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Technoeconomic Analysis of Integrated Bioethanol from Elephant Grass (*Pennisetum purpureum*) with Utilization of Its Residue and Lignin

Analisis Teknoekonomi Bioetanol Terintegrasi Berbahan Baku Rumput Gajah (Pennisetum purpureum) dengan Pemanfaatan Limbah dan Lignin

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Abstract

Bioethanol has been developed as an alternative biofuel. Elephant grass is one of the lignocelluloses that can be used as a source of bioethanol. The bioethanol fermentation process should be improved along with its economic competitiveness to promote its wider application. This study aims to investigate and to evaluate the best scheme of biethanol (standalone) and the combination of bioethanol and its by-products through technoeconomic analysis. The method used is collecting data from several previous studies and simulating it with SuperPro Designer. Data from flowsheeting simulation is used as economic simulation data using Microsoft Excel. The results of this study indicate that the processing of biogas and lignin waste as fuel and lignosulfonates can increase the economic value of the bioethanol production process. The best economic value is the bioethanol production process using biogas and lignin as fuel for a Biomass Power Plant which is called *Pembangkit Listrik Tenaga Biomassa* (PLTBm) with a Net Present Value (NPV) of IDR 364,358,976,036, Internal Rate of Return (IRR) 11.32%, Pay Back Period (PBP) 7.2 years, and Profitability Index (PI) 1.08

Keywords: bioethanol, biogas, elephant grass, lignosulfonate, SuperPro Designer

Abstrak

*Bioetanol telah dikembangkan sebagai bahan bakar nabati alternatif. Rumput gajah merupakan salah satu lignoselulosa yang dapat digunakan sebagai sumber bioetanol. Proses fermentasi bioetanol harus ditingkatkan seiring daya saing ekonomi untuk mempromosikan penerapannya yang lebih luas. Tujuan studi ini adalah untuk menginvestigasi dan mengevaluasi skema terbaik bietanol (*standalone*) serta kombinasi bioetanol dan produk sampingnya melalui analisis teknoekonomi. Metode yang digunakan ialah melakukan pengumpulan data dari beberapa penelitian sebelumnya dan disimulasikan dengan SuperPro Designer. Data dari simulasi flowsheeting digunakan sebagai data simulasi ekonomi menggunakan Microsoft Excel. Hasil studi ini menunjukan bahwa pengolahan biogas dan limbah lignin sebagai bahan bakar dan lignosulfonat dapat meningkatkan nilai ekonomi dari proses produksi bioetanol. Nilai ekonomi yang paling baik adalah proses produksi bioetanol dengan pemanfaatan biogas dan lignin sebagai bahan bakar Pembangkit Listrik Tenaga Biomassa (PLTBm) dengan nilai* Net Present Value *(NPV) Rp 364.358.976.036-;* Internal Rate of Return *(IRR) 11,32%,* Pay Back Periode *(PBP) 7,2 tahun, serta* Profitability Index *(PI) 1,08.*

***Kata kunci:** bioetanol, biogas, lignosulfonate, rumput gajah, SuperPro Designer*

INTRODUCTION

The supply of fuel in 2017 to 2025 is estimated to not be able to meet domestic fuel consumption. This is because the increase in fuel consumption exceeds the increase in fuel supply. Fuel supply in 2025 is estimated to reach 651,092 million barrels (104 GL), while fuel consumption will reach 719,048 million barrels (115 GL) (Sa'adah et al., 2017). The efforts to ensure supply security and achieve energy independence have been carried out by the government in the Minister of Energy and Mineral Resources No. 12/2015 (which is called *Permen ESDM No. 12/2015*) by issuing a policy on the minimum target of using biofuels by 2025 of 20% of national energy consumption. (Kementerian Energi dan Sumber Daya Mineral, 2015).

One of the materials developed as an alternative biofuel is bioethanol. The total production of the ethanol plant reaches 0.53 GL per year and there are several new plant developments with a capacity of 3.12 GL per year until 2010(Siahaan et al., 2013). Not all ethanol products produced meet the criteria as a premium fuel mixture. Ethanol products produced by the Agency for the Assessment and Application of Technology which is called *Badan Pengkajian dan Penerapan Teknologi* (BPPT) are not included in the anhydrous 99.5% specification, so they require additional materials and methods to increase their purity. This causes the production cost to be more expensive so that the bioethanol is less effective to be used as a mixture in fuel. The need for ethanol as a fuel mixture in 2020 is estimated to reach 5,528 GL. Import capacity is estimated at only 163,075 kL, while export needs may increase to 18,467 GL, so that a deficit of 23,992 GL is estimated. The new supply capacity reached 0.016% of the total target and export needs. The comparison of capacity to the target ethanol demand is only about 0.068%. It can be seen that there is a decrease in the ratio between the capacity and target use of ethanol as a fuel mixture. Therefore, additional bioethanol production capacity is needed to achieve this target.

One of the biomass that can be used as raw material for making bioethanol is elephant grass (*Pennisetum purpureum* or *napier grass*) because it has a fairly high cellulose content (Nasution et al., 2016; Herawati et al., 2019). The availability of elephant grass in Indonesia is very large because elephant grass is easy to grow in any environmental conditions and the harvest time is relatively fast. The first harvest of elephant grass was done at 90 days post-planting. The next harvest is once every 40 days in the rainy season and every 60 days in the dry season. Forage production of elephant grass is between 525 tons of fresh grass per hectare per year or about 63 tons of dry grass per hectare per year. Rejuvenation of old plants from elephant grass is done after 5-6 years to be replaced with new plants (Singh et al., 2013). The need for elephant grass to produce 1 L of bioethanol is 4.05 kg, so the estimated area of elephant grass cultivation land to set up a bioethanol factory with a capacity of 60,047 kL per year is 3,857 ha. The Provincial Government of West Nusa Tenggara stated that there is a productive forest land (Limited Production Forest which is called *Hutan Produksi Terbatas* or *HPT*) covering an area of 33,000 ha in North Lombok (Badan Penelitian dan Pengembangan Energi Sumber Daya Mineral, 2019). The availability of this vast land shows that the potential of elephant grass as a raw material for bioethanol will not interfere with the availability of animal feed. Therefore, the potential of elephant grass to be used as a source of renewable energy is quite large.

Research on the production of bioethanol from elephant grass has been carried out quite a lot, especially in Indonesia (Nasution et al., 2016; Pobas et al., 2017; Herawati et al., 2019). The results of the conversion of bioethanol from elephant grass are quite varied. The results are influenced by the type of hydrolyzer, reaction time, pH, and time of hydrolysis and fermentation. The results showed that the yield from the conversion of elephant grass into bioethanol was around 17.3% - 27.83%. Liu et al. (2018) conducted a biofuel feasibility analysis study by combining life cycle assessment and economics. Liu et al. (2017) stated that the yield of bioethanol production from elephant grass in Hawaii is significantly low and the financial analysis of the bioethanol production project from elephant grass is not positive. This is due to the low yield of bioethanol conversion so that the selling price is higher than fossil fuels. Capital risks for new technologies and production costs of biomass cultivation need to be reduced (Popp et al., 2014). The cost of making bioethanol from biomass also needs to be reduced. Oyegoke & Dabai (2018) Oyegoke analyzed the feasibility of sugar-based bioethanol using Aspen Hyprotech Systems (HYSYS) software. The cost of production of bioethanol is \$0.61/L or IDR 8845/L. Technoeconomic studies of grass and straw based bioethanol have also been carried out. The results of this study indicate that the net present value (NPV) of the standalone bioethanol industry, without the use of side products, is negative or unprofitable. (Song et al., 2014; Achinas et al., 2019). Lignocellulosic biorefinery for biofuel production requires increasing the value of all fractions (lignin and unreacted organic matter) in order to be more cost effective (de Jong et al., 2017).

The government targets around 4.99 million kL of bioethanol in 2025 so that the lignin waste produced is around 4.7 million tons. (Sahoo et al., 2011). The development of added value from lignin is considered very important and a challenge to achieve a sustainable economy and reduce carbon on earth (Sahoo et al., 2011; Dong et al., 2011). Therefore, this study calculates the technological feasibility of bioethanol by utilizing its by-products such as solid waste (lignin) and liquid waste from bioethanol production (fermentation). This study aims to investigate and evaluate biethanol (standalone) and the combination of bioethanol and its by-products through technoeconomic analysis. This investigation aims to obtain the best scenario for the feasibility of bioethanol from elephant grass. The feasibility of bioethanol was assessed in several scenarios by utilizing fermentation by-products as biogas and lignin by-products as fuel and lignosulfonates.

METHODS

This study was conducted by making several scenarios. The scenario is a bioethanol integration business scheme that is varied to increase the feasibility value of elephant grass as a raw material for bioethanol production which is shown in Table 1. The capacity of the bioethanol production process analyzed in this study is 60,047 kL/year. This capacity is to meet 0.25% of the total deficit in bioethanol needs.

Data processing was carried out using SuperPro Designer Flowsheet software for the analysis of bioethanol, biogas, and lignin production technology analysis, and the energy required during the production process. The research stages used to analyze production refer to secondary data based on available documents, books, scientific journals, previous studies related to bioethanol production and the results of research that has been carried out on a laboratory scale with optimal results. The secondary data includes data on bioethanol production from elephant grass, national bioethanol production and demand data, and related research results so that they can be used as references (covering the characteristics and properties of elephant grass to become fuel grade ethanol (FGE)), and other data. which is related).

Table 1. Scenario of bioethanol production process from elephant grass

Scenario	Process Detail
Baseline	Production of bioethanol (standalone)
Scenario 1	Utilization of bioethanol liquid waste as biogas (biomethane) through anaerobic digestion (AD), without the use of waste lignin.
Scenario 2	Development of scenario 1 by utilizing solid waste (lignin) as its own source of energy (own used), which is a substitute for electricity and steam from external sources and partly to be commercialized.
Scenario 3	Development of scenario 1 using solid waste (lignin) to be commercialized as *PLTBm*.
Scenario 4	Development of scenario 1 using solid waste (lignin) to be commercialized as lignosulfonate chemicals for plasticizers.

Data processing for economic feasibility analysis also uses secondary data. The data includes production capacity, mass and energy balance flows for each process, the size and specifications of the equipment used to produce bioethanol from elephant grass, cash flow over the life of the plant and the economic parameters of the factory with sensitivity values. The entire data is processed using a scientifically feasible and reliable techno-economic analysis. Techno-economic analysis is a methodological framework for analyzing the technical and economic performance of a process, product, and calculating production costs and market opportunities. (Zimmermann et al., 2020).

Technology Analysis

Flowsheeting Process

The flowsheeting process is carried out to determine the equipment used and calculate the consumption of raw materials, chemicals, and energy required during the production process. The flowsheeting process in this study is divided into 4 main processes, i.e. the bioethanol production process, the biogas production process, the power generation process, and the lignosulfonate production process. The content of elephant grass can be calculated based on wet weight or dry weight. The content of elephant grass in this study is the result of the characterization of Mohammed et al. (2015) which is shown in Table 2.

Table 2. The content of elephant grass

No	Component	Concentration (%)
1	Cellulose	34.21
2	Extractive	9.26
3	Hemicellulose	20.44
4	Lignin	24.34
5	Air	11.75
	Total	100

Source: Mohammed et al. (2015)

The bioethanol production process is simulated into 4 process stages, i.e., pretreatment, biogas production from bioethanol liquid waste, power plant production using lignin solid waste fuel, and lignosulfonate production from lignin filtrate. The pretreatment process is the process of cutting elephant grass to obtain high glucose levels and cellulose can be hydrolyzed with HCl solution (Noviani et al., 2014). Elephant grass is mixed with HCl solution until the mixed solution has a pH of 2.3 (Shang et al., 2017). The solution is added with NaOH solution to get a pH of 4.5 which is the optimum pH in the fermentation process (Zambare & Christopher, 2012; Le & Le, 2014). The fermentation process is carried out by adding 10% Saccharomyces cerevisiae starter into the solution under anaerobic conditions (Papapetridis et al., 2018). Fermentation is carried out for 6 days (Nasution et al., 2016). The resulting bioethanol content is then purified through a distillation process at a temperature of 70-80 °C (Yang et al., 2012; Nasution et al., 2016). Distillation was stopped after the volume of the bottom solution remained 10%. Further purification is carried out by a dehydration process, in which the resulting bioethanol distillate is dried using a molecular sieve. The process is carried out to obtain fuel grade ethanol.

The biogas production process from bioethanol liquid waste is carried out using anaerobic digestion (AD) technology. AD is a complex process involving two stages, namely decomposition by fast-growing acid-forming (acidogenic) bacteria and methanation by methanogenic bacteria. Hydrolysis and metabolism are carried out on cellulose, and hemicellulose in wastewater into short chains of acetic, propionic, and butyric fatty acids, as well as CO_2 and hydrogen (H_2) gases. Metabolism by methanogenic bacteria is carried out on most organic acids and all H_2. The end result is the production of a mixture of 55-70% CH_4 and 30-45% CO_2 which is called biogas. The most effective condition for converting organic acids into biogas are pH above 6 (Wang et al., 2019), sufficient time (usually more than 15 days) (Wang et al., 2019), and temperatures at or above 70 °F (Cho et al., 2013; Moset et al., 2015).

The production process of a power plant using lignin solid waste fuel requires the main components of a steam boiler and a steam turbine connected to a generator. Steam is generated in a steam boiler at high pressure (1.25 MPa) and continues to the turbine. Steam expansion is carried out in the turbine to run a generator that produces electricity.

The last process is the process of producing lignosulfonates from lignin filtrate. The filtrate from the delignification result was added with 2N H_2SO_4 solution and stirred until the solution reached pH 2. The solution was then filtered and dried. The dried filtrate was then dissolved in NaOH (as a base catalyst) and precipitated again with 2N H_2SO_4 dropwise. The lignin precipitate was filtered and dried at 50±2 °C. The filtrate is reacted with sodium bisulfite ($NaHSO_3$) to produce sodium lignosulfonate (Azadi et al., 2013; Mulyawan et al., 2015; Thungphotrakul et al., 2019). The yield of lignosulfonates obtained from lignin varies widely from 50-80% (Ismiyati et al., 2009). It is influenced by temperature and concentration of sodium bisulfite.

Net Energy Analysis

This energy analysis aims to identify environmental impacts and performance (Kapila et al., 2019) of bioethanol production based on the net energy for every 1 L of bioethanol from elephant grass feedstock. This net energy is for elephant grass feedstock, physical pretreatment of elephant grass, elephant grass conversion process which includes hydrolysis (saccharification), fermentation, and bioethanol separation, as well as utilization of waste from bioethanol which includes lignin and biogas. The net bioethanol energy system used in this study consists of inputs of raw materials and utilities (diesel, electricity, and steam), and product outputs. The equivalent energy of raw materials, chemicals, utilities, and products (bioethanol as the main product and lignosulfonate as a by-product) is shown in Table 3.

The net energy calculation model used is a model that has been developed by the Intergovernmental Panel of Climate Change (IPCC) to define the potential energy savings that can be provided by the use of bioethanol as an alternative fuel. The net energy value (NEV) and

Table 3. Equivalent energy per unit of raw materials, utilities and products

Component	Unit	Equivalent Energy	References
Elephant grass	MJ/kg	6.33	(Todaro et al., 2015)
HCl	MJ/kg	1.7	(Yamdagni & Kebarle, 1974)
NaOH	MJ/kg	1.5	(Lide, 1995)
Yeast	MJ/kg	16.1	
H_2SO_4	MJ/kg	3.7	
$NaHSO_3$	MJ/kg	0.811	(Calvo-Flores & Dobado, 2010)
Diesel	MJ/L	34.45	
Electricity	MJ	1	
Steam	MJ/kg	2.11	
Bioethanol	MJ/L	29.7	(Nwufo et al., 2016)
Biogas	MJ/m^3	36.6	(Pannucharoenwong et al., 2017)
Lignin	MJ/kg	26.58	(Todaro et al., 2015; Demirbas, 2017)
Lignosulfonates	MJ/kg	30.6	(Parto et al., 2019)

net energy ratio (NER) are calculated in this net energy analysis. NEV is the accumulation of energy resulting from the production of bioethanol by reducing the energy required from electricity, diesel, and steam (utility) to produce the bioethanol, while NER is the ratio of the energy produced to the energy required from converting elephant grass into bioethanol (Bello et al., 2012). NEV and NER are calculated by the following equation:

$$NEV = \sum(E_{eq} \times m_o) - \sum(E_{eq} \times m_i) \quad (1)$$

$$NER = \frac{\sum(E_{eq} \times m_o)}{\sum(E_{eq} \times m_i)} \quad (2)$$

where,
NEV = net energy value per liter bioethanol
NER = net energy ratio per liter bioethanol
m_i = the amount of incoming mass flow used by each part of the system
m_o = total mass flow out of each part of the system
E_{eq} = *equivalent* energy per unit of mass

The net energy of a good system is indicated by a positive NEV value and NER above 1.

Economic Analysis

The cost of producing bioethanol is the sum of the depreciation of investment costs and operational costs (Oyegoke & Dabai, 2018; Bulkan et al., 2020). The cost of producing bioethanol made from elephant grass is determined based on investment costs, operating costs, and taxes used in this economic analysis. Investment costs (Capital Expenditure or CAPEX) are all the capital to set up a factory since the business is started until the business is able to earn revenue from sales. The investment costs for bioethanol production made from elephant grass include the investment costs for main equipment and installation. Calculation of investment costs for reactors, fermenters, and utilities based on the Chemical Engineering Plant Cost Index (Dempfle et al., 2021).

Operating costs (Operating Expenditure or OPEX) include fixed costs (fixed costs) and variable costs (variable costs). Fixed costs are costs that do not depend on the amount of production (Pujawan, 2012). Fixed costs in the production of bioethanol are calculated based on employees' fixed salaries, depreciation and amortization, and fixed maintenance. Variable costs are costs that depend on the amount of production (Pujawan, 2012). The variable costs considered in this study include the cost of raw materials, supporting materials, utilities, and salaries of non-permanent employees.

The price of elephant grass feedstock used in this economic analysis simulation is IDR 18,500/m^3 (Fitriadi et al., 2017). This economic analysis uses the assumption that the discount rate is 10%, the factory age is 15 years, the price of chemicals uses an estimated price adjusted for price trends, and the selling price of bioethanol, biogas, and lignosulfonate products is IDR 6,950/kg, IDR 9,407.98/kg, IDR 10,660/kg respectively. Economic feasibility indicators used in this simulation are Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and Profitability Index (PI).

Sensitivity Analysis

Sensitivity analysis in a feasibility study is a calculation taking into account the uncertainty principle. Wang et al. (2013) Wang reviewed the sensitivity of bioethanol production based on paper waste with a range of 30-50% uncertainty from investment costs, raw materials, paper waste, prices and enzymes, while the uncertainty range for electricity is 10-20%. The elephant grass sensitivity analysis study shows that a 5% increase in the cost of elephant grass production affects farmers' income by around 25% (Fitriadi et al., 2017). Therefore, a sensitivity analysis was carried out by calculating the 25% change in several uncertainty factors related to the feasibility of producing bioethanol made from elephant grass. Uncertainty factors that can affect this calculation are elephant grass yields which can interfere with supply availability, elephant grass nutritional content which can indirectly affect bioethanol yields, and fluctuating electricity rates. This analysis is viewed from the variation of the selling price of bioethanol, the price of elephant grass, and the cost of electricity. This analysis aims to see the significance of the effect on NPV as an indicator of industrial feasibility.

RESULTS AND DISCUSSION

Flowsheeting Process

Flowsheet is a sketch diagram representing the relationship of a series of machines and equipment, the sequence of performance and the expected operating conditions of a proposed operating process flow or the actual performance of an already operating process (Couper et al., 2010). The stages of the bioethanol production process from elephant grass are pretreatment, hydrolysis, fermentation, distillation and reuse of waste resulted from the production process. Figure 1 shows a flow chart of the bioethanol production process from elephant grass.

Elephant grass is put into the hopper and chopped using a grinder in the pretreatment process so that it is smaller in size. The simulation results show a power capacity of 0.1 kW/(kg/hour) and a chopping capacity of 243 kton/year. The chopped grass are then transferred to the hydrolysis tank using a conveyor. In the hydrolysis process, there is a change in the breaking of the lignin bonds and the sugar polymer bonds (polysaccharides) into simple sugars. A good hydrolysis process is carried out under acidic conditions of pH 2.3 (Shang et al., 2017). The acid used in a year is 54.737 kton HCl. HCl is added to the hydrolysis tank so that the hydrolysis process can be carried out under acidic conditions. The function of the addition of this acid is to break the lignin bonds and sugar polymer bonds by hydrolysis. This hydrolysis process is important to facilitate the reaction in the next process. The temperature at which the sugar polymer breaks is 100-120 °C (Amezcua-Allieri et al., 2017; Rusanen et al., 2019). After the hydrolysis process was completed, the pH of the solution was conditioned to reach 4.5 using a NaOH solution of 59.73 kton/year. The inner

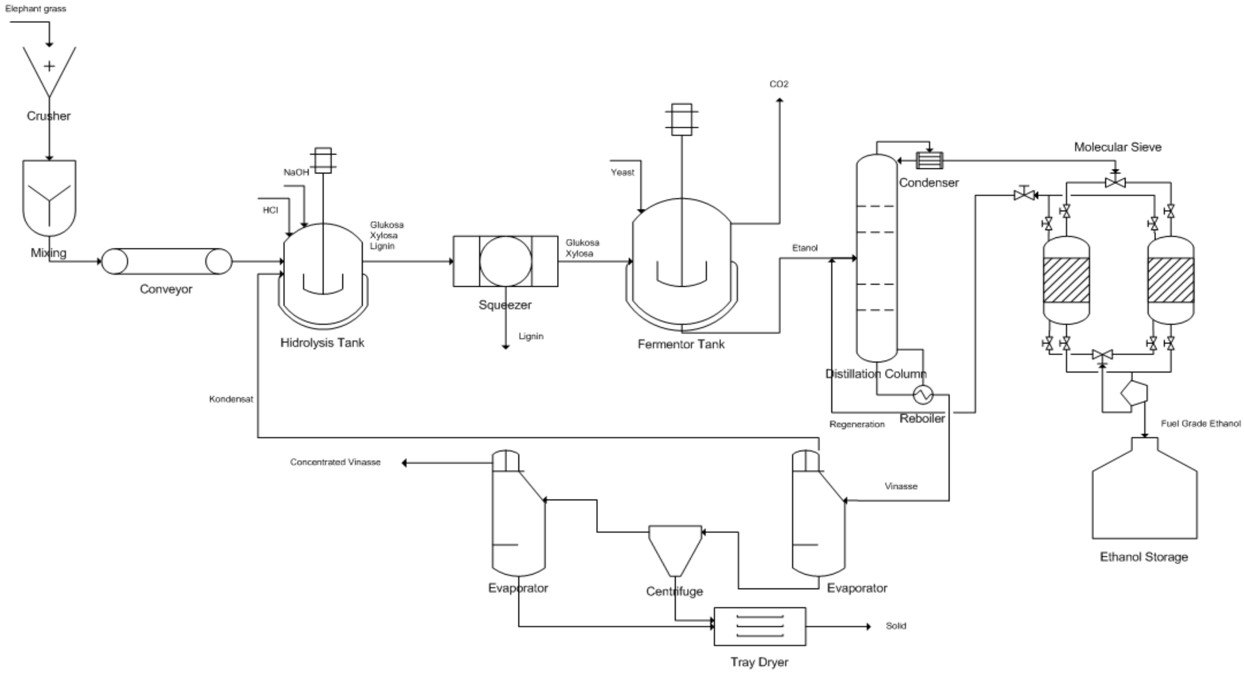

Figure 1. Process *Flow Diagram* of Bioethanol

lignin must be removed (delignified) so as not to block the fermentation reaction through the squeezer.

The next process is the fermentation process in the fermentation tank. Yeast of 23,325 kton/year was added in this process. The main process that occurs is the conversion process of monomer sugars (glucose and xylose) into ethanol. The CO_2 emission coming out of the fermenter in this simulation is assumed to be 100%. The equation for the reaction of the content of elephant grass into ethanol during the hydrolysis and fermentation processes is as follows:

1 Cellulose + 1 Water → 1 Glucose
1 Hemicellulose +1 Water→ 1 Xylose
1 Glucose→1 Hydroxymethylfurfural + 3 Water
1 Xylose → 1 Furfural + 3 Water
1 Glucose → 2 Ethanol + 2 CO_2
3 Xylose → 5 Ethanol + 5 CO_2

The CO_2 produced from the production of 1 kg of bioethanol made from elephant grass in this simulation is 0.96 kg. This was determined from the content of cellulose, hemicellulose, and extraction from elephant grass (Table 2). The total CO_2 that has the potential to be emitted from the use of raw materials to the bioethanol production process is 45,366 tons/year. This value is the same as bioethanol emissions produced from various other agricultural feedstock sources. Muñoz et al. (2014) has conducted a life cycle analysis of bioethanol from various agricultural products. The results of the calculation of CO2 emissions resulting from the production of 1 kg of bioethanol with various sources of agricultural feedstocks are between 0.7 – 1.5 kg CO_2. Bioethanol from the biosyngas fermentation process produces CO2 emissions of 1.19 – 1.32 kg CO_2/L bioethanol. This calculation does not include the process of degradation and release from the use of bioethanol into the air (end of life).

The next stage of bioethanol production is the distillation process and molecular sieve (P-42 & P-44). In this process, bioethanol and water are separated to obtain high-purity bioethanol (99.5%). The water that comes out of the distillation process will then be recycled to optimize process costs. The simulation results of bioethanol production from elephant grass obtained a yield of 24.6% and produced 60,047 kL bioethanol from 243 ktons of elephant grass per year.

Table 4. Mass balance in bioethanol production 60,047 kL/year from each scenario

Process/Material	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Material Input					
Elephant grass (kton)	243	243	243	243	243
Pretreatment					
Diesel (kL)	31.812	31.812	31.812	31.812	31.812
Conversion					
Electricity (TJ)	35.142	35.608	35.608	35.608	35.142
Steam (kton)	710	710	710	710	710
HCl (ton)	54.737	54.737	54.737	54.737	54.737
NaOH (ton)	59.73	59.73	59.73	59.73	59.73
Yeast (kton)	23.325	23.325	23.325	23.325	23.325
Sulfonation					
H_2SO_4					35
NaOH (kton)					5.235
$NaHSO_3$ (kton)					1.848
Material Output					
Waste Treatment					
Biomethane (GL)		19.865	19.865	19.865	19.865
Lignin (fuel) (kton)			26.410	57.824	
Electricity (TJ)			35.608		
Steam (kton)			710		
Lignosulfonates (kton)					42.817
Final product					
Bioethanol (kL)	60,047	60,047	60,047	60,047	60,047

Table 4 shows the mass balance, composition of raw materials, and utilities required at each stage of the bioethanol production process as much as 60,047 kL for each scenario of bioethanol production from elephant grass. The resulted waste will be utilized through scenario 1 to scenario 4. Scenario 1 utilizes liquid bioethanol waste as biogas (biomethane) through anaerobic digestion (AD), without the use of lignin waste. The remaining waste of cellulose, hemicellulose, glucose, xylose and others that do not react completely into ethanol will be utilized as biogas. The anaerobic process is a complex process involving various groups of bacteria. The group of acid-forming bacteria in the form of acetic acid will be utilized by acetotroph methanogenic bacteria to form methane gas while the gas produced in the form of CO2 and H2 gas will be utilized by the hydrogenotroph methanogenic bacteria group to form methane gas. (Ahmad et al., 2011).

The simulation results show that the waste produced has a chemical oxygen demand (COD) value of 40 kton/year. COD is the total amount of oxygen required to chemically oxidize organic matter (Lumaela et al., 2013). The COD value is proportional to the organic matter used as the AD substrate (Latif et al., 2015; Riggio et al., 2015; Maspolim et al., 2015), indicating the potential for residual organic matter to be converted into methane. Stillage filtrate accounts for about 80% of COD release when fed to 15 million liters of semi-continuous AD process. Menurut Filer et al. (2019), the substrate can be expressed as biodegradable with a chemical ratio of 1 kg COD = 0.35 m^3 CH_4 at standard temperature and pressure (STP). The simulation results for scenario 1 obtained conversion from 40 kton of COD to 19.8 GL of methane.

Scenario 2 is the development of scenario 1 by utilizing solid waste (lignin) as its own source of energy (own used), which is a substitute for electricity and steam from external sources and some others for commercialization. Lignin used as fuel for power plants for own use in scenario 1 is 31,414 kton. Scenario 2 also requires electricity and steam to produce ethanol (60,047 kL) and biogas (19.8 GL) of 35.608 MW and 710 kton. The remaining lignin (26,410 kton) will be supplied to power generation companies as fuel.

Scenario 3 is the development of scenario 1 by utilizing solid waste (lignin) to be commercialized as *PLTBm* so that the electricity consumption is the same as scenarios 1 and 2 to produce bioethanol and biogas. Lignin in scenario 3 is completely sold to power plants (*PLTBm*) as fuel. Lignin produced from the delignification process is 57,824 ktons in a year. Lignin has a fuel value of 26.56 MJ/kg (Todaro et al., 2015; Demirbas, 2017) so it has the potential to produce 53.88 MW of electrical power in a year.

Lignin from the bioethanol process is used as lignosulfonate in scenario 4. Waste from the delignification process (lignin) will be isolated with 20% H_2SO_4 until it reaches pH 2. The lignin produced is 57,824 kton/year and the addition of NaOH to Na-Lignate is 48,662 kton/year. Sulfonation was then carried out with sodium bisulfite into sodium lignosulfonate (SLS) of 42.817 kton/year.

Table 5 shows that 1,783 TJ/year of energy is needed to produce 60,047 kL/year of bioethanol and other derivative products from lignocellulose contained in elephant grass. The utility input value data from the conversion process are electric power 0.59 MJ/L and steam 24.94 MJ/L taken based on the simulation results of bioethanol production per liter. The net energy value (NEV) and net energy ratio (NER) of each scenario of bioethanol production made from elephant grass are then calculated based on Table 5 whose results are shown in Table 6. For example in scenario 1, the total energy needed to produce 60,047 kL bioethanol in a year is 3448 TJ, while the total energy produced is 2510 TJ so that the net energy value in a year is 2510 – 3448 = -937 TJ. This means that the NEV per liter is -937 TJ/60.047 kL = -15.61 MJ/L, while the NER value is 2510 TJ/3448 TJ = 0.73. The results of these calculations are used as the basis for determining the feasibility of environmental aspects of each bioethanol production scenario.

The input energy consists of the consumption of electrical energy, steam, and raw materials. The raw materials consist of the process of planting elephant grass and chemicals used during the process of converting biomass into ethanol (Mishra et al., 2018). Energy output is calculated based on the products produced from each scenario, i.e. bioethanol, biogas, lignosulfonates. Production of bioethanol (standalone) from elephant grass (baseline) results in negative environmental (energy) performance. This is due to the yield of ethanol from elephant grass is only about 24.6% so that the energy requirement to produce bioethanol from elephant grass is greater than the energy produced by bioethanol. The heating value of bioethanol produced with a concentration of 99.5% is 29.7 MJ/L bioethanol or equivalent to 7.337 MJ/kg elephant grass. This is the same as bioethanol produced from 7,319 MJ/kg straw (Mishra et al., 2018).

Biogas has a heating value of 36.6 MJ/m^3 (Pannucharoenwong et al., 2017), but the yield of biogas produced from the conversion of bioethanol liquid waste is only 0.49 m3/kg COD. The integration of bioethanol and biogas cannot significantly increase the energy value of elephant grass as fuel. This is indicated by the performance of the energy environment in

Table 5. Equivalent energy for each scenario in a capacity of 60,047 kL/year

Material	Equivalent Energy (TJ/Year)				
	Baseline	**1**	**2**	**3**	**4**
Input Material					
Elephant Grass	1,539	1,539	1,539	1,539	1,539
Pretreatment					
Diesel	1.10	1.10	1.10	1.10	1.10
Hydrolysis					
Electricity	35.1	35.6	35.6	35.6	35.1
Steam	1,497	1,497	1,497	1,497	1,497
HCl	0.09	0.09	0.09	0.09	0.09
NaOH	0.09	0.09	0.09	0.09	0.09
Yeast	375	375	375	375	375
Sulfonation					
H_2SO_4	-	-	-	-	0.00
NaOH	-	-	-	-	7.85
$NaHSO_3$	-	-	-	-	1.50
Output Material					
Waste treatment					
Biogas (biomethane)		727.06	727.06	727.06	727.06
Lignin		-	702.15	1,537	-
Electricity		-	35.6	-	-
Steam		-	1,497	-	
Lignosulfonates		-	-	-	1,310
Final Product					
Bioethanol	1,783	1,783	1,783	1,783	1,783

Tabel 6. Variable of net energy analysis

	Net Energy Value (MJ/L)	**Net Energy Ratio**
Baseline	-31.276	0.487
Scenario 1	-15.629	0.727
Scenario 2	21.6	1.376
Scenario 3	10.596	1.186
Scenario 4	6.045	1.105

Table 7. Specifications of bioethanol production equipment with a capacity of 60,047 kL/year

Equipment	**Specification**	
Belt conveyor	Width (inch)	32
	Length (ft)	984
	Material	*carbon steel*
Acid hydrolysis tank	Volume (kgal)	285.41
Plate and Frame Filtration (Delignification)	Area Filter (m^2)	257.2585
Blending tank NaOH	Volume (kgal)	281.26
Fermentor	Volume (Mgal)	22.45
	Diameter (m)	38
	Height (m)	13
Distillation Column	Column height (m)	38
	Column diameter (m)	13

scenario 1 which has a negative value.

Utilization of liquid waste as biogas and solid waste (lignin) from bioethanol production as a source of energy itself can significantly improve the environmental performance (energy) of bioethanol made from elephant grass. Utilization of lignin (scenario 2-4) can increase the energy produced by 52-89% from scenario 1 (Table 6). This can be seen from scenario 2-4 having a positive energy environment performance (NEV).

The simulations carried out in this study also resulted in the design specifications of the equipment needed to produce bioethanol with a capacity of 60,047 kL/year. Table 7 shows the specifications of the required equipment from the simulation results.

Financial Analysis

Determining the selling price of bioethanol is very important in assessing the feasibility of bioethanol production. The selling price of bioethanol can be determined based on the flowsheeting process. The cost of production is the total cost required to produce per unit mass or volume of product, which includes raw materials, utilities, maintenance, and depreciation of equipment investment. The investment cost for the production of standalone (baseline) bioethanol is calculated from the use of a hydrolysis reactor, fermenter, plate & frame (delignification), distillation tank, and utilities. Utilization of by-products (liquid waste) requires additional investment of anaerobic digestion for biogas production. Utilization of the results of the delignification process (lignin) and compounds that are not converted into glucose as electrical energy and steam in scenarios 2 and 3 require additional installations of a power generation system (steam boiler and turbine). The use of lignin as a lignosulfonate chemical in scenario 4 requires additional investment costs for stirred tanks used in the acidification, neutralization, and sulfonation processes. Equipment investment depreciation is assumed to be based on the life time of the bioethanol plant. Several previous studies stated that the life time of the bioethanol plant in the feasibility study ranged from 10 to 20 years (Zhao et al., 2015; Oyegoke & Dabai, 2018; Bulkan et al., 2020), so this study used a life time of 15 years.

The economic analysis of standalone bioethanol needs to be reviewed with comparisons of various other types of bioethanol raw materials. The cost composition used in this study is assumed to be almost the same as that of several other researchers. Table 8 shows that the biomass-based ethanol industry is an unprofitable business sector. This can be seen from the negative NPV value. The NPV is influenced by the type of raw material, production capacity, and the selling price of bioethanol.

The calculation results of the selling price of bioethanol based on the cost of production before tax can be seen in Table 9. The cost of production or the cost of goods sold of bioethanol is IDR 6,819/L. This is almost the same as the cost of producing bioethanol from other lignocellulosic

Table 8. Comparison of standalone bioethanol industry analysis of various types of raw materials

Economic Details	Standalone Bioethanol				
	Elephant Grass	**Corn**	**Sugar Beet**	**Grass**	**Straw**
Total Capital Investment (IDR Trillion)	4.963	2.623	0.043	0.666	0.336
Operating Cost (IDR Trillion /year)	0.409	1.571	0.018	0.037	0.058
Main Revenues (IDR Trillion /year)	0.417	2.185	0.019	0.027	0.042
Other Revenues (IDR Trillion /year)	-	-	-	-	-
Total Revenues (IDR Trillion /year)	0.417	2.185	0.019	0.027	0.042
Cost Basis Annual Rate (kL MP/ year)	60,047	159,932	1,803	2,485	4,564
Unit Production Cost (IDR/L MP)	6,819	9,822	10,010	14,947	12,711
Unit Production Revenue (IDR/L MP)	6,950	13,662	10,462	10,835	9,257
Return On Investment (%)	7.35	N/A	N/A		N/A
Payback Time (year)	13.9	N/A	-	-	>10
IRR (After Taxes) (%)	1.04	13	-	-	5,76
NPV (at 10.0% Interest) (IDR Trillion)	-2.063	0	-0.011	-0.178	-0.074
MP = Total Flow of Ethanol					
References	This study	(Zhao et al., 2015)	(Achinas et al., 2019)	(Achinas et al., 2019)	(Song et al., 2014)

Table 9. Cost of goods sold calculation of 1 L bioethanol of each scenario

Production Costs	**Scenario**				
	Baseline (IDR)	**1 (IDR)**	**2 (IDR)**	**3 (IDR)**	**4(IDR)**
Raw material	354	354	354	354	623
Utilities	827	829	-	829	3,433
Labor & maintenance	128	148	380	655	1,240
Depreciation	5,511	5,605	5,662	5,608	6,328
Revenue of Biogas	-	-2,849	-2,849	-2,849	-2,849
Revenue of Lignin	-	-	-1,579	-3,457	-
Revenue of Lignosulfonate	-	-	-	-	-7,577
Total	6,819	4,088	1,968	1,194	1,199

materials that are USD 0.47/L for raw material (feedstock) costs of USD 30/ton and USD 0.67/L for raw material costs of USD 100/ton (International Renewable Energy Agency, 2013). If the income tax value is at 12% (Badan Kebijakan Fiskal Kementerian Keuangan, 2022), then the selling price of bioethanol will be IDR 7,638/L to get the break-even value. The selling price of bioethanol in this simulation is determined based on the premium price in 2020 so that the selling price offered as a mixed fuel can be competitive with gasoline (premium), which is IDR 6,450/L. The price is IDR 1,188/L, lower than the selling price of bioethanol.

Biogas in this simulation is used as fuel for biogas power plants which is called *Pembangkit Listrik Tenaga Biogas* (*PLTBg*). The selling price of biogas for power generation fuel is determined by referring to the Regulation of the Minister of Energy and Mineral Resources No. 4 of 2020 article 9 paragraph 3 regarding the benchmark price for purchasing electricity from *PLTBg*, which is a maximum of 85% of the cost of provision for local power generation (Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, 2020). The cost of provision for national power generation determined by the Ministry of Energy and Mineral Resources is IDR 983/kWh, (Sujatmiko, 2017) so the selling price of biogas as fuel for power generation is IDR 9,407.98/kg.

Figure 2 shows the comparison of total Operating Expenditure (OPEX) and revenue from the use of lignin as fuel in scenario 1 to scenario 3. Utilization of liquid waste as biogas in scenario 1 can increase revenue by about 41% of the total cost of producing bioethanol and biogas. The decrease in production costs or the cost of goods sold of bioethanol occurs in scenario 2 that is IDR 6,396/L. The price includes tax. This shows that the use of liquid waste as biogas and lignin as fuel for electricity and heat energy (steam) can reduce production costs by 44.8% and increase revenue by 63.7%. Utilization of liquid waste as biogas and lignin as fuel for *PLTBm* in scenario 3 increases income by 90.7%, which means that the utilization of the waste can reduce the cost of producing bioethanol by about 82.5%. Utilization of liquid waste as biogas and lignin as lignosulfonate in scenario 4 can reduce production costs by about 82.4%. These results are in accordance with the results of the study of Song et al. (2014) which shows that the use of by-products can reduce bioethanol production costs by 87%.

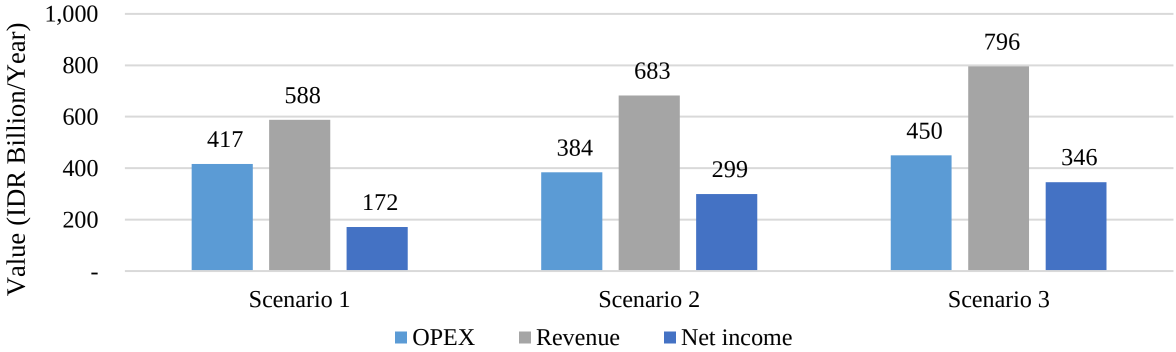

Figure 2. Comparison of Total OPEX and Revenue of Lignin Utilization as Fuel (Scenario 1-3)

Table 10 shows the results of the economic simulation for each scenario. The results of the economic simulation show that scenario 1 increases the feasibility value, but is still not effective. This is indicated by a negative NPV that is IDR1,047,321,091,626 and an IRR of 5.87% (below the discount rate). This economic feasibility also occurs in the utilization of bioethanol fermentation residue from oat straw using the steam explosion method as a substrate for anaerobic decomposition. (Dererie et al., 2011). The results of Cesaro & Belgiorno (2015) research on the integration of bioethanol and biogas from a corn stover show that the utilization of fermentation by-products can increase energy conversion by 9.6%. Scenario 1 is not feasible because the investment and costs incurred to produce bioethanol and biogas are greater than the revenue. The inflation of selling price of bioethanol and biogas is lower than the stated interest rate. This indicates that the value of the income to be received in the coming year is lower than the current investment costs so that the income cannot cover the investment costs of the current value of money.

Utilization of lignin as fuel to supply electrical and heat energy in the production process of bioethanol and biogas in scenario 2 can reduce the cost of producing bioethanol and biogas by around 99% from the use of electricity and steam. Lignin needed as fuel to supply electricity and steam is 31.413 million tons per year. Scenario 3 is more profitable than scenario 2. Lignin which is used as fuel is supplied to *PLTBm* commercially in scenario 3. This is because lignin has a lower heating value than the fuel used by State Electricity Company. The amount of lignin needed to meet the same energy needs in the production of bioethanol and biogas will be more so that cost savings are obtained and income increases if lignin is supplied to *PLTBm* commercially.

Figure 3 shows a comparison of the benefits (NPV) and costs of the Capital Expenditure (CAPEX) investment from each scenario. Revenue from the use of lignin as lignosulfonate

Table 10. Economic simulation results for each scenario

Economic Details	Scenario				
	Baseline	**1**	**2**	**3**	**4**
Total Capital Investment (IDR Trillion)	4.963	5.049	5.100	5.100	5.700
Operating Cost (IDR Trillion /year)	0.409	0.417	0.384	0.450	0.698
Main Revenues (IDR Trillion /year)	0.417	0.417	0.417	0.417	0.417
Other Revenues (IDR Trillion /year)	-	0.171	0.266	0.379	0.626
Total Revenues (IDR Trillion /year)	0.417	0.588	0.683	0.796	1.043
Cost Basis Annual Rate (kL MP/ year)	60,047	60,047	60,047	60,047	60,047
Unit Production Cost (IDR/L MP)	6,819	6,937	6,395	7,494	11,357
Unit Production Revenue (IDR/L MP)	6,950	9,799	11,374	13,256	17,370
Return On Investment (%)	7.35	7.35	14.29	17.24	15.38
Payback Time (year)	13.9	9.9	7.7	7.2	7.6
IRR (After Taxes) (%)	1.04	5.87	10.09	11.32	10.36
NPV (at 10.0% Interest) (IDR Trillion)	-2.063	-1.047	0.026	0.364	0.108

MP = Total Flow of Ethanol

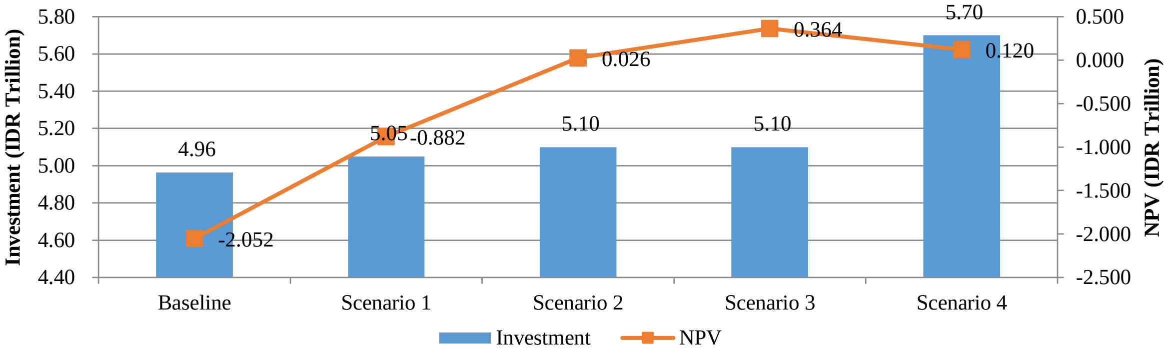

Figure 3. Comparison of CAPEX and NPV of Each Scenario

is lower than the use of lignin as fuel. This is because the investment in making lignosulfonates from lignin is very high, and operating costs are expensive, and the product yield is only 76% of the total lignin, while the selling price of lignosulfonates is not different from the selling price of lignin as fuel. The investment cost of a lignosulfonate with a capacity of 42.817 kton/year is Rp. 651 billion. The most feasible scenario to run in this simulation is scenario 3, i.e. the use of liquid waste from the bioethanol production process as biogas and the use of solid waste (lignin) as fuel which is commercialized in *PLTBm* with an NPV value of IDR 364,358,976,036, IRR 11.32%, PBP 7.2 years, and PI 1.08.

Sensitivity Analysis

The most influencing factor for cash flow is the selling price of bioethanol. A 25% change in the price of bioethanol can affect the NPV value up to three times the normal price (Figure 4). The selling price of fuel grade ethanol in the international market in 2020 is USD1.49/gal or around IDR 5,248/L. The selling price of bioethanol in this simulation is determined from the competition in the fuel market. This aims to meet the government's target of switching fuel into bioethanol blended fuel and increasing the value of bioethanol revenue. The implication of the difference between the selling price of bioethanol and the global market is a decrease in net income so that the value of the benefit-cost ratio will decrease. This indicates that the increased risk posed by the decline in the selling price of bioethanol is very high. The price of bioethanol is strongly influenced by price stability and the availability of fuel.

Electricity rates also affect cash flow. A 25% change in electricity rates can affect an NPV of 79%. This shows that the rate of financial flow in the bioethanol industry made from elephant grass is very sensitive to changes in electricity tariffs. Changes in electricity tariffs have an effect on changes in production costs and income due to the integration of bioethanol production and the use of lignin waste as fuel (scenario 3).

A 25% change in the purchase price of elephant grass only affects the NPV by 9%, while the results of other studies show that a 41.7% reduction in the cost of straw feedstock can reduce production costs by up to 27%. (Song et al., 2014). This difference is due to the different cellulose content in the biomass, i.e. 34.21% for elephant grass and 47% for straw (Sun & Cheng, 2005). Cellulose content is an important factor that can indirectly affect the economic value in the bioethanol industry. Zhao et al. (2015) investigated the effect of the rate of cellulose conversion to glucose and conversion of glucose to ethanol on the cost of producing bioethanol. The results obtained are the cost of bioethanol production decreased by 27%. if the rate of conversion of glucose to ethanol increases by 60%.

CONCLUSIONS

A feasibility study of the elephant grass-based bioethanol industry through the SuperPro Designer simulation has been carried out. The standalone bioethanol industry, without the use of waste as a product diversification, is not economically feasible if it is projected as a substitute for fossil fuels. Utilization of liquid waste without lignin solid waste as biogas is not effective in increasing the feasibility value of the elephant grass-based bioethanol industry. The combination of the use of liquid waste and lignin waste as own used electricity, commercial

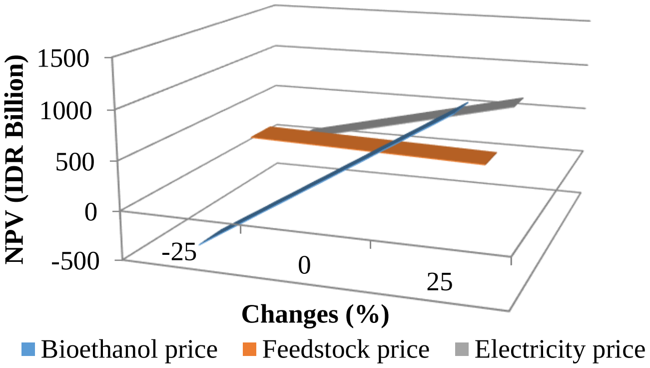

Figure 4. Sensitivity Analysis

electricity (*PLTBm*), and lignosulfonates can increase the economicvalue of the elephant grass-based bioethanol industry. The optimum result is the bioethanol industry scheme by utilizing liquid waste as biogas and lignin waste as the raw material for commercial *PLTBm* electricity. The factors that most influence the cash flow are the selling price of bioethanol and electricity tariffs. Further studies need to be carried out on the feasibility of elephant grass-based bioethanol in terms of the cellulose content and technology related to the conversion rate of elephant grass into ethanol. The feasibility study of bioethanol based on elephant grass needs to be reviewed as well from the environmental aspects, such as a life cycle analysis study because this process produces CO_2 emissions.

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