HASIL CEK_Selection of environmental impact reduction

by Tatbita Titin Suhariyanto Selection Of Environmental Impact Reduction

Selection of Environmental Impact Reduction Strategies Based on Life Cycle Assessment (LCA) and Analytical Network Process (ANP): A Case Study of Wood Charcoal Industry in Indonesia

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Abstract

Up to now, the people of Mantewe (South Kalimantan, Indonesia) have utilized ironwood waste by turning it into commercial charcoal. However, most charcoal production processes still use traditional combustion methods which have negative impacts on the environment and society, such as air pollution due to incomplete combustion. Therefore, this study aims to analyze the environmental impact of the charcoal production process using the Life Cycle Assessment (LCA) method and to design improvement strategies to reduce environmental impacts using the Analytical Network Process (ANP). This study selected a wood charcoal industry in South Kalimantan as the case study with a "gate-to-gate" scope. The CML2001 method with nine impact categories selected in the LCA. Furthermore, the ANP method is used to design environmental impact reduction strategies based on the LCA results. The result of the analysis shows that the main critical point in the wood charcoal industry is the burning of ironwood waste, while the second critical point is the use of heat energy from peat soil. Based on the weight, the environmental impact reduction strategies obtained from the ANP method are product diversification (0.4031), formulating the right

materials (0.2765), replacing raw materials (0.26027), and using the furnace method (0.0618). This research is expected to be useful for the owners of the wood charcoal industry and can be a reference for how LCA and ANP can produce strategies for reducing environmental impacts in the wood charcoal industry.

Keywords
Wood Waste, Wood Charcoal Industry, Environmental Impact, Life Cycle Assessment (LCA), and Analytical Network Process.

1. Introduction

Each stage of wood processing produces wood waste in various sizes, quantities, and shapes. One of the potential industries in utilizing wood waste is the wood charcoal industry. According to Salim (2016), most of the chemical components of charcoal are carbon. Charcoal can be produced from wood decomposition because of the heat decomposition process, which is carried out directly or indirectly to heat the material using a kiln or a landfill. The utilization of wood waste is carried out by several communities in Mantewe, Indonesia, by using ironwood waste as charcoal. However, the production process is still not environmentally friendly because it uses a traditional combustion method, such as a kitchen stove filled with soil. The manufacture of this charcoal stove consists of three parts, namely the body, cover, and chimney. According to preliminary observations, this combustion method harms the environment, such as uncontrolled air pollution due to incomplete combustion.

Based on these problems, this study aims to analyze the environmental impact of the charcoal production process and select improvement strategies to minimize the environmental impact. Life Cycle Assessment (LCA) is an impact analysis method that is often used to evaluate the consumption of energy and raw materials, emissions released to the environment, and other wastes related to the life cycle of a product or system (ISO 14040, 2006). Meanwhile, Analytical Network Process (ANP) is one method that is often used to select improvement strategies and solve problems in decision-making without making assumptions related to the independence between higher and weaker levels of elements and the independence of elements at one level (Katili, 2017). The ANP method considers the relationship between criteria and sub-criteria to represent the level of interest of various parties. Therefore, this study aims to combine the two methods to gain better strategies. Using LCA, each input and output of charcoal production activities is calculated and analyzed to determine the critical point of the process. Furthermore, several environmental reduction strategies are proposed through ANP.

2. Literature Review

This section presents several previous research regarding the use of LCA and ANP, as well as the integration of both methods. LCA has been widely used to assess the environmental impacts of diverse products and processes (Fidan et al., 2021). The LCA results can be applied to establish sustainable strategies and improvement (Suhariyanto et al., 2018). The LCA points out to evaluate all stages of the product's life cycle. Certain LCA studies on biomass densification have been caried out. Muazu et al. (2017) reviewed data from 19 sources with 48 case scenarios to assess the current status of LCA of biomass densification. As a result of different decisions regarding system boundary, functional unit, allocation procedure, densification technology, and biomass residues, it was discovered that existing LCA studies of biomass densification did not provide enough and inconsistent information for full transparency and comparability.

On the other hand, regarding the strategy selection, dependencies between factors and interactions within factors are present in many decision-making problems. The ANP technique was put up by Saaty (1980) as a solution for issues involving internal or external dependencies between alternatives and criteria (Sah, 2010). There are four steps in the ANP approach (Sah, 2010), namely defining the problem and establishing the network structure, creation of binary comparison matrices, calculation of vector weights and consistency analysis, and create the super matrix. Much research have been carried out in various cases, such as banking and financial. Dewi (2011) implemented the ANP method to reduce the problem of corporate sukuk in Indonesia. The order of priority problems formed in the research is lack of understanding, lack of liquidity of the secondary market, lack of knowledge, and lack of incentives. Meanwhile, the order of priority of the proposed strategy is to carry out intensive socialization, encourage SOEs, improve tax system regulations, innovate on products, and provide incentives. Rusydiana (2016) researched an analysis of problems in the development of Islamic banking in Indonesia using the ANP method. This study aims to find out what are the problems faced by Islamic banking institutions in Indonesia and how strategies must be applied in a long-term strategic framework with the ANP approach. The results of the research show that the problems that arise in the development of Islamic banks in Indonesia consist of 4 important aspects in order, namely: human resources, technical, legal/structural aspects, and market/communal aspects. Aghnina (2020) conducted research on financing with the application of Character, Capacity, Capital, Collateral, Condition of Economy, and Syariah (5C+1S) using the ANP method. This study aims to find out the most important factors behind the approval of financing by employees at Mandiri Syariah Bank. The study found that character criteria were the most important in the background for employee financing approvals. This is because people can be judged on their personality, lifestyle, and background so that banks can know the quality of prospective debtors. The order of priority criteria formed in this study is the character, sharia, capacity, collateral, condition of economics, and capital.

Furthermore, the integration of LCA and ANP has been implemented in various cases, such as product development and environmental performance management. Pringgajaya and Ciptomulyono (2012) researched the implementation of LCA and the ANP approach for the development of environmentally friendly Hetric Lamp products. This study found the contribution of the environmental impact that appears in the hetric lamp production process is 60.2 pt, the distribution process is 46 pt, and the product use process is 16.1 pt. The environmental impact with the largest contribution is the impact of human toxicity on the water during the production process, and when the product is used, as well as the global warming impact caused during the production process. The best alternative obtained from the results of ANP data processing is the replacement of DOP lamp components by using LED lamps which are much more environmentally friendly. Another research conducted by Purba (2013) was integrated LCA and ANP to identify and determine how much the environmental impact of the processes that occur in the processing department and provide alternative solutions for improvement. The largest environmental impact contribution was obtained during the production process, which was 3.34 GPt., in the distribution process of 15.5 Pt, and at the stage of product use, which was 2.25 KPt. The biggest environmental impact is caused by soaping materials and dispersing agents. The chosen strategy using ANP in this study was to replace the soaping agent with alkyl benzene sulfonate and replace the dispersing agent with sodium perborate with a weight of 0.75. Furthermore, Effendi (2016) researched the implementation of environmental management at PT. Charoen Pokhpand-Krian using LCA and ANP. The research aims to find the environmental impact that has the greatest contribution to the production process at PT. Charoen Pokhpand-Krian uses LCA in the production process, as well as provides a strategy proposal using the ANP method. The impacts found are impacts on ecosystem quality, human health, and resources.

Based on previous research, there is still few research evaluates the environmental impact of the wood charcoal industry using LCA and ANP. Most of the previous research focused on stove and tool design, charcoal manufacture, quality, and characteristics, such as Mardijanto (2018) and Salim (2016). Therefore, the purpose of this study was to determine the environmental impact of the wood charcoal production process using LCA. This research is also different from previous research because it proposes improvement strategies designed in reducing the environmental impact of the wood charcoal industry using ANP.

3. Methods

The first method used is LCA, which consists of four stages: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation. The first stage aims to describe the objectives and formulate the system to be evaluated, the constraints and assumptions related to impacts throughout the life cycle. There are four LCA scopes: cradle-to-grave, cradle-to-gate, cradle-to-cradle, and gate-to-gate (ISO 14040, 2006). In this study, the scope of the research is gate-to-gate, which only covers the stage of the production process.

Furthermore, LCI is the stage of collecting data in input materials and the resulting output. According to Finnveden et al. (2000), four stages of LCI, namely the stage of identification of all processes involved in the production cycle, the stage of collecting data in each process, the stage of determining system boundaries, the stage of adjusting materials or energy entering and leaving the process to link functional units. The third stage is the LCIA which uses the 2001 CML method to assess environmental impacts in several categories of impacts that can cause pollution to the environment. Each impact category refers to a different potential for environmental pollution. The last stage is the interpretation of the activities carried out previously and provides suggestions for improvement following the problems.

The second method used in this research is ANP which is a technique of measuring data from a questionnaire given to the respondents, then collected and processed by calculating the ANP method to produce output in the form of priority. The ANP method consists of 3 phases: model construction, model quantification, and analysis of ANP results. The first phase, namely constructing the ANP model, was prepared according to the literature review, interviews, and distribution questionnaires with experts and practitioners to obtain more in-depth information about analyzing environmental impact reduction strategies and creating a questionnaire model. The second phase, namely model quantification, was carried out by distributing questionnaires to respondents in pairwise comparison statements or pairwise comparisons between criteria and sub-criteria. This is to find out which of the two has the more significant influence and the magnitude of the difference by using the Saaty comparison scale. The last phase is the analysis of the results of the ANP, which consists of pairwise comparisons, consistency tests, and determining the importance of each sub-criteria. The pairwise comparison stage is done by calculating the geometric mean. Calculating the geometric mean is to accumulate respondents' answers in a formula to get a decision. After getting the geometric mean calculation results, the next step is to enter the geometric mean calculation results into the super decision software. Then, perform pairwise comparison matrix calculations between criteria and sub-criteria. From this matrix, normalize the values in each column of the pairwise comparison matrix. The next step is to calculate the eigenvector value by multiplying the pairwise comparison matrix by the average value of the sum of each row of the matrix.

To determine the consistency of the criteria, sub-criteria, and alternative models, measurements were made by calculating the Consistency Index (CI) and Consistency Ratio (CR). CR (Consistency Ratio) is the result of a comparison between CI (Consistency Index) and random index (RI). If the CR is 10% or 0.10, the respondent's answer is consistent. After the consistency test is carried out, the weight of the importance of the sub-criteria is determined by normalizing the limiting value for each element. After obtaining the weight of importance for each criterion and sub-criteria, the next step is to rank priorities to determine which criteria are more important. The priority results are obtained from the average value on the eigenvectors and provide policy recommendations. The closer the value is to one, the more priority the element is.

4. Data Collection

In this study, the data collection techniques used were observation, interviews, questionnaires, and documentation. Observations were made by knowing the input and output and seeing how the traditional wood charcoal production process was in Bulurejo Village, Mantewe District. The interview was done by asking questions directly and freely in a structured manner to the parties concerned in the company. In this study, interviews were conducted with business owners, workers, and road users in the traditional wood charcoal industrial area. This interview method was used to obtain LCA data. The list of questions is as follows:

a. What process is used to make wood charcoal?
b. What materials are used to make wood charcoal?
c. How many ingredients are needed to make wood charcoal?
d. What kind of power source is used during the process?
e. What type of equipment is used to support the wood charcoal-making process?
f. What are the specifications of each tool used?
g. Has the company ever caused any problems to the environment?

Next, questionnaires are conducted so that the data and information obtained can be following the research to be carried out. This questionnaire is used for the ANP method.

This study uses the purposive sampling method, namely the technique of determining the sample with certain considerations. Purposive sampling is also often referred to as judgmental sampling. The purpose of purposive sampling is to classify or determine the research sample based on criteria specifically determined by the researcher. This technique can solve the problem more clearly and provide a representative value. In this study, respondents were selected based on their expertise areas, either from practitioners or academicians. Respondents in this study were 5 people consisting of two chemical engineering lecturers and three owners of the traditional wood charcoal industry who had been operating for at least 4 years to support the validity of the research data. The determination of the number and qualifications of respondents is based on research conducted by Aghnina (2020) and Rusydiana (2016) which explains that respondents are experts in their fields.

5. Results and Discussion

5.1 Numerical and Graphical Results

Input and output data for single charcoal production are summarized in the LCI phase. The input required for one production is 52000 kg of ironwood waste as the primary material, 90000 MJ of heat energy from the soil and 0.5 liters of gasoline to burn charcoal, and 3000 liters of water. Then, the output produced from this process is the final product of wood charcoal and waste debris in the form of dust and ash. This LCI data is then inputted into the GaBi© software for environmental impact analysis. Based on the LCIA results shown in Table 1 and Figure 1, the burning of ironwood waste contributes the first most significant impact and heat energy from the soil contributes the second-largest impact.

Table 1. Life cycle impact assessment

Impact Category		**Unit**	**Total**	**Ulin Wood Waste Burning**	**Use of Thermal Energy from the Soil**	**Use of Water**	**Use of Fossil Fuel**	**Charcoal and Ash Flakes**
Acidification potential	AP	kg SO_2 eq	6.E+01	**4.E+01**	**2.E+01**	4.E-01	9.E-01	4.E-01
Global warming potential	GWP	kg CO_2 eq	6.E+04	**5.E+04**	**1.E+04**	2.E+02	3.E+02	4.E+03
Depletion of abiotic resources-elements	ADPE	kg SB eq	3.E-04	0.E+00	**2.E-05**	**1.E-04**	8.E-05	4.E-05
Depletion of abiotic resources-fossil fuels	ADPF	MJ	1.E+05	0.E+00	**9.E+04**	3.E+03	**2.E+04**	8.E+02
Freshwater aquatic ecotoxicity potential	FAETP	kg DCB eq	1.E+03	**1.E+03**	4.E+00	4.E+00	**7.E+00**	1.E-01
Terrestrial ecotoxicity potential	TETP	kg DCB eq	8.E+01	**7.E+01**	**4.E+00**	4.E+00	2.E+00	8.E-02
Ozone layer depletion potential	ODP	kg R11 eq	8.E-03	**8.E-03**	4.E-13	2.E-12	3.E-13	1.E-12
Human toxicity potential	HTP	kg DCB eq	8.E+05	**8.E+05**	**3.E+02**	2.E+01	3.E+01	3.E+00
Eutrophication potential	EP	kg Phosphate eq	2.E+01	**2.E+01**	**2.E+00**	3.E-01	1.E-01	1.E-01

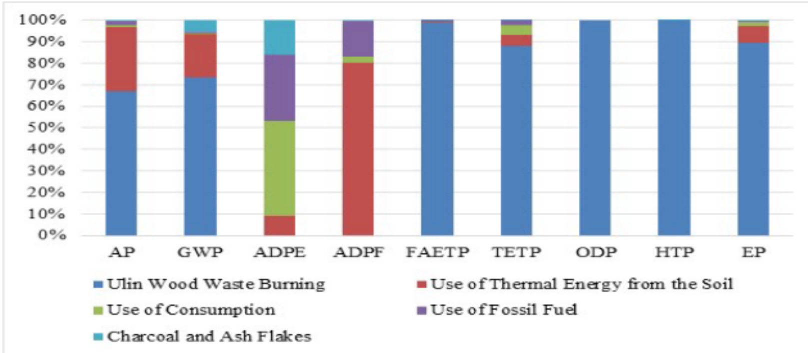

Figure 1

The next impact is the use of water, gasoline, and the waste of charcoal and ash flakes. The burning of ironwood waste accounts for more than 60% of AP, 70% of GWP, almost 100% of FAETP, 90% of TETP, 100% of ODP and HTP, and close to 90% of EP. Burning ironwood waste can cause air pollution, which impacts human health. Smoke and dust from combustion can cause respiratory problems and pneumonia. Meanwhile, water use contributes the largest impact on ADPE, 40%. This is because the use of water continuously can affect the decline in biotic resources. Then, charcoal flakes and ash had the biggest impact on ADPE, 28%. This is because charcoal flakes and ash can contaminate abiotic resources, one of which is water. Furthermore, the use of heat energy from the ground has the greatest impact, 80% on ADPF. This is due to the continuous consumption of abiotic resources. In addition, the use of thermal energy from the ground has a 33% impact on AP and a 20% impact on GWP. Then, the use of gasoline contributed 0.5% impact on AP, 0.5% impact on GWP, 0.5% impact on FAETP, 2% impact on TETP, 1% impact on EP, and 18 % on ADPF. The use of gasoline has the biggest impact on ADPE at 30%. This is because gasoline is an abiotic resource.

After evaluating the potential environmental impact of the wood charcoal production process, the next step is to construct the ANP model based on the results of questionnaires distributed to research respondents. Research respondents were selected by examining at their expertise and work experience. From the distribution of the questionnaire, three criteria were obtained, namely raw materials, processes, and products. As presented in Table 2, each sub-criteria is described based on three criteria obtained from the literature and interviews with practitioners and academicians who are experts in the field of wood charcoal.

Table 2. Criteria and sub-criteria

Criteria	Sub-criteria	References
Raw materials	Type of raw materials	Budi (2017)
	Availability of raw materials	Isa (2012)
	Cost of raw materials	Interview with practitioners
	Quality of raw materials	Interview with academicians
Process	Ability to minimize smoke	Interview with practitioners; Salim (2016); Mardijanto (2018)
	Environmental safety	Interview with academicians; Mardijanto (2018)
	Burning time efficiency	Interview with practitioners
Product	Affordable price	Winanda (2021)
	Environmentally friendly product	Interview with practitioners, Dharma, dkk. (2017)
	Quantity of product	Interview with practitioners

Furthermore, several alternatives are obtained by considering the existing criteria. In this study, there are three criteria that are considered by researchers, academics and owners of the wood charcoal industry in making alternatives, namely the criteria for raw materials, process criteria, and product criteria or results in order to achieve the goals in this study, namely for strategies to reduce environmental impacts from the charcoal industry. wood. As for some alternatives that are a concern for designing a strategy for reducing environmental impacts on the wood charcoal industry in Mantewe can be seen in Table 3.

Table 3. Model Alternatives

Alternative	References
Replacing raw materials	Isa (2012); Budi (2017); Sulistyono (2006); Subroto (2007); Rahmawati (2013); Gifani (2017); Efiyanti dkk (2020).
Formulating the right ingredient composition	Sulistyono (2006); Subroto (2007); Gifani (2017).
Using the furnace method	Interview, Soolany (2007); Salim (2016); Efiyanti dkk (2020); Elsaprike (2018); Mardijanto (2018); Winanda (2021); Dharma dkk (2017).
Diversifying products into charcoal briquettes	Interview, Rindayatno & Lewar (2017); Isa (2012); Sulistyono (2006); Subroto (2007); Rahmawati (2013); Gifani (2017).

The next step is to calculate the geometric mean of criteria, sub-criteria, and alternatives. Geometric mean is the calculation of the average weight of the respondent's assessment given by all respondents. It means that the geometric mean is a combination of all respondents' answers which are then searched for the geometric mean value. The rounding of the geometric mean value obtained is called the ANP value and used as input data in the Super decision software. Then, normalize by dividing the value in the row matrix by the result of the sum of the corresponding columns. Next, the values in each column are averaged, and then the order of priority can be arranged from the highest value to the lowest value. Furthermore, to see the consistency of respondents' answers to the questionnaires, a ratio consistency test was carried out. Respondents' answers are consistent if the inconsistency value in the software is 0.1. The consistent answers of respondents in the questionnaire indicate that the research data is valid and feasible to use. Expert respondents are selected based on their level of expertise in their field and have been in related work for more than four years. As presented in Table 4, the inconsistency value for all criteria and sub-criteria is less than 0.1, so it can be said that the research data is feasible to proceed to the next calculation stage.

Table 4. Inconsistency Ratio for Criteria

Criteria	Cconsistency Ratio (CR)	CR ≤ 0,1
Availability of raw materials	0,100098	CR ≤ 0,1
Cost of raw materials	0,072572	
Quality of raw materials	0,062798	
Type of raw materials	0,056606	
Environmental safety	0,100697	
Ability to minimize smoke	0,085392	
Burning time efficiency	0,042430	
Quantity of product	0,104902	
Environmentally-friendly product	0,086368	
Affordable price	0,074638	

As shown in Table 5, after selecting alternative strategies using the ANP method, the priority weight of each alternative is obtained. Product diversification gets the highest priority weight, which is 0.4031, formulating the right material composition with a weight of 0.2765, replacing raw materials with a weight of 0 .26027, and using the furnace method with a weight of 0.0618.

Table 5. Inconsistency Ratio for Each Alternative

Alternative	Cconsistency Ratio (CR)	CR ≤ 0,1
Diversifying products into charcoal briquettes	0,080262	CR ≤ 0,1
Formulating the right ingredient composition	0,055312	
Replacing raw materials	0,052053	
Using the furnace method	0,012373	

5.2 Proposed Improvements

Charcoal briquettes are solid fuels that contain carbon, have a high calorific value, and can burn for a long time (Fitriana & Febrina, 2021). Some of the advantages obtained when replacing ironwood charcoal products (product diversification) with charcoal briquettes are that they emit less smoke when burned, are made from renewable materials, and are more efficient because of the same number of raw materials more briquettes than if made ordinary charcoal. Charcoal briquettes can be made using palm shells, empty fruit bunches, and oil palm flowers. This will undoubtedly make it easier for companies to obtain raw materials because Mantewe District is one of the palm oil commodity areas in South Kalimantan, so the raw materials used are locally available, cheap, abundant, and most importantly, it is renewable and sustainable materials.

Research conducted by Kurniawan et al. (2017) in the manufacture of charcoal briquettes using empty palm oil bunches showed that the water content obtained was between 6.6-8.4%, ash content was between 6-16%, and the calorific value with kaji flour adhesive was 5,971 J/g and with water adhesive. Sugarcane has a calorific value of 5,391 J/g. Aziz et al. (2019) made briquettes using palm shells. The calorific value produced using tapioca adhesive was 6,328 kcal/kg, sugar palm sago 6,330 kcal/kg. Resin 6,366 kcal/kg, the moisture content of tapioca adhesive was 6.0%, sago sugar palm 6.7 %, and resin 5.5%, ash content of tapioca adhesive 7.70 %, palm sago 6.74%, and resin 7.11%, and the burning time on tapioca adhesive 78 minutes, sago 74 minutes, and resin 92.3 minutes. The charcoal briquettes made by Firdaus & Nurdin (2019) using oil palm flowers with a mixed composition of 80%:20% resulted in an average heating value of 10,312.60 Kj/Kg for the tapioca flour adhesive mixture and 13,081.59 Kj/Kg for gum resin adhesive mixture. Oil palm flower briquettes using resin adhesive have the highest heating value because resin contains hydrocarbons that can increase the heating value.

In Table 1, it is known that the composition of the materials used in one single production of wood charcoal is 52000 kg of ironwood waste: 90000 MJ of heat energy from the soil: 0.5 liters of gasoline to burn charcoal, 3000 liters of water. Based on this composition, the burning of ironwood waste contributes the first most significant environmental impact, and thermal energy from the soil contributes the second-largest impact. The following impact is the use of water, the use of gasoline, and the waste of charcoal and ash flakes. The primary raw material for making charcoal at the company is using ironwood, but the burning of ironwood waste causes a sizeable environmental impact, so an alternative strategy that can be applied is to replace the primary or raw materials. Ironwood can be replaced by using coconut shell waste. Triono (2006) stated that coconut shell charcoal has good thermal diffusion properties and can produce heat around 6500-7600 kcal/kg. Some of the advantages obtained when replacing ironwood raw materials with coconut shells are that alternative fuels will be more environmentally friendly, easy to obtain, more economical, and used by the wider community.

According to Budi (2017), replacing the primary raw material with using coconut shell has several advantages, such as the material is easy to obtain, less ash is produced, the flame will last a long time, the smoke is not much, and the price of raw materials is more affordable than ironwood charcoal waste. Musabbikhah (2015) found that coconut shell charcoal provides a higher heating value than wood charcoal and proves that coconut shell charcoal has a better combustion quality than other biomass-based fuels. However, replacing raw materials using coconut shell charcoal requires certain appropriate technologies to minimize the impact of smoke generated from the combustion process. Various combustion methods are more environmentally friendly, such as the dome furnace method, drum clinch, and pyrolysis furnace method. The burning method used by the company is to arrange the wood and then fill it with soil.

This method produces a process output in the form of wood charcoal as a final product and waste debris in the form of dust and ash. This is detrimental to the charcoal business because there is less charcoal produced, so the method used needs to be changed. In addition, the smoke produced from the combustion process is considerable by using this method. One alternative method that can be used is to use an environmentally friendly furnace method. Mardijanto (2018) designed a green, ergonomic, and environmentally friendly coconut shell charcoal burning stove with a combination model of record kiln, ear mound kiln, and drum kiln. The furnace made has green ergonomic characteristics, which is more environmentally friendly because 2% of the combustion dust waste is concentrated in the drum and can only be spread in a 3m radius around the production site so that there is less exposure to harmful dust. The chimney is 4-5m long, so the smoke is spread over the house's roof, and the smoke pollutant is relatively more minor. In addition, not much material is burned into ash and dust to produce more charcoal. The calorific value of coconut shell charcoal produced has calories of 6,489 cal/gr; an increase in calorific value indicates a reduced water content so that less smoke is produced. The water content produced is only 5.704%, and the low water content in the charcoal produced also indicates that the smoke produced is relatively small.

Soolany (2007) recommends making charcoal using the drum kiln method by modifying the chimney section with a liquid smoke installation pipe added to make liquid smoke with minimal pollution. In addition, the handrails on the drum kiln blanket are also designed to facilitate the disassembly process. Making charcoal with this method is not tied to location (it can be moved), and the cost is relatively cheap. In addition to using the drum kiln method, another method is the double burner pyrolysis furnace, which can produce two products at once, namely, charcoal and wood vinegar. This method is more environmentally friendly because the pyrolysis system involves a carbonization process that can minimize the elements that form smoke and soot. In addition, the products produced using this method are of good quality. This is also following research conducted by Elsaprike, (2018), which explains that the results of the charcoal quality test include the calorific value and the bonded carbon value produced by the double burner pyrolysis furnace method, which is significantly higher than the brick lin method. However, the value of water content, volatile matter, and ash content was significantly lower. The combustion method using the furnace method also has disadvantages, such as it requires skilled workers and the cost of making a furnace is expensive. The combustion method can be replaced by using a green ergonomics-based furnace method that has been designed and experimented with by Mardijanto (2018), in which the process of making the furnace is relatively easy to imitate because it uses used materials. However, the company needs time and energy to make the stove. Moreover, Bailis et al. (2013) analyzed comparatively the environmental impacts between hot-tail kilns and metal container kilns. In terms of a number of environmental performance indicators, such as greenhouse gas (GHG) emissions, water demand, energy return on investment (EROI), ozone depletion potential (ODP), photochemical oxidation (PCO), acidification, and eutrophication, the research recommends that container kilns perform better than hot-tail kilns.

The results of this ANP processing were consulted with the owner of the wood charcoal industry. Based on the results of interviews, product diversification from ordinary charcoal to charcoal briquettes only emits a little smoke when burned and is more efficient. However, product diversification into charcoal briquettes is difficult currently because there is no consumer need for this product. Meanwhile, the company that cooperates with the owner of the wood charcoal industry in Mantewe, namely PT. CPU (collector) only orders ordinary charcoal products. Formulating the suitable composition of ingredients, for now, is commonly used in burning wood charcoal in Mantewe. This is done to maintain the wood charcoal's quality and reduce the smoke generated from the combustion process. The quality of wood charcoal will be even better if a lot of thatch/straw is used in the combustion process. This can happen because the weeds block the soil from entering the woodpile undergoing the burning process so that the charcoal produced is clean. It is impossible to replace raw materials using coconut shell waste because it is difficult to obtain in Mantewe, and no consumers have purchased this product. The combustion method using the furnace method can be done. It just requires a large enough capital. Meanwhile, the owner obtains capital from collectors who cooperate to buy their wood charcoal products.

6. Conclusion

Environmental impact analysis on the wood charcoal industry has been carried out using the LCA method with the help of GaBi© software. Nine impact categories were obtained with the 2001 CML method, namely, AP, GWP, ADPE, ADPF, FAETP, TETP, ODP, HTP, and EP. The critical point in the wood charcoal industry is the burning of ironwood waste which contributes the first most significant impact, which is more than 60% on AP, 70% on GWP, almost 100% on FAETP, 90% on TETP, 100% on ODP and HTP, and approaching 90% on EP. Thermal energy from the ground contributes the second-largest impact, 80% on ADPF, 33% on AP, and 20% on GWP. Meanwhile, the impact of the use of water, the impact of the use of gasoline, and flakes of charcoal and ash are not too significant compared to the two previous impacts. Then, after selecting an alternative strategy using the ANP method, the results of the priority weights of each alternative are obtained, then the product diversification gets the highest priority weight, which is 0.4031, formulating the suitable material composition with a weight of 0.2765, replacing raw material with a weight of 0.26027, and using the furnace method with a weight of 0.0618.

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