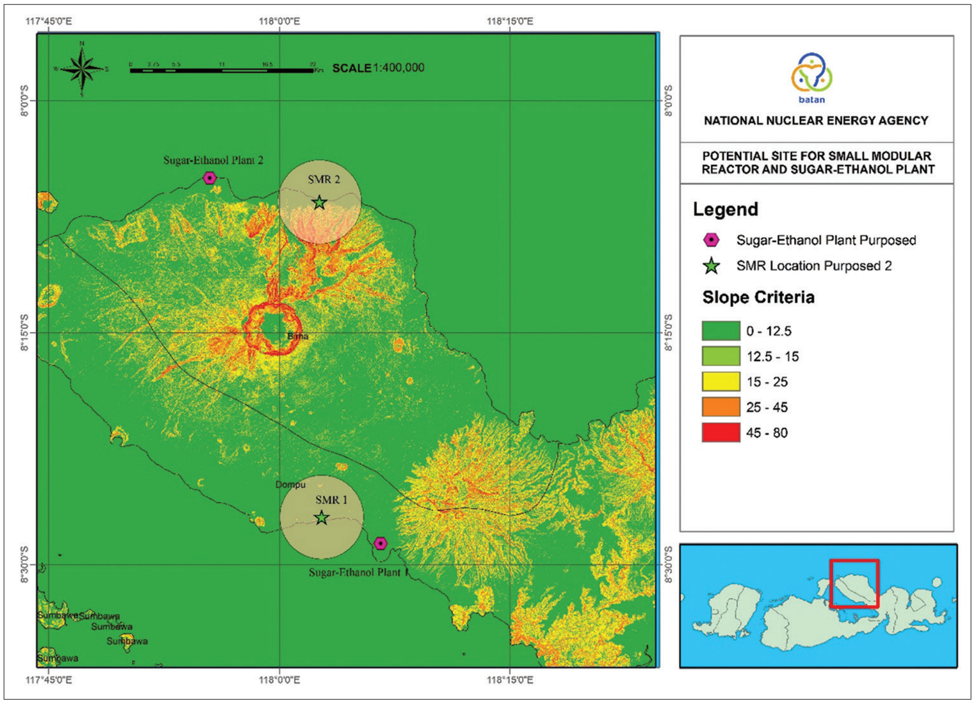
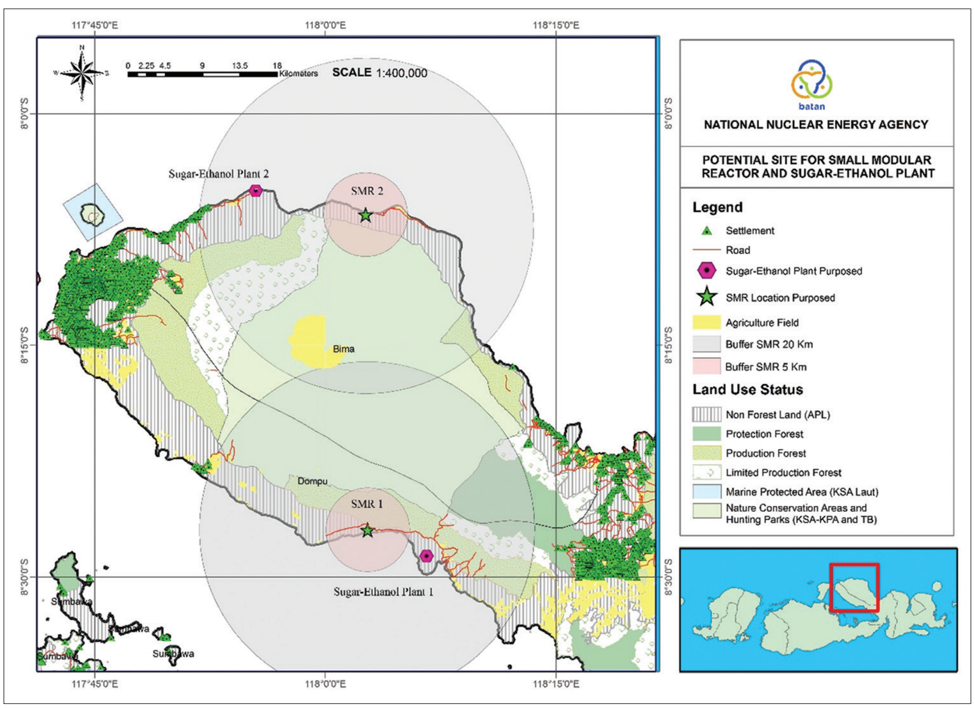


Figure 9: Land use map



new land to be used for sugar cane plantations, meanwhile in the process of land preparation, the budget for the land clearing process could be handled by the central and regional governments which would eventually be returned with a profit-sharing system with the company. The government and the company are to provide assistance for land management and to strengthen farmers' finances, banks could provide micro-credit programs (KUR) for farmers as starting capital. The policies needed to encourage the development of renewable energy based on nuclear energy are as follows:

- Open investment opportunities through fiscal and non-fiscal incentives for investors;
- Implementation of mandatory policies on the use of ethanol with a strong legal basis to encourage stakeholders to succeed in the ethanol program;
- Ethanol price control to ensure stability and competitiveness, (if the price is higher than the price of fossil fuels, it is difficult to diversify renewable energy);

Figure 10: Available land for Sugar cane plantation

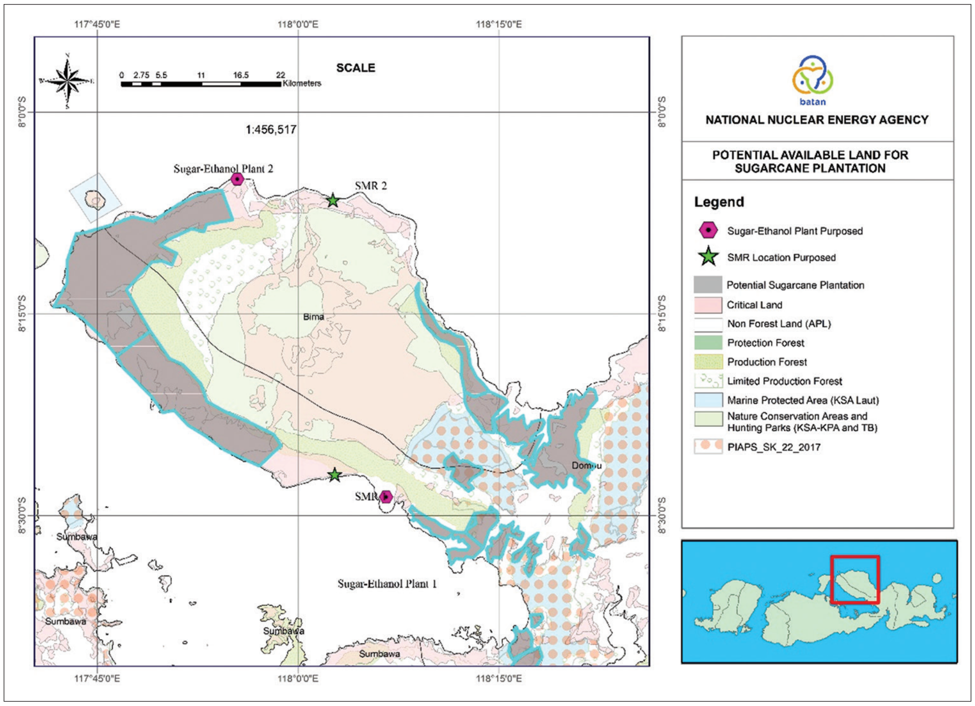
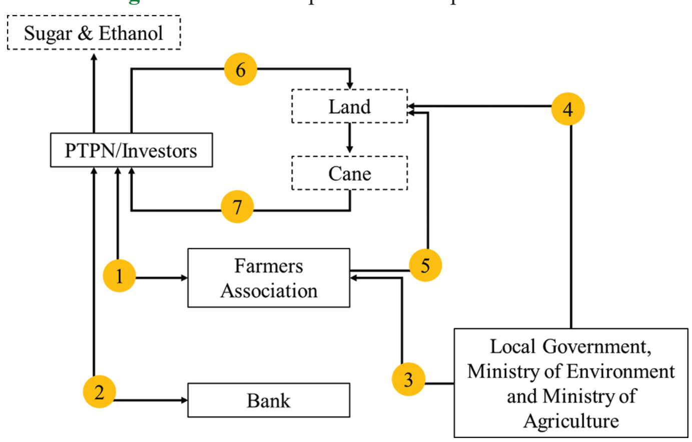


Figure 11: Business process development scheme



- Integration of existing government programs such as the Social Forestry program so as to create new, efficient economic resources;
- Campaigns for more efficient and cleaner sources of nuclear energy for the community welfare; and
- Competitive electricity pricing policy to enable investors and users to create a price balance between companies and users.

4. CONCLUSION

Based on economic calculations, the SMR has an IRR from of 9% and 13 years payback period, whereas the sugar-ethanol plant has an IRR of 12.6% and a payback period of 10.06 years. This integrated concept will be an economical option in the future and the SMR could be a diversified energy option for processing feedstock. Presently, the development of SMR as a source of energy processing is still way behind other sources of energy (coal, fossil fuel, etc.), hence there is a need to reduce the cost, especially the capital cost. In NTB Province, there are several potential locations for SMR development, namely in Bima and Dompu. To harmonize with the renewable energy utilization program, land is also available for the development of sugar cane commodities which are used as feedstock to produce sugar and ethanol. Economically, the SMR and the sugar-ethanol plant are very feasible to be developed, employing of a scheme which involves state-owned and private companies to participate in programs to increase the use of renewable energy. The policies needed to encourage this renewable energy development program could be in the form of incentives from the government, strong regulations, product price competitiveness, integration of existing government programs, campaigning for the use of nuclear energy, and competitive electricity tariffs for companies and users.

5. POLICY IMPLICATIONS

The implementation of industrial development policies based on nuclear and renewable energy has several policy implications:

- The industrialization development scheme involves high investment costs. Large resources both from internal and external parties are required to realize the policy. The government needs to provide the broadest possible incentives to investors.
- The use of nuclear energy requires enthusiasm from both the government and the community. It is necessary to conduct a positive campaign for the use of nuclear energy, to counter parties who oppose the use of nuclear energy.
- This policy would have an impact on regional economic development and therefore it is necessary to improve the mechanism for empowering energy resources from upstream to downstream. The business processes involved are typically sophisticated and fiscal instruments for agriculture are needed

to ensure that the development of sugar commodities remains economical and farmers' income improves. For downstream products, fuel products from sugar cane requires price incentives or price control in order to be able to compete with fossil fuel prices which are much lower. Competitive prices would help increase Indonesia's energy mixed in terms of renewable energy.

- By looking at the prospect of land used for the development of sugar cane commodities, it is necessary to harmonize policies that encourage the production process to downstream. This policy involves many stakeholders and the government needs to focus on programs to improve farmers' welfare and the energy mixed, hence stakeholders need to synergize to jointly realize the policy.

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