Techno-economic Evaluation of Biodiesel Production from Edible Oil Waste via Supercritical Methyl Acetate Transesterification

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ABSTRACT: This study aimed to assess the economic and engineering feasibility of a large-scale biodiesel manufacturing operation from edible oil waste. The edible oil model used for economic analysis in this study is palm oil waste. Several economic parameters (i.e., gross profit margin (GPM), payback period (PBP), break-even point (BEP), cumulative net present value (CNPV), profitability index (PI)), and internal rate return (IRR) were examined to inform the potential production of biodiesel from edible oil waste in ideal condition. To confirm the feasibility of a manufacturing project, the project is estimated from ideal to worst-case conditions in production activities such as analysis of changing raw material, labor, tax, utility, and selling price costs. Based on an engineering perspective, the result indicated that biodiesel production from edible and non-edible oil is feasible. From an economic perspective, economic analysis shows that biodiesel production from edible oil waste is promising because the economic parameters as analyzed show positive results. Our findings are expected to provide an industrial-scale picture of economic evaluation and layout, particularly in the production of biodiesel, which is commonly used as a renewable energy source for fuel in trucks, trains, ships, and barges.

KEYWORDS: Biodiesel, Cumulative net present value, Economic evaluation, Edible oil waste, Engineering evaluation, Transesterification

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I. INTRODUCTION

Biodiesel has recently gained popularity due to its environmental benefits and the fact that it is made from renewable resources. Biodiesel has benefits for the environment because the carbon atom in the oil or fat comes primarily from carbon dioxide in the air, biodiesel is thought to contribute far less to global warming than non-renewable fuels. When diesel engines run on biodiesel instead of petroleum-based diesel fuel, they emit less carbon monoxide, unburned hydrocarbons, particulate matter, and air toxics (Van Gerpen, 2005).

To produce biodiesel, transesterification of animal fat or vegetable oil with short-chain alcohol is the most common way (Li *et al*., 2008). Several methods to produce biodiesel from waste oil are using supercritical alcohols (Saka *et al*., 2010; Quesada *et al*., 2011), supercritical carbon dioxide (Rodrigues *et al*., 2011), methyl acetate transesterification (Campanelli *et al*., 2010; Saka *et al*., 2009), homogeneous-catalyzed transesterification (Shimada *et al*., 2022; Georgogianni *et al*., 2009), heterogeneous- catalyzed transesterification (Kiss *et al*., 2010; Agarwal *et al*., 2012), enzyme-catalyzed transesterification (Al-Zuhair *et al*., 2009; Hama *et al*., 2011), and non-catalyzed transesterification (Lee *et al*., 2012; Tan *et al*., 2011). The advantages drive the method selection for producing biodiesel. Because it can be performed without the use of a catalyst, supercritical transesterification is an appealing alternative to conventional transesterification. It also enables easier product separation and faster reaction rates (Campanelli *et al*., 2010).

There are many reports on economic evaluation as discussed in the literature. From the literature, an economic evaluation was used to analyze the feasibility of the project on the production of zinc sulfide nanoparticles by microwave irradiation method, hyaluronic acid through an extraction method, coal to SNG power plant, poly-DADMAC, and sepiolite nanocomposite, zinc sulfide nanoparticles by precipitation assisted ultrasonic radiation method, copper oxide nanoparticles by green synthesis method, copper nanoparticles by biosynthetic method using citrus medica Linn Extract, hydroxyapatite nanoparticles from eggshell waste, magnesium oxide nanoparticles by precipitation method, aluminum oxide nanoparticles through precipitation method, magnesium oxide nanoparticles using sol-gel method. In addition, economic analysis is also analyzed in education (Ragahita *et al*., 2022; Nurdiana *et al*., 2022; Elia *et al*., 2023; Andika *et al*., 2016; Mojaveri *et al*., 2017; Rosmawati *et al*., 2021; Astuti *et al*., 2021; Putra *et al*., 2021; Anggiat e*t al*., 2021; Annisa *et al*., 2021; Febriani *et al*., 2020; Supriyadi *et al*., 2021; Kurniadianti *et al*., 2021; Veronica *et al*., 2021). Understanding biodiesel production necessitates an understanding of the techno-economy. This techno-economic

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analysis seeks to comprehend current market conditions to ensure that the product marketing strategy runs smoothly and profitably. Although many reports on economic evaluation, the research regarding biodiesel production is still limited.

The purpose of this study was to analyze the economic and engineering perspective of large-scale biodiesel production from edible oil waste through supercritical methyl acetate transesterification. The analysis used in this study is based on computational calculation. Several economic evaluation parameters (i.e., gross profit margin (GPM), internal rate return (IRR), payback period (PBP), cumulative net present value (CNPV), break-even point (BEP), and profitability index (PI)) were analyzed for informing the feasibility of the project. Then, to confirm the feasibility of a manufacturing project in the worst condition, the changing various economic conditions, such as labor, sales, raw material, utility, and tax were also evaluated. In short, in the worst condition evaluation, the influence of raw material prices, utility, tax, labor, and product prices were all modified in this study to evaluate what effect they had on the economic evaluation. This research is essential in the industry to help support future development and large-scale manufacturing by examining the process from two angles: engineering and economics.

II. THEORETICAL SYNTHESIS OF BIODIESEL PRODUCTION

The main components of biodiesel are methyl palmitate (16:0), methyl stearate (18:0), methyl oleate (18:1), methyl linoleate (18:2), and methyl linoleate (18:3). Here, palm oil as edible oil is used as raw material for biodiesel production. The fatty acid composition of palm oil is presented in Table 1 (Rahman *et al*., 2022).

Table 1. Fatty acid composition of the palm oil.

Component	Amount (%)
Palmitic acid	44.00
Oleic Acid	41.20
Linolenic Acid	8.00

Figure 1 is a step-by-step of the biodiesel production process using methyl acetate and palm oil as raw materials through the supercritical methyl acetate transesterification method. Based on Figure 1, the reactor vessel is filled with methyl acetate through a high-pressure pump. The reactor containing methyl acetate is heated and when the target reaction temperature is reached, a certain amount of palm oil is added to be reacted through a high-pressure pump. The reaction process undergoes under stirring conditions of 960 rpm, temperature of 300°C, a pressure between 10 and 30 Mpa for 50 minutes, and the molar ratio of methyl acetate:palm oil varied between 25:1 and 59:1 (Campanelli *et al*., 2010).

To produce biodiesel, some common chemicals are involved as shown in Table 2. The simple reactions that occur in the manufacture of biodiesel using the supercritical methyl acetate transesterification method are expressed by reactions 1 and 2.

$$\mathrm{TG} + \mathrm{MA} \rightleftharpoons FAME + TA \quad (1)$$

$$\mathrm{FA} + \mathrm{MA} \rightleftharpoons FAME + AA \quad (2)$$

The product that is needed to produce biodiesel is fatty acid methyl ester (FAME). However, the triacetin formation in this reaction is not referred to as a residue because the

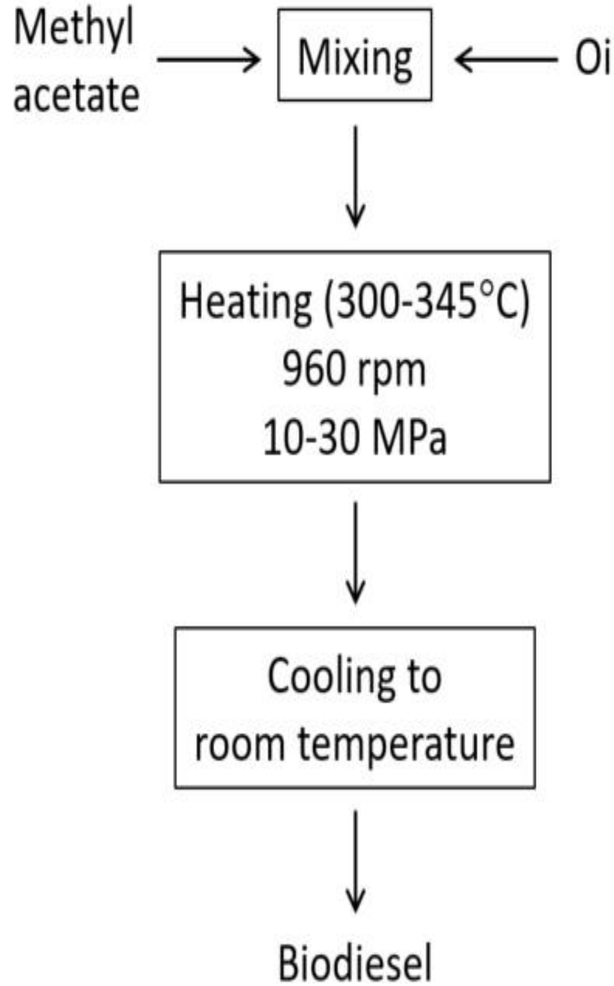

Figure 1: Step-by-step biodiesel production via supercritical methyl acetate transesterification cycle.

triacetin production benefits FAME as it was found that the mixture of FAME and triacetin in this process can be used as biodiesel fuel. In this reaction, acetic acid is used as both a solvent and a catalyst for the reaction. Thus, the same with the formation of other residues such as acetic acid. This is why no residue is produced in this reaction (Campanelli *et al.*, 2010).

Table 2. Some common chemicals are needed to produce biodiesel.

No	Chemical Name	Chemical Structure	Abbreviation
1	Triglyceride	$CH_2 - OCOR_1$ | $CH_2 - OCOR_2$ | $CH_2 - OCOR_3$	TG
2	Methyl Acetate	CH_3COOCH_3	MA
3	Fatty Acid Methyl Ester	R_1COOCH_3 R_2COOCH_3 R_3COOCH_3	FAME
4	Triacetin	$CH_2 - OCOCH_3$ | $CH_2 - OCOCH_3$ | $CH_2 - OCOCH_3$	TC
5	Acetic Acid	CH_3COOH	AA

III. METHODOLOGY

To guarantee the current price of the materials, the current method used several data based on the average price of commercially available products on online shopping websites. A simple mathematical analysis was used to calculate all of the data. Several economic evaluation parameters were used to confirm the project's economic evaluation (Priyatna and Nandiyanto, 2019; Prabowo et al., 2018; Nandiyanto, 2018), including:

- GPM is the gross profit of a project.
- BEP is a value that describes the smallest amount of production required to make a profit or a loss. Fixed costs and profits were divided to arrive at this figure.
- CNPV was used to predict and assess the project's conditions as a function of time (in years).
- IRR is the rate of return on annual income for the initial capital that will be reduced to zero during the project.
- PI is defined as the ratio of the CNPV to the total cost. The PI corresponds to the type of return on investment or profit for each sale.
- PBP is the period required to return the value of the investment that has been issued.

IV. RESULTS AND DISCUSSION

A. Mass Balance Analysis

For mass balance analysis, the following assumptions were made: (i) all reactants are consumed perfectly, (ii) the reduced mass (as a mass loss) of the material is 10% in each process, (iii) the conversion rate of methyl acetate and waste palm oil into biodiesel is 100%, (iv) the final product is FAME and triacetin (the product that needed to make biodiesel), (v) the absolute handling cycle is 12 transesterification reaction cycles in a single day, and (vi) about 136,892 L methyl acetate and 7,109 L oil is needed to produce 144,000 L biodiesel in a single day.

B. Economic Assumption for Analysis

Several assumptions were used to ensure the economic analysis. This assumption is required to analyze and predict several possible outcomes during the project. The assumptions are as follows: (i) all examination was in USD (1 USD is assumed to be equivalent to 14,368 in the Indonesian rupiah (IDR)), (ii) all of the apparatuses' prices are based on online store prices such as Alibaba, (iii) the chemical composition of the reaction for biodiesel production is scaled up to 144,000 times, (iv) the purity of biodiesel produced from this process is assumed to be 100%. No residue is generated and that means this will be a significant benefit, (v) in a single day, it takes 12 hours to complete the 12 cycles of biodiesel production, (vi) every month, the total salary of every worker in Indonesia is assumed to be IDR 4,310,300 (about 300 USD per month), (vii) the total number of workers is 50 people (viii) the income tax rate is assumed to be 10%, (ix) the project is assumed to be operational for 20 years, and (x) the project is only 300 days long every year.

C. Engineering Perspective

Figure 2 shows an illustration of the biodiesel production process using the supercritical methyl acetate transesterification method. According to engineering calculations, the total cost of raw materials required is 20,896,359.00 USD. The profit for one year is 13,231,641.00 USD for a selling price of 34,128,000.00 USD after a year. The cost of equipment needed for biodiesel production is 817,306.48 USD. A detailed list of the required equipment is presented in Table 3.

Consequently, the investment cost which is informally defined as the "true cost" of purchasing a product or service from a supplier is 3,056,726.24 USD. This investment cost shows a relatively cheap cost. The investment cost is a very useful tool that gives investors an accurate understanding of the actual costs incurred when investing in investment schemes. When dealing with investments, effective cost management is essential. High investment costs can have a significant negative impact on investor returns. The investment was decided primarily based on the Lang Factor (Nandiyanto, 2018). The total investment cost for biodiesel production shows in Table 4. From an engineering perspective, the project can be easily operated, improved, and developed using readily available and inexpensive technologies and apparatuses.

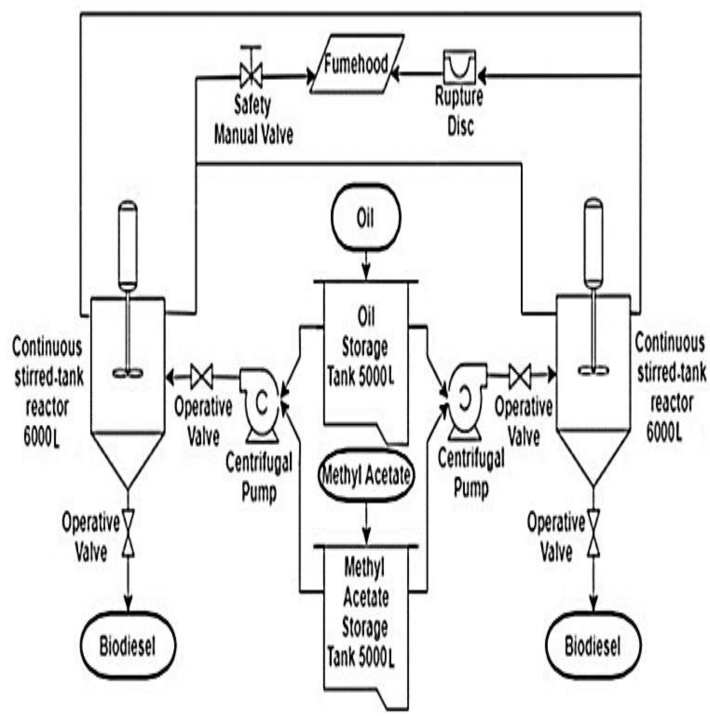

Figure 2: Illustration of the production process of biodiesel via supercritical methyl acetate transesterification method.

Table 3: Equipment cost and process condition. All prices and apparatus information are taken from currently available apparatuses on the online shopping web.

No	Equipment	Price (USD)	Electricity (kW)	Temp (°C)	Process time (h)
		SC Procedure			
1	Stirred tank reactor 6000 L	19,200.00	900	300	12
2	Liquid nitrogen gas generator	200,000.00	2,400	-	12
3	Rupture disc	40.00	-	-	-
4	Safety manual valve	20.00	-	-	-
5	Liquid storage tank 5000 L	40,000.00	-	-	-
6	High-pressure pump	18,000.00	681.6	-	12
7	Operative valve	46.48	-	-	-
8	Storage liquid tank 10 L	540,000.00	-	-	-

Table 4. Estimated total investment for 2 production procedures.

Component	Factor	Price (USD)
Plant Cost (Equipment)		
Purchased Equipment	1.0	817,306.48
Piping	0.5	408,653.24
Electrical	0.1	81,730.65
Instrumentation	0.2	163,461.30
Utilities	0.5	408,653.24
Foundations	0.1	81,730.65
Insulations	0.06	49,038.39
Painting, fireproofing, safety	0.05	40,865.32
Yard Improvement	0.08	65,384.52
Environmental	0.2	163,461.30
Building	0.08	65,384.52
Land	0.5	408,653.24
Subtotal 1		2,754,322.84
Plant Cost (Management Services)		
Constructions, engineering	0.6	490,383.89
Contractors fee	0.3	245,191.94
Subtotal 2		735,575.83
Total Plant Cost (Equipment + Management Service)		3,489,898.67
Total Plant Cost – Land		3,081,245.43
Starting-up Fee		
Off-cite facilities	0.2	163,383.89
Plant start-up	0.07	245,191.94
Working Capital	0.2	163,461.30
Subtotal 3		384,134.05
Total Investment Cost (Total Plant Cost + Starting-up Fee		3,465,379.48
Total Investment Cost - Land		3,056,726.24

D. *Economic Evaluation under Ideal Condition*

Figure 3 shows the CNPV curve of the project that shows the relationship between the return on investment (PI) and the ideal year of production. This CNPV curve is used for decision-making on the alternative determination of several investment projects (Ragadhita *et al*., 2019). Based on the CNPV curve, the trend of earnings or yield prospects investment for this project is increasing every year. In short, the net value receipts for the coming year are greater than the current net value receipts (see Figure 3). This shows that the project is profitable and acceptable. According to the CNPV curve (Figure 3), the project cannot recover the initial capital cost for biodiesel production from year 0 to year 2 due to the project (Elia *et al*., 2021). The project began to benefit from the sale proceeds after the third year. The profit that began in the third year gradually increased until the following year.

Table 5 shows the values for several economic parameters such as GPM, PBP, BEP, IRR, and PI. In detail, the economic parameters describe as follows. The GPM of this project shows positive results. Usually, the GPM indicator indicates that the higher the gross profit margin the better the operatable 3ting state of a project (Nandiyanto *et al*., 2021). The period during which the project can return the value of the investment that has been spent is referred to as PBP. From the investor's perspective, this profit period is one of the factors that investors pay attention to because the length of the PBP of a project will determine investor interest (Alnasser *et al*., 2014). Based on PBP's analysis, this project has a relatively short period to return the investment value that has been spent, which is within 3 years. Therefore, this project is prospective. BEP is also often a benchmark for someone to invest in or start a business. BEP is considered as the point when the revenue is exactly equal to the estimated total cost, at which the company's losses end and the company just collects profits (Rahmadianti *et al*., 2021). In short, BEP is when all costs incurred for production operations can be covered by revenue from product sales. Here, BEP can be achieved after biodiesel production reaches 360 cycles. The efficiency level indicator of an investment can also be seen from its IRR value. A large IRR value indicates that the project or investment will be profitable if it is continued. Conversely, if the IRR value is small, it indicates the initial investment cost will lead to bad prospects (Nandiyanto *et al*., 2021). This project shows that the IRR level is relatively large, which is at a value of 10%. This value gives an advantage because the value is greater than the current interest rate in Indonesia, which is 3.75%. PI values are also analyzed to measure income levels and the net income derived from the total investment of a project (Rahmadianti *et al*., 2021). The PI for this project is positive.

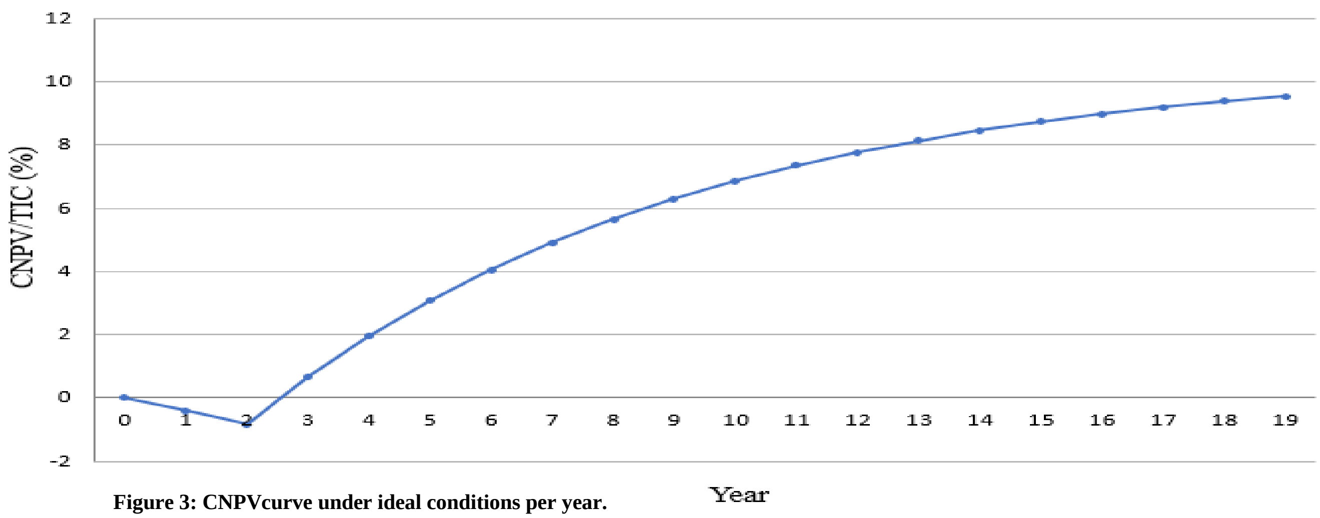

Figure 3: CNPVcurve under ideal conditions per year.

Table 5. Detailed information on the economic parameter value.

Economic Parameters	Value
GPM/year	13,231,641
PBP (year)	3
BEP (cycle)	360
IRR (%)	10
Last CNPV/TIC (%)	9.53
Profit to sales (%)	0.26
Profit to investment (%)	2.56

E. Economic Evaluation under Worst Condition

1) Changing raw material cost

Figure 4 shows the curve of raw material cost variation on CNPV/TIC. Raw material costs in the worst-case scenario were examined at sensitivities of 80, 90, 100, 110, and 120%. Looking at the graph legend, a valuable sensitivity that is less than the ideal sensitivity (100%) assumes that the price of raw materials is less than the set ideal cost of raw materials. Meanwhile, if the sensitivity is greater than the ideal sensitivity, the raw material cost is assumed to be higher than the ideal raw material price. According to the findings of the analysis in Figure 4, if the cost of raw materials falls (i.e., 80% and 90% sensitivity) from the ideal cost, higher project profits can be realized. However, if the raw material cost rises to exceed the ideal price, the project's profits will be reduced. Figure 4 shows that despite a more than 110% increase in raw material prices, the project is still profitable. However, if the price of raw materials rises by more than 120%, the project is expected to fail. As a result, the sensitivity threshold for rising raw material prices is 120%. Raw materials are industrial goods that account for the majority of a company's costs and profits. To increase profitability, any manufacturing organization should strive to reduce the cost of raw materials, which will eventually lead to a reduction in manufacturing costs (Asaolu *et al.*, 2012; Oyedekun *et al*., 2019).

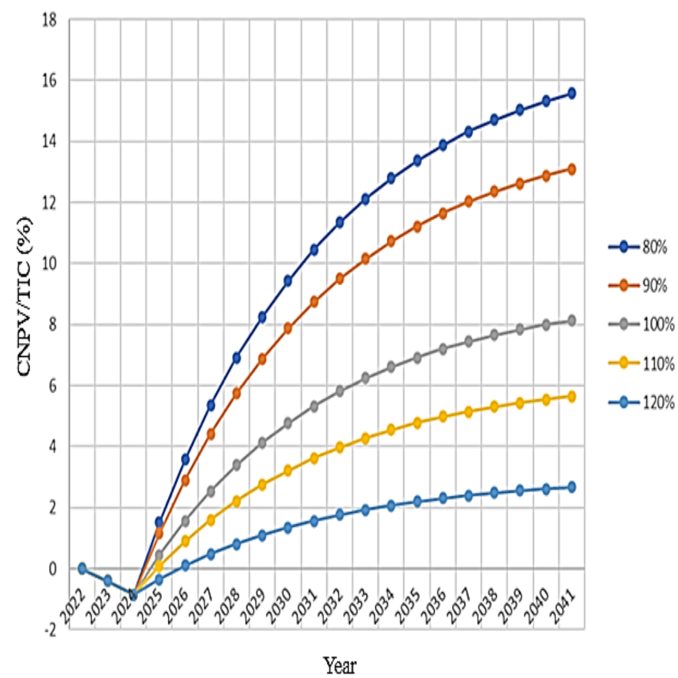

Figure 4: The effect of Variation in Raw Material Price against CNPV/TIC.

2) Changing labor payment cost

Figure 5 shows the effect of variations in labor costs on CPNV/TIC. Labor costs in the worst conditions are assumed to have different sensitivity variations ranging from 80-120%. Based on Figure 5, the effect of labor costs does not affect project profits. This can be seen from the curve line in all sensitivity conditions which coincide with ideal conditions. Labor has a lower impact on project profitability, in this case, indicating that changing this parameter (up to 120%) is not a major issue in project sustainability. Here, the increase in labor wages does not affect the profit of the project because the project is assumed to have not too many workers. Project management is carried out by utilizing materials and equipment efficiently. Although labor costs do not affect project profit, labor must be considered as another influencing parameter for project sustainability (Nandiyanto, 2018; Eskander, 2018).

(Shalahuddin *et al*., 2019; Maulana & Nandiyanto, 2019; Zahra *et al*., 2020). All projects must be completed with sales greater than 50%. When product prices fall below 50% of ideal sales, the project will fail. This 50% sensitivity has a curve that coincides with the x-axis. Based on the analysis of changes in selling prices (Figure 6), if the product being sold is getting cheaper, then the profit is smaller than the ideal calculation, but if the product being sold is getting more expensive, then the profit is greater than the ideal calculation.

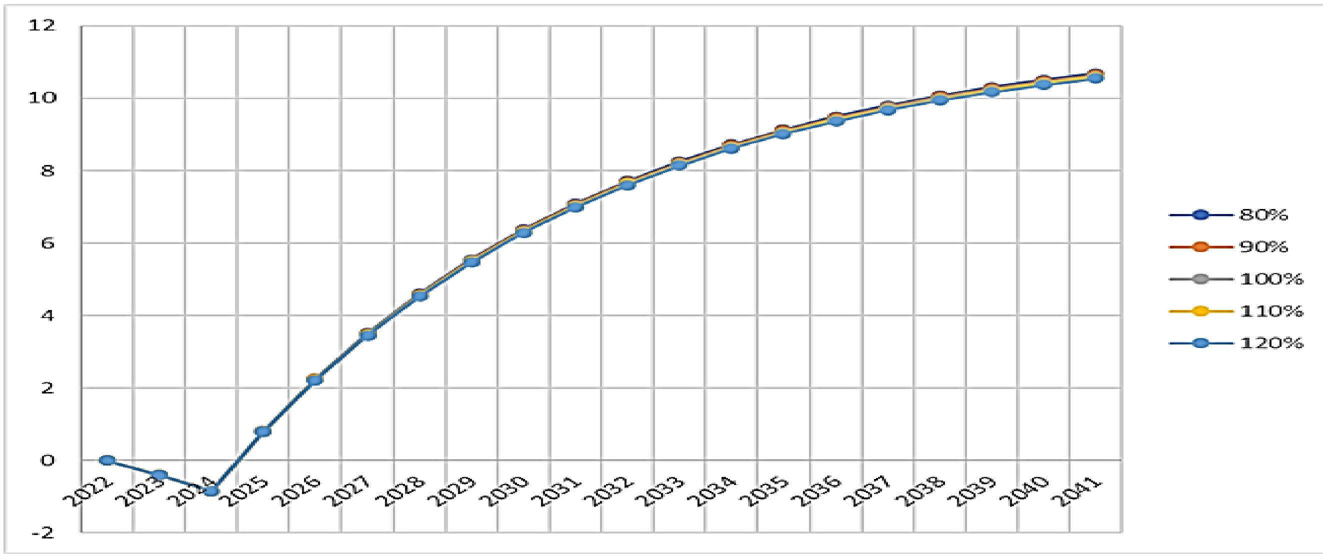

Figure 5: The effect of Variation in Labor Payment Cost against CNPV/TIC.

3) Changing selling cost

Figure 6 depicts a sensitivity analysis of the product's selling price under the worst-case scenario. The sensitivity of the product's selling price ranged from -100 to -50, 0, 50, 100, 150, 200, and 250%. Where, at the 100% sensitivity point (ideal selling price), the price is 0.79 USD. According to the findings, increases in selling prices have a positive effect on profits

However, the decision to determine the selling price is very important, because, in addition to influencing the profit the company wants to achieve, it also affects the survival of the company. Determining the wrong selling price can have fatal financial problems company and will affect the continuity of the company's business such as continuous loss (Haeldermans *et al*., 2020). Besides affecting profits, the selling price also affects the BEP. Each percentage has the same initial PBP but has a different BEP, the reason is that if the selling price of the

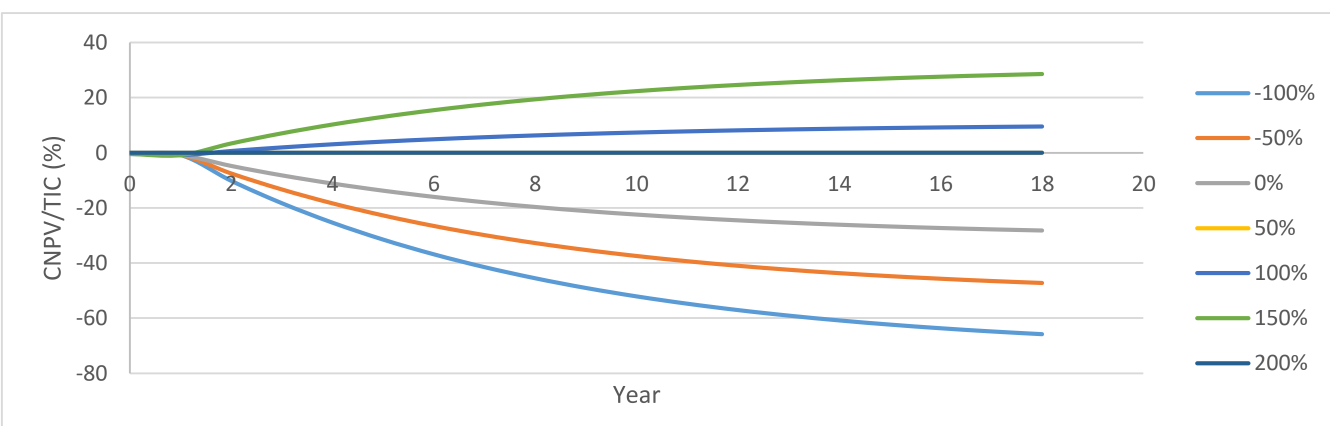

Figure 6: The effect of Variation in Selling Price against CNPV/TIC.

product is cheaper, it means it will take a long time to reach a profit. The opposite reason, if the selling price of the product is more expensive, then the BEP is achieved faster than the ideal calculation because the amount of profit is greater than the ideal calculation.

4) Changing tax cost

Figure 7 shows the effect of tax variations on CNPV/TIC. An income tax levied by the government to fund various government expenditures is one of the external factors influencing project success (Rahmadianti *et al*., 2021; Lazăr & Istrate, 2018). The tax we use for the ideal calculation is a 10% tax, but what happens if the tax is increased from 10% to 50%, the results are shown in Figure 7. Based on Figure 7, the tax does not significantly affect the profit of this project.

However, of course, if taxes continue to increase, the project benefits will be lower and of course, also affect the BEP. The time to reach the BEP becomes longer as taxes increase. For example, if comparing the 10% tax and 50% tax, the 10% tax can reach the BEP in the third year of the project, but at the 50% tax, because the tax is relatively large, the BEP is achieved almost in the third and a half years of the project. Here, tax costs have a less significant impact on project profits, where changing this parameter (up to 50%) is not a major problem in project sustainability.

5) Changing utility cost

Figure 8 is a CNPV curve that subtracts the effect of utility cost variations on CNPV/TIC. The utility costs here include the cost of the electricity and water bills. When conditions are

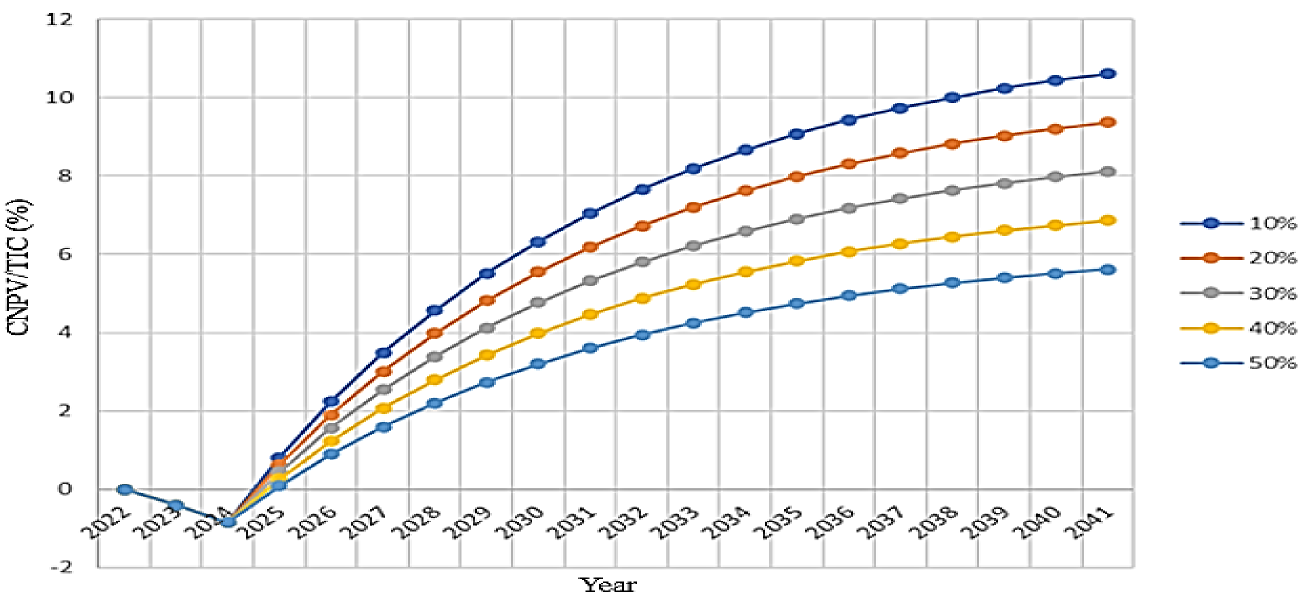

Figure 7: The effect of Variation in Tax increases against CNPV/TIC.

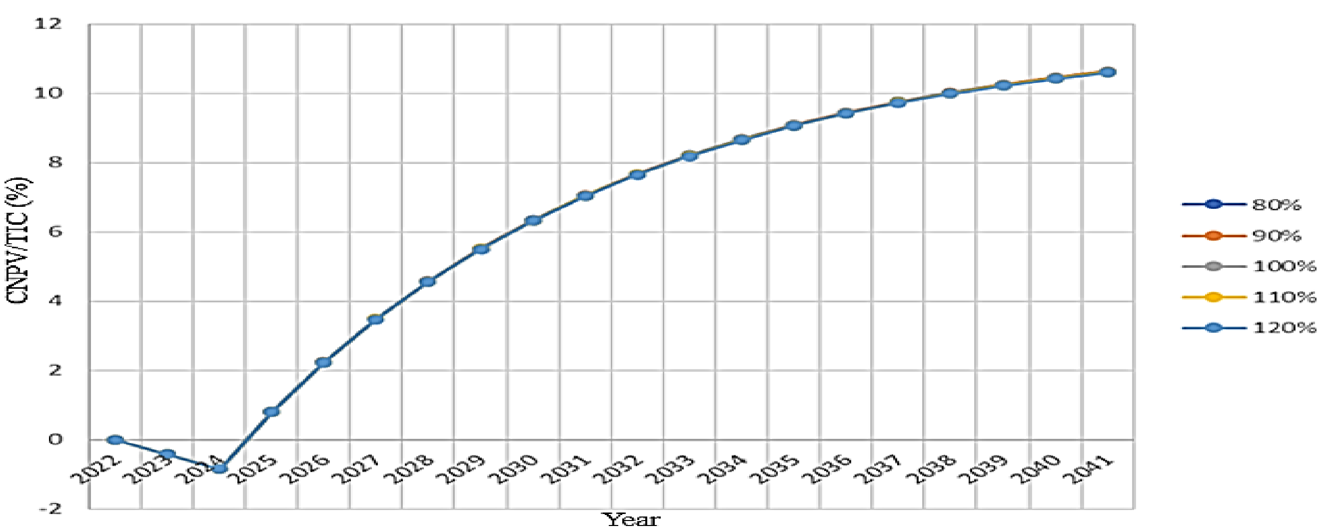

Figure 8: The effect of Variation in Utility Cost against CNPV/TIC.

not ideal, the cost of electricity bills is assumed to increase and decrease from the ideal cost so that the sensitivity of electricity costs is varied from 80-120%. As shown in Figure 8, the effect of the increase in utility costs does not affect the project's profit because the increase in costs up to 120% of the project still earns a relatively high profit. The utility does not affect profit, which is indicated by the curve line coincides with the ideal cost sensitivity, which means the profit or loss does not change too much when compared to the sensitivity at the ideal price. Here, utility costs do not affect the sustainability of the project and this result is in line with the literature (Zahra *et al*., 2020; Elia *et al*., 2021).

V. CONCLUSION

Based on the findings, the economic and engineering perspective shows that the biodiesel production project from edible oil waste through the supercritical methyl acetate transesterification method is feasible and promising. From an economic perspective, this project is promising due to economic parameters showing positive results. GPM parameters show positive results indicating the benefits of the project. The project reaches the profit point as PBP in 3 years and reaches the BEP in 360 production cycles. The PBP and BEP values represent a relatively short time which indicates that the project is relatively quick to make a profit. The IRR rate is also relatively high and can be maintained until the interest rate reaches 10%.

Analysis of several sensitivity parameters was also carried out which shows some limiting conditions for profit. Changes in the cost of raw materials, selling prices, and taxes significantly affect the profit of the project. However, changes in labor costs and utilities do not affect the project's profitability. From an engineering perspective, the investment cost shows the actual cost which is relatively cheap and has a positive impact on investors' returns. Some of the factors influencing this benefit include the use of simple manufacturing methods and the absence of hazardous materials. Based on the economic evaluation analysis, this project is feasible and will become a promising project in the future.

AUTHOR CONTRIBUTIONS

Asep Bayu Dani Nandiyanto: Conceptualization, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. **Eddy Soeryanto Soegoto:** Supervision, Writing – original draft, Writing – review & editing. **Safta Ananda Maulana:** Writing – review & editing. **Axel William Fritz Setiawan:** Writing – review & editing**. Fadel Shal Almay:** Writing – review & editing**. Muhammad Ridwan Hadinata:** Writing – review & editing. **Risti Ragadhita:** Writing – review & editing. **Senny Luckyardi:** Writing – review & editing.

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REFERENCES

Agarwal, M.; G. Chauhan; S. P. Chaurasia and K. Singh. (2012). Study of Catalytic Behavior of KOH as Homogeneous and Heterogeneous Catalyst for Biodiesel Production. Journal of the Taiwan Institute of Chemical Engineers, 43 (1): 89-94.

Alnasser, N.; O. S. Shaban and Z. Al-Zubi. (2014). The Effect of using Break-Even-Point in Planning, Controlling, and Decision Making in the Industrial Jordanian Companies. International Journal of Academic Research in Business and Social Sciences, 4 (5): 626.

Al-Zuhair, S.; A. Dowaidar and H. Kamal. (2009). Dynamic Modeling of Biodiesel Production from Simulated Waste Cooking Oil using Immobilized Lipase. Biochemical Engineering Journal, 44 (2-3): 256-262.

Andika, R. (2016). Techno-Economic Assessment of Coal to Sng Power Plant in Kalimantan. Indonesian Journal of Science and Technology, 1 (2): 156-169.

Anggiat, L. S.; R. A. Fadhilah; F. K. Insan; G. C. S. Girsang and A. B. D. Nandiyanto, (2021). Techno-Economic Analysis in the Production of Copper Nanoparticles by Biosynthetic Method using Citrus medica Linn Extract. International Journal of Research and Applied Technology (INJURATECH), 1 (1): 200-210.

Annisa, T; A. Azkiya; R. N. Fauzi; A. B. D. Nandiyanto and S. N. Hofifah. (2021). Cost Analysis and Economic Evaluation for Manufacturing Hydroxyapatite Nanoparticles from Eggshell Waste. International Journal of Research and Applied Technology (INJURATECH), 1 (1): 211-226.

Asaolu, T. O.; C. J. Agorzie and J. M. Unam. (2012). Materials Management: An Effective Tool for Optimizing Profitability in the Nigerian Food And Beverage Manufacturing Industry. Journal of Emerging Trends in Economics and Management Sciences, 3 (1): 25-31.

Astuti, L.; R. P. Dewi; A. Nurdiana; R. Ragadhita and A. B. D. Nandiyanto. (2021). Techno-Economic Analysis on the Production of Zinc Sulfide Nanoparticles by Precipitation Assisted Ultrasonic Radiation Method. International Journal of Research and Applied Technology (INJURATECH), 1 (1): 173-186.

Campanelli, P.; M. Banchero and L. Manna. (2010). Synthesis of Biodiesel from Edible, Non-Edible and Waste Cooking Oils via Supercritical Methyl Acetate Transesterification. Fuel, 89 (12): 3675-3682.

Elia, S. H.; B. S. Maharani; I. Yustia; G. C. S. Girsang; A. B. D. Nandiyanto and T. Kurniawan. (2021). Techno-Economic Evaluation of Hyaluronic Acid Production through Extraction Method using Yellowfin Tuna Eyeball. ASEAN Journal of Science and Engineering, 1 (3): 161-170.

Eskander, R. F. A. (2018). Risk Assessment Influencing Factors for Arabian Construction Projects using Analytic Hierarchy Process. Alexandria Engineering Journal, 57 (4): 4207-4218.

Febriani, L. I.; C. Nurhashiva; J. Veronica; R. Ragadhita; A. B. D. Nandiyanto and T. Kurniawan. (2020). Computation Application: Techno-Economic Analysis on the Production of Magnesium Oxide Nanoparticles by

Precipitation Method. International Journal of Informatics, Information System and Computer Engineering (INJIISCOM), 1 (1): 117-128.

Georgogianni, K. G.; A. K. Katsoulidis; P. J. Pomonis; G. Manos and M. G. Kontominas. (2009). Transesterification of Rapeseed Oil for the Production of Biodiesel using Homogeneous and Heterogeneous Catalysis. Fuel Processing Technology, 90 (7-8): 1016-1022.

Haeldermans, T.; L. Campion; T. Kuppens; K. Vanreppelen; A. Cuypers and S. Schreurs. (2020). A Comparative Techno-Economic Assessment of Biochar Production from Different Residue Streams using Conventional and Microwave Pyrolysis. Bioresource Technology, 318 (2020): 124083.

Hama, S.; S. Tamalampudi; A. Yoshida; N. Tamadani; N. Kuratani; H. Noda and A. Kondo. (2011). Process Engineering and Optimization of Glycerol Separation in A Packed-Bed Reactor for Enzymatic Biodiesel Production. Bioresource Technology, 102 (22): 10419-10424.

Kiss, F. E.; M. Jovanović and G. C. Bošković. (2010). Economic and Ecological Aspects of Biodiesel Production Over Homogeneous and Heterogeneous Catalysts. Fuel Processing Technology, 91 (10): 1316-1320.

Kurniadianti, Y. S.; A. Z. Ziva; Y. K. Suryana; R. Ragadhita; A. B. D. Nandiyanto and T. Kurniawan. (2021). Computation in he Analysis of Techno-Economic of the Production of Al2O3 (Aluminum Oxide) Nanoparticles through Precipitation Method. International Journal of Informatics, Information System and Computer Engineering (INJIISCOM), 2 (1): 65-76.

Lazăr, S. and Istrate, C. (2018). Corporate Tax-Mix and Firm Performance. A Comprehensive Assessment for Romanian Listed Companies. Economic Research-Ekonomska Istraživanja, 31 (1): 1258-1272.

Lee, S.; D. Posarac and N. Ellis, N. (2012). An Experimental Investigation of Biodiesel Synthesis from Waste Canola Oil using Supercritical Methanol. Fuel, 91 (1): 229-237.

Li, Q.; W. Du and D. Liu. (2008). Perspectives of Microbial Oils for Biodiesel Production. Applied Microbiology and Biotechnology, 80 (5): 749-756.

Maulana, M. I. and Nandiyanto, A. B. D. (2019). Economic Evaluation of Different Solvents in the Production of $LaCoO_3$ Nanoparticles Prepared by the Co-Precipitation Method. International Journal of Advanced Smart Convergence, 1 (4): 7-15.

Mojaveri, H. S. and Moghimi, V. (2017). Determination of Economic Order Quantity in a fuzzy EOQ Model using of GMIR Deffuzification. Indonesian Journal of Science and Technology, 2 (1): 76-80.

Nandiyanto, A. B. D. (2018). Cost Analysis and Economic Evaluation for the Fabrication of Activated Carbon and Silica Particles from Rice Straw Waste. Journal of Engineering Science and Technology, 13 (6): 1523-1539.

Nandiyanto, A. B. D.; D. F. Al Husaeni; R. Ragadhita and T. Kurniawan. (2021). Resin-Based Brake Pad from Rice Husk Particles: From Literature Review of Brake Pad From Agricultural Waste to the Techno-Economic Analysis. Automotive Experiences, 4 (3): 131-149.

Nurdiana, A.; L. Astuti; R. P. Dewi; R. Ragadhita; A. B. D. Nandiyanto and T. Kurniawan. (2022). Techno-Economic Analysis on the Production of Zinc Sulfide Nanoparticles by Microwave Irradiation Method. ASEAN Journal of Science and Engineering, 2 (2): 143-156.

Oyedokun, G. E.; A. O. Tomomewo and S. A. Owolabi. (2019). Cost Control and Profitability of Selected Manufacturing Companies in Nigeria. Journal of Accounting and Strategic Finance, 2 (1): 14-33.

Prabowo, B.; T. Khairunnisa and A. B. D. Nandiyanto. (2018). Economic Perspective in the Production of Magnetite (Fe_3O_4) Nanoparticles by Co-Precipitation Method. World Chemical Engineering Journal, 2 (2): 1-4.

Priatna, D. and Nandiyanto, A. B. D. (2019). Engineering and Economic Evaluation of Production of MgO Nanoparticles using a Physicochemical Method. International Journal of Advanced Smart Convergence, 8 (4): 26-33.

Putra, R. F.; C. Satari; R. S. Sidqi; S. R. Putri and A. B. D. Nandiyanto. (2021). Techno-Economic Analysis on the Production of Copper Oxide Nanoparticles by Green Synthesis Method using Abultion indicum Leaf Extract on an Industrial Scale. International Journal of Research and Applied Technology (INJURATECH), 1 (1): 187-199.

Quesada-Medina, J. and Olivares-Carrillo, P. (2011). Evidence of Thermal Decomposition of Fatty Acid Methyl Esters during the Synthesis of Biodiesel with Supercritical Methanol. The Journal of Supercritical Fluids, 56 (1): 56-63.

Ragadhita, R. and Nandiyanto, A. B. D. (2022). Computational Bibliometric Analysis on Publication of Techno-Economic Education. Indonesian Journal of Multidiciplinary Research, 2 (1): 213-220.

Ragadhita, R.; A. B. D. Nandiyanto; A. C. Maulana; R. Oktiani; A. Sukmafitri; A. Machmud and E. Surachman. (2019). Techno-Economic Analysis for the Production of Titanium Dioxide Nanoparticle Produced by Liquid-Phase Synthesis Method. Journal of Engineering Science and Technology, 14 (3): 1639-1652.

Rahmadianti, S.; K. P. Tyas; P. Maratussolihah; G. C. S. Girsang and A. B. D. Nandiyanto. (2021). Economic Evaluation of Gold Nanoparticle (Au Np) Production using Laser Ablation Synthesis Method. Urecol Journal. Part D: Applied Sciences, 1 (2): 95-103.

Rahman, H.; J. P. Sitompul and S. Tjokrodiningrat. (2022). The composition of fatty acids in several vegetable oils from Indonesia. Biodiversitas Journal of Biological Diversity, 23 (4): 2167-2176.

Rodrigues, A. R.; A. Paiva; M. G. da Silva; P. Simões and S. Barreiros. (2011). Continuous Enzymatic Production of Biodiesel from Virgin and Waste Sunflower Oil in Supercritical Carbon Dioxide. The Journal of Supercritical Fluids, 56 (3): 259-264.

Rosmawati, D. A.; A. A. Rizqia; S. Jannah; N. N. Azizah and A. B. D. Nandiyanto. (2021). Economic Evaluation on the Production of Poly-DADMAC and Sepiolite Nanocomposite. International Journal of Research and Applied Technology (INJURATECH), 1 (1): 162-172.

Saka, S. and Isayama, Y. (2009). A New Process for Catalyst-Free Production of Biodiesel using Supercritical Methyl Acetate. Fuel, 88 (7): 1307-1313.

Saka, S.; Y. Isayama; Z. Ilham and X. Jiayu. (2010). New Process for Catalyst-Free Biodiesel Production using Subcritical Acetic Acid and Supercritical Methanol. Fuel, 89 (7): 1442-1446.

Shalahuddin, F. A.; S. S. Almekahdinah and A. B. D. Nandiyanto. (2019). Preliminary Economic Study on the Production of ZnO Nanoparticles using A Sol-Gel Synthesis Method. Jurnal Kimia Terapan Indonesia, 21 (1): 1-6.

Shimada, Y.; Y. Watanabe; A. Sugihara and Y. Tominaga. (2002). Enzymatic Alcoholysis for Biodiesel Fuel Production and Application of the Reaction to Oil Processing. Journal of Molecular Catalysis B: Enzymatic, 17 (3-5): 133-142.

Supriyadi, A.; T. Wang; M. R. Juwita; R. Gunaningrat; S. Safitri and G. T. Cirella. (2021). Sustainability Policy in Indonesia: Case Study Economic Structure and Determinants in Banjar Municipality. International Journal of Informatics, Information System and Computer Engineering (INJIISCOM), 2 (1): 25-46.

Tan, K. T.; K. T. Lee and A. R. Mohamed. (2011). Prospects of Non-Catalytic Supercritical Methyl Acetate Process in Biodiesel Production. Fuel Processing Technology, 92 (10): 1905-1909.

Van Gerpen, J. (2005). Biodiesel Processing and Production. Fuel Processing Technology, 86 (10): 1097-1107.

Veronica, J.; L. I. Febriani; C. Nurhashiva; R. Ragadhita; A. B. D. Nandiyanto and T. Kurniawan. (2021). Practical Computation in the Techno-Economic Analysis of the Production of Magnesium Oxide Nanoparticles using Sol-gel Method. International Journal of Informatics, Information System and Computer Engineering (INJIISCOM), 2 (2): 1-12.

Zahra, F.; F. A. Utami; G. C. S. Girsang; S. Z. M. S. Mulya; V. D. Fentiana; Y. K. Putri and A. B. D. Nandiyanto. (2020). Economic Evaluation of Zinc Oxide Nanoparticle Production through Green Synthesis Method using Cassia Fistula Plant Extract. International Journal of Energetica, 5 (2): 18-24.