Analysis of Eco-Efficiency Level in Tofu Processing Using the Life Cycle Assessment (LCA) Method

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Abstract. A tofu industrial center in Sukoharjo Regency, Central Java requires approximately 700 kg of soybeans per day. There is some waste in tofu processing, including energy consumption, water consumption, and has a negative impact on the environment in the form of liquid waste and solid waste. This study aims to analyze and provide suggestions for improvements regarding the level of eco-efficiency in tofu processing. The method used is Life Cycle Assessment (LCA) using SimaPro software with the scope of "gate to gate". This research resulted in an eco-cost value of IDR 2,005,000 and an EEI value of 0.13 which means that it is affordable but not sustainable. Then obtained an EVR value of 7.5 and an EER rate of -6.5%, which means that the eco-efficiency of tofu products is quite poor. So that the proposed improvements that can be used are minimizing the use of raw materials, water and energy and treating waste from tofu processing according to the predetermined booklet.

1 Introduction

Regional potential is the ability of a region to regional development by utilizing its resources and potential to increase the economic income of the region concerned [1]. Therefore, the industrial center is one of the containers for centralizing macro and small industries in supporting the development of the region. The industrial center is one of the sectors that can support regional and national economic growth. According to the Central Bureau of Statistics, in 2020 the most industrial centers were in Central Java, namely the spread of food industry centers to reach 1,555 centers an increase of 4.82% [2]. One of the food industry centers is tofu processing in Kartasura District. Kartasura is one of the sub-districts where the majority of people do tofu production. The tofu industry is one type of industry engaged in food processing using the main raw material, namely soybeans [3].

Yus Kartasura Tofu Factory is one of the tofu industry centers in Sukoharjo Regency, Central Java, which requires approximately 700 kg of soybeans per day. Yus Kartasura Tofu Factory still operates traditionally with 10 workers. The processing of tofu in this factory is still manual and semi-automatic. This tofu processing process uses the main raw material, namely soybeans. In addition, it uses vinegar water as a mixture in cooking tofu porridge, as well as electrical energy to help the dynamo in the grinding process. Making tofu is fairly easy without having to require special skills, making it attractive to entrepreneurs because the tofu processing industry has profitable business opportunities. On the other hand, the tofu industry is also one of the contributors to waste in the environment, especially liquid waste. Processing that is still traditional and relies on human labor makes the production process less effective and no system regulates the disposal of waste from the production. In addition to waste, the tofu processing industry also produces non-product outputs in the form of tofu waste [4].

In the process of processing tofu at Yus Kartasura Tofu Factory, there are several wastes in energy consumption, including the use of electricity to power the lights and dynamos used for 9 hours per day. While in the production site, there is ventilation for bright lighting. In addition, during the boiling process, tofu porridge uses 18 sacks of firewood per day while during the rainy season, it can reach 23 sacks of firewood per day. The remaining ash is only disposed of at the disposal site and has not been utilized properly[5].

Yus Kartasura Tofu Factory uses water sourced from wells so it does not require water costs. However, the use of water is inefficient due to its excessive use. When the water container is full, the water faucet is not turned off with the excuse of running the floor to clean the epidermis. The continuous flow of water onto the production floor can cause workers to slip. This high water consumption causes a waste of water resources, which can affect the company's profits[6]. This waste can be seen from the amount of liquid waste generated from the boiling, clumping, and printing process of tofu which is often directly discharged into the river. This is because there is no WWTP (IPAL) that regulates the waste treatment system. Wastes that are discharged into the river include vinegar water waste, washing water waste, and epidermis waste. As a result of dumping waste into the river, the ecosystem is disturbed, the smell is unpleasant and the river water becomes cloudy[7]. Poor quality of

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liquid waste will have an impact on the polluted environment, especially on the aquatic environment[8].

Therefore, it is necessary to conduct research by measuring the level of eco-efficiency in the tofu processing process. Measuring the level of eco-efficiency is carried out in the food industry to improve the quality of raw materials and introduce modern technology for production [9]. Research using openLCA software shows that the stages of grinding and boiling tofu are the stages that produce the greatest impact on the environment and the largest use of energy, namely boiler steam, wood saw residue fuel and biogas, and PLN electricity so they must minimize the use of these resources [10]. This research will analyze all production processes with SimaPro software. Using the LCA method with the help of the CML-IA Baseline method to analyze abiotic depletion, global warming, human toxicity, and eutrophication which resulted in tofu production can cause global warming, depletion of the ozone layer caused by the transportation of soybeans and the use of firewood, acidification, and eutrophication [7]. In this research, using the LCA method with the help of the Eco-Indicator 99 (H) method to determine the impact of in terms of human health, ecosystem quality, and resources.

According to the Ministry of Environment of the Republic of Indonesia in 2007, the concept of eco-efficiency is to minimize the use of raw materials, water, energy, and impact on the environment per unit of product [4]. With the application of the concept of eco-efficiency, the production process will be effective and efficient so that savings occur to increase profits for the company and have no impact on the surrounding environment. So, the concept of eco-efficiency must be applied in the company to create a positive impact on the environment [11].

This eco-efficiency level measurement uses the Life Cycle Assessment (LCA) method to create environmentally friendly clean production. Life Cycle Assessment is a method used to identify and measure the use of natural resources, and energy discharged into the environment [12]. By using the LCA method, industrial activities will be measured in terms of economics, technology, and the environment from raw material procurement, and production processes to finished products. So, LCA can be used to analyze all processes that have an impact on the environment and energy use for the production process using SimaPro software [13]. Knowing how much impact it can provide improvements to the environment so that it can increase eco-efficiency in each process and can be used to determine what improvements must be made by tofu producers so that production is categorized as a sustainable industry.

Based on the problems described, the *Life Cycle Assessment* (LCA) method is used to measure the level of eco-efficiency to provide improvements to the environmentally friendly production process.

2 Method

This research uses the Life Cycle Assessment (LCA) method using SimaPro software with the scope of "gate to gate" with the help of the Eco-Indicator 99 (H) method. The following are the steps in the research conducted.

2.1 Object of Research

The object of this research is Yus Kartasura Tofu Factory located in Sukoharjo, Central Java.

2.2 Type of Research

This type of research uses quantitative research by taking data directly based on field studies and conducting interviews with 1 owner and 3 workers at Yus Kartasura Tofu Factory.

2.3 Data Collection

Data collection was carried out by observation and interview. This observation was carried out to obtain information related to the tofu production process, data on material requirements along with the size and units used for the production process. Interviews were conducted to find out the raw materials, energy, and costs used in the production process. Interviews were also conducted to find out the flow of waste left over from the disposal of production[14].

2.4 Data Processing

The data entered in the SimaPro software include materials and sizes in the soaking and washing process, the milling process, the boiling process of soybean pulp, the agglomeration of soybean juice, and the cutting of tofu. The filtering and pressing processes do not require materials so they do not have an impact on the environment. After that, process the data and analyze the level of eco-efficiency in the production process using SimaPro software. The following are the stages of Life Cycle Assessment.

1. Goal and Scope Determination

This stage is to determine the objectives and scope of the research conducted. The goal of this research is to determine the level of eco-efficiency and evaluate the environmental impact of the tofu processing process. The scope of this research is "gate to gate" which focuses only on the production process from start to finish. The production process consists of soaking and washing, grinding, boiling, filtering, clumping, pressing, and cutting tofu.

2. Life Cycle Inventory (LCI)

This stage is to determine the materials used in each tofu processing process. The data in the LCI must be accurate so that it can help in identifying impacts on the environment. The data covers all production processes from start to finish except the filtering process and pressing process. Both processes are processes that do not require materials so they do not have an impact on the environment. The following breakdown of material input in tofu processing per day with 700 kg of soybeans can be seen in Table 1.

Table 1. Life Cycle Inventory of Yus Kartasura Tofu Factory

Process	Materials Used	Number of Inputs	Unit	Corresponding LCA SimaPro
Washing and soaking	Soy Beans	700	kg	Soybean protein-isolate, at processing {US} Economic, U
	Water	3000	liter	Tap water {RoW}| tap water production, underground water without treatment | Conseq, S
Soy bean milling	Water	233	liter	Tap water {RoW}| tap water production, underground water without treatment | Conseq, S
Boiling tofu porridge	Water	900	liter	Tap water {RoW}| tap water production, underground water without treatment | Conseq, S
	Firewood	180	kg	Wood fuel, hardwood, purchased, combused in industrial boiler, NE-NC/kg/RNA
Soybean juice agglomeration	Vinegar Water	2400	liter	Acetid acid, at plant/kg/RNA
Tofu cutting	Water	750	liter	Tap water {RoW}| tap water production, underground water without treatment | Conseq, S

3. Life Cycle Impact Assessment (LCIA)
This stage is the stage to analyze the type and value of each impact category resulting from the production process. There are four stages of assessment in LCIA, namely characterization, damage assessment, normalization, and weighting. This impact measurement uses the Eco-Indicator 99 (H) method so that the assessment is seen in terms of human health (DALY), ecosystem quality (PAF*m2myr, PDF*m2myr), and resources (MJ Surplus) from tofu processing.

4. Interpretation
Interpretation is the stage to analyze the results so as to draw conclusions. In addition, this stage can provide suggestions for improvement in reducing the impact on the environment. The results of the LCA calculation will be used to find eco-cost. Eco-cost is the cost incurred to express the amount of environmental impact. Finding eco-cost with the formula shown in Table 2. Unit Conversion. For the conversion of 1 dollar to rupiah of Rp. 16,137.00 on March 1, 2023.

Table 2. Unit Conversion

Category	Unit	Description
Human Health	Euro	1 QALYs*74000
Ecosystem Quality	Euro	PDFm2yr*1.4
Resources	Euro	MJ*0.00411
Convert	Rupiah	1 Euro*16,137

Once the eco-cost value is obtained, the next step is to calculate the cost benefit analysis or net value of a product. The net value formula is as follows.

$$\text{Net value} = \text{Selling price} - \text{production cost} \quad (1)$$

The results of the eco-cost and cost benefit analysis above are used as a reference in determining product feasibility or eco-efficiency index (EEI) from affordable and sustainable values. The calculation of EEI is carried out by using equation (2).

$$EEI = \frac{Net\ Value}{Eco\ Cost} \quad (2)$$

The calculation results are then analyzed using the EEI criteria. The following is Table 3. Eco-Efficiency Index Criteria.

Table 3. Eco-Efficiency Index Criteria

Eco-Efficiency >1	affordable	sustainable
Eco-Efficiency = 0-1	affordable	not sustainable
Eco-Efficiency < 0	not affordable	not sustainable

The last step is the calculation of the Eco-Cost Value Ratio (EVR) to determine the value of the Eco-Efficiency Ratio (EER) level. EVR is an indicator when a certain product design is needed. In determining EVR and EER, we can use the following equation [15].

$$EVR = \frac{Eco\ cost}{Net\ Value} \dots\dots\dots\dots\dots\dots (3)$$

$$EER = (1 - EVR)X\ 100\% \dots\dots\dots. (4)$$

The results of the equation can be used to see how good the production eco-efficiency level is determined from the EVR value. If the EVR value is low, the EER value will be high, which means that the eco-efficiency level of the product is getting better and vice versa.

3 Results and Discussion

3.1 Environmental Impact Results

In Life Cycle Impact Assessment (LCIA), the stages of assessing and classifying impacts on the environment are characterization, damage assessment, normalization and weighting.

1. Characterization
Characterization is an assessment of the impact of each material needed based on their respective characteristics. The goal is to see how much impact is generated on the environment from production activities with 11 impacts.

Table 4. Characterization of Tofu Processing

Impact category	Unit	Total	Description
Carcinogens	DALY	0,0021	DALY (Disability-Adjusted Life Years) is a unit for measuring the burden of disease that means one year of healthy life lost.
Resp.organics	DALY	1,33E-5	
Resp.inorganics	DALY	0,00388	PDF*m2yr (Potentially Disappeared Fraction of Species per Square meter per year) is the loss of ecosystems per m2 per year.
Climate change	DALY	0,00125	PAF*m2yr (Potentially Affected Fraction per square meter per year) is the percentage loss of population per m2 per year.
Radiation	DALY	2,94E-6	
Ozone layer	DALY	4,1E-7	Mj Surplus to measure the amount of energy required for natural resource extraction.
Ecotoxicity	PAF*m2yr	1,03E3	
Acidification / Eutrophication	PDF*m2yr	102	
Land use	PDF*m2yr	18,4	
Minerals	Mj Surplus	30,1	
Fossil fuels	Mj Surplus	2,13E4	

Based on Table 4. Tofu Processing Characterization shows that the biggest impact on Respiratory Inorganics is 0.000388 DALY which causes respiratory problems. Ecotoxicity of 1,030 PAF*m2yr due to damaged ecosystems. In addition, it has the largest impact on fossil fuels of 21,300 Mj Surplus due to the depletion of fossil fuels.

2. Damage Assessment
Damage assessment is an assessment of damage caused by the 11 impacts above and then grouped into three impact categories, namely human health, ecosystem quality, and resources. The following is Table 5. Damage Assessment of Tofu Processing[16].

Table 5. Damage Assessment of Tofu Processing

Damage category	Unit	Total	Washing and soaking		Milling	Boiling		Clumping	Cutting
			Soybeans	Water	Water	Water	Firewood	Vinegar water	Water
Human Health	DALY	0,00725	0,00315	1,19E-6	9,23E-8	3,56E-7	0,000883	0,00321	2,97E-7
Ecosystem Quality	PDF*m2yr	223	128	0,0394	0,00306	0,0118	21,8	73,9	0,00994
Resources	MJ surplus	2,13E4	4,96E3	0,598	0,0464	0,179	19,8	1,64E4	0,15

Based on Table 5. Tofu Processing Damage Assessment resulted in a total human health category impact of 0.00725 DALY which means the number of years of healthy life lost by 0.00725 years received by a person caused by disability or premature death. In the ecosystem quality category of 223 PDF*m2yr which means 223 species per m2 per year are lost. While the resources category is 21,300 MJ Surplus which means that the amount of energy is lost for natural resource extraction[17].

3. Normalization
Normalization is the stage of uniforming units for each impact category so that in normalization the units are no longer used. The goal is to make it easier to analyze the

impact so as to obtain more accurate results. Table 6. provides the Normalization of the tofu processing.

Table 6. Normalization of Tofu Processing

Damage category	Total	Washing and soaking		Milling	Boiling		Clumping	Cutting
		Soybeans	Water	Water	Water	Firewood	Vinegar water	Water
Human Health	0,827	0,36	0,000136	1,05E-5	4,07E-5	0,101	0,366	3,39E-5
Ecosystem Quality	0,0391	0,0223	6,88E-6	5,34E-7	2,06E-6	0,0038	0,0129	1,72E-6
Resources	2,83	0,657	7,92E-5	6,15E-6	2,38E-5	0,00263	2,17	1,98E-5

Based on Table 6. Normalization of Tofu Processing shows that the human health category is 0.827, ecosystem quality is 0.0391, and resources are 2.83.

4. Weighting

Weighting is the assignment of weights to impact factors so as to produce a total value of environmental impacts that can be compared consistently. Table 7. presents the weighting of the processing.

Table 7. Weighting of Tofu Processing

Damage category	Unit	Total	Washing and soaking		Milling	Boiling		Clumping	Cutting
			Soybeans	Water	Water	Water	Firewood	Vinegar water	Water
Total	Pt	912	284	0,0728	0,00566	0,0218	42,3	585	0,0182
Human Health	Pt	331	144	0,0542	0,00421	0,0163	40,3	146	0,0136
Ecosystem Quality	Pt	15,6	8,93	),00275	0,000214	0,000826	1,52	5,16	0,000688
Resources	Pt	565	131	0,0158	0,00123	0,00475	0,525	433	0,00396

Based on Table 7. Tofu Processing Weighting shows a total weighting of 912 Pt consisting of three categories namely human health 331 Pt, ecosystem quality 15.6 Pt, and resources 565 Pt.

3.2 Eco-Cost

Eco-cost is the cost that must be incurred to deal with the amount of impact on the environment resulting from life cycle assessment using SimaPro software. The following is the calculation of eco-cost in tofu processing.

a. Human health category
   1 DALYs = 1 QALYs
   Human health = 0,00725*74000*16137
   = IDR 8,657,501
b. Ecosystem Quality category
   Ecosystem Quality = 223*1,4*16137
   = IDR 5,037,971
c. Resources
   Resources = 21300*0,00411*16137
   = IDR 1,412,681

The total eco-cost of the three categories can be seen in Table 8.

The calculation shows that the results of eco-cost or costs that must be incurred by Yus Kartasura Tofu Factory to overcome the environmental impacts generated based on the human health category amounted to Rp 8,657,501. The costs incurred for damage to ecosystem quality amounted to Rp 5,037,971 and the costs incurred on resources amounted to Rp 1,412,681. So that the total cost that must be incurred from the tofu processing process is IDR 15,108,153.

Table 8. Tofu Processing Eco-Cost Recap

Damage category	Unit	Total eco-cost
Human health	DALY	IDR 8,657,501
Ecosystem quality	PDF*m2yr	IDR 5,037,971
Resources	MJ surplus	IDR 1,412,681
		IDR 15,108,153

3.3 Cost Benefit Analysis and Eco-Efficiency Index

Cost benefit analysis is used to determine the net value/profitability of a product. Net value input is the cost used in the production process. Net value is influenced by production costs and product selling prices. The production cost per day of the tofu is available in Table 9.

Table 9. Tofu Production Cost per Day

No.	Variable Production Cost	Total
1	electricity	IDR 33,000
2	raw materials	IDR 9,800,000
3	fuel	IDR 162,000
4	labor	IDR 1,500,000
	Total	IDR 11,495,000

Selling price of tofu/1 day: IDR 13,500,000, so the daily Net value selling price of tofu:
= selling price - production cost
= Rp 13,500,000 - Rp 11,495,000
= IDR 2,005,000

Eco-efficiency index is used to determine the feasibility of products from affordable and sustainable values. So the following calculation can be done.

Eco-efficiency index = Net Value : eco cost
= Rp 2,005,000 : IDR 15,108,153
= 0.13

From these calculations it can be concluded that the eco-efficiency result is 0-1 where the product of Yus Kartasura Tofu Factory can be financially affordable so that it can be accepted by consumers (affordable) but is not safe for the environment (not sustainable).

3.4 Eco Cost Value Ratio (EVR) and Eco-Efficiency Ratio (EER Rate)

Eco-Cost Value Ratio (EVR) is a calculation used to determine the value of the Eco-Efficiency Ratio (EER) level. So that by knowing this value, it can be seen how much the efficiency level of the production process is.

EVR = Eco-cost : net value
= IDR 15,108,153 : Rp 2,005,000
= 7,5

EER Rate = (1-EVR) x 100%
= (1-7,5) x 100%
= - 6,5%

Based on the above calculation results, the EVR value is 7.5 and the EER rate is -6.5% so that the eco-efficiency of tofu products is poor. Therefore, the tofu product is less efficient in the use of resources and reduction of impact on the environment.

4 Conclusion

4.1 Summary

Based on the research that has been conducted at Yus Kartasura Tofu Factory, it can be concluded as follows:

a. The tofu production process has several stages, namely soaking and washing, grinding, boiling, filtering, clumping, pressing and cutting. The waste generated is in the form of liquid waste (soybean and tofu soaking residual water and vinegar water), solid waste (tofu pulp, epidermis, and firewood ash).
b. Based on data processing using SimaPro software with the Eco-Indicator 99(H) method, the results of the impact on the three categories are obtained, among others:
   1) The human health category is respiratory inorganics at 0.000388 DAILY with a healthy life year loss impact of 0.00725 DALY. This is due to the emission of inorganic substances in the air that cause respiratory problems.
   2) The ecosystem quality category is ecotoxicity at 1,030 PAF*m2yr with an impact of 223 species per m2 per year lost due to ecosystem quality (air, soil, and water) being damaged by ecotoxic substances.
   3) The resources category has the largest impact on fossil fuels at 21,300 Mj Surplus and the amount of energy lost to extract natural resources due to resource depletion.
   4) Based on the impact weighting, it shows a total weighting of 912 Pt consisting of 3 categories, namely human health 331 Pt, ecosystem quality 15.6 Pt, and resources 565 Pt. The biggest impact on resources is due to the vinegar water waste that is discharged directly into the environment.
c. Tofu production with 700 kg of soybeans has a profit of Rp 2,005,000 per day. The Eco-efficiency Index results in 0-1 affordable economically but not sustainable environmentally. Therefore, the resulting EER of -6.5% means that eco-efficiency is still poor so that the tofu production is less efficient in resource use and reducing environmental impacts.
d. Recommendations for improvement that can be given are in the form of booklets regarding guidelines for minimizing the use of raw materials, water, and energy as well as guidelines for managing liquid waste or vinegar water to neutralize pH and solid waste in the form of firewood ash as plant fertilizer and epidermis as animal feed according to predetermined conditions. So as to increase eco-efficiency in tofu processing.

References

[1] A. Putri, "Jurnal Geografi Potensi Wilayah Beberapa Daerah Di Indonesia," *J. Geogr.*, vol. XX, no. November, pp. 0–20, 2019.
[2] F. Agusti, T. Wisudawati, F. T. Risqi, and K. Kumaratunggadewi, "Evaluasi Teknologi Produksi pada Sentra Industri Keripik Tempe Grobog Wonogiri," vol. 1, no. 2, pp. 30–35, 2022.
[3] N. Andarwulan, L. Nuraida, D. R. Adawiyah, R. N. Triana, D. Agustin, and D. Gitapratiwi, "Pengaruh Perbedaan Jenis Kedelai terhadap Kualitas Mutu Tahu," *J. Mutu Pangan*, vol. 5, no. 2, pp. 66–72, 2018.
[4] N. N. Agtriani and B. Prabawani, "Analisis

Proses Produksi Pada Usaha Kecil Dan Menengah (Ukm) Tahu Di Kelurahan Jomblang Berbasis Eko-Efisiensi (Studi Pada Ukm Tahu Harapan Tenang Semarang)," *J. Ilmu Adm. Bisnis*, vol. 9, no. 2, pp. 106–118, 2020, doi: 10.14710/jiab.2020.27224.

[5] A. Riyanto and Y. Pramesti, "Pemanfaatan Limbah Plastik dengan Teknologi Daur Ulang pada Hot Rolled Asphalt Ditinjau dari Aspek Properties Marshall, Nilai Ketidakrataan, dan Durabilitas," *Din. Tek. Sipil Maj. Ilm. Tek. Sipil*, vol. 1, no. 1, pp. 18–27, 2022, doi: 10.23917/dts.v1i1.18088.

[6] S. Hartini, B. S. Ramadan, R. Purwaningsih, S. Sumiyati, and M. A. A. Kesuma, "Environmental impact assessment of tofu production process: Case study in SME Sugihmanik, Grobogan," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 894, no. 1, 2021, doi: 10.1088/1755-1315/894/1/012004.

[7] I. P. Sari, W. Kuniawan, and F. L. Sia, "Environmental impact of tofu production in West Jakarta using a life cycle assessment approach," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 896, no. 1, 2021, doi: 10.1088/1755-1315/896/1/012050.

[8] S. D. Kayode-Afolayan, E. F. Ahuekwe, and O. C. Nwinyi, "Impacts of pharmaceutical effluents on aquatic ecosystems," *Sci. African*, vol. 17, p. e01288, 2022, doi: https://doi.org/10.1016/j.sciaf.2022.e01288.

[9] A. Zielińska-Chmielewska, A. Olszańska, J. Kaźmierczyk, and E. V. Andrianova, "Advantages and constraints of eco-efficiency measures: The case of the polish food industry," *Agronomy*, vol. 11, no. 2, pp. 1–13, 2021, doi: 10.3390/agronomy11020299.

[10] E. U. Lolo, R. I. Gunawan, A. Y. Krismani, and Y. S. Pambudi, "Penilaian Dampak Lingkungan Industri Tahu Menggunakan Life Cycle Assessment (Studi Kasus: Pabrik Tahu Sari Murni Kampung Krajan, Surakarta)," *J. Serambi Eng.*, vol. 6, no. 4, pp. 2337–2347, 2021, doi: 10.32672/jse.v6i4.3480.

[11] X. Zhang and D. Xu, "Assessing the eco-efficiency of complex forestry enterprises using LCA/time-series DEA methodology," *Ecol. Indic.*, vol. 142, no. April, p. 109166, 2022, doi: 10.1016/j.ecolind.2022.109166.

[12] R. Purwaningsih, C. F. Simanjuntak, and Z. F. Rosyada, "Eco-Efficiency of Pencil Preduction Using Life Cycle Assessment to Increase the Manufacture Sustainability," *J. Tek. Ind.*, vol. 22, no. 1, pp. 47–54, 2021, doi: 10.9744/jti.22.1.47-52.

[13] M. Faishal, M. N. Arfan, and H. M. Asih, "Reducing Environmental Impact on SME Metals Production Process Using Life Cycle Assessment and Analytical Hierarchy Process Method," *J. Ilm. Tek. Ind.*, vol. 19, no. 1, pp. 84–94, 2020, doi: 10.23917/jiti.v19i1.10041.

[14] Yuniaristanto, W. Sutopo, A. Widiyanto, and A. S. Putri, "Concept of economic readiness levels assessment," *AIP Conf. Proc.*, vol. 1902, 2017, doi: 10.1063/1.5010640.

[15] N. Susanto and T. T. Putranto, "Pengukuran Tingkat Eko-Efisiensi Batik Cap Menggunakan Metode Life Cycle Analysis (Studi Kasus: Batik Encim pada Kampoeng Batik Kauman Pekalongan)," *J. Ilmu Lingkung.*, vol. 20, no. 3, pp. 654–664, 2022, doi: 10.14710/jil.20.3.654-664.

[16] E. Muslimah, S. Soeparman, B. Yanuwiyadi, and H. Riniwati, "Using eco-efficiency to analyze environmental impact of the batik industry," *Technol. Reports Kansai Univ.*, vol. 62, no. 4, pp. 1809–1814, 2020.

[17] W. Sutopo, M. Nizam, A. Purwanto, N. Atikah, and A. S. Putri, "A cost estimation application for determining feasibility assessment of Li-Ion battery in mini plant scale," *Int. J. Electr. Eng. Informatics*, vol. 8, no. 1, pp. 189–199, 2016, doi: 10.15676/ijeei.2016.8.1.13.