

Implementation of Life Cycle Assessment (LCA) in environmental impact evaluation on production of ground coffee

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Abstract. This study aims to evaluate and identify potential environmental contaminants from the production process of ground coffee. The research was conducted at CV. XYZ in Bali province, Indonesia which processes dry coffee beans into ground coffee with the trademark “Kopi PQR”. Life Cycle Assessment (LCA) was used to identify and evaluate environmental impacts by applying the Environmental Design of Industrial Product (EDIP) method in the SimaPro 8.20 software. The Analytical Network Process (ANP) was then used to determine the priority of improvement recommendations. The results showed that the “Kopi PQR” production process had several environmental impacts, i.e. water acute eco toxicity, chronic water eco toxicity, and human toxicity soil. This impact resulted from the use of the use of plastic packaging which was difficult to decompose, and the accumulation of coffee powder waste. The recommendation for recycling coffee powder waste was chosen as an alternative for improvement in CV. XYZ.

1 Introduction

Ground coffee is the result of the processing of coffee beans by changing their physical form from bean to fine or powdery grains. The production of ground coffee starts from sorting, roasting, and grinding until its size is reduced. Roasting is used to increase organoleptic (aroma, taste and colour) and reduce the moisture content of the coffee beans by heating coffee around 60°C-250°C for 15-30 minutes [1,2]. The ground coffee packaging can be aluminium foil, paper, and plastic [3]. Coffee processing will produce solid, liquid, and gas waste. The solid wastes produced are the skin of the fruit and coffee grounds. The liquid waste comes from washing the coffee cherries. Gas waste comes from steam from roasting and combustion emissions [4]. Coffee waste products can be problematic for the environment. The waste from processing 30 tons of coffee will produce 15355.2 kg of waste with a composition of 13819.83 kg of liquid waste and 1533.52 kg of coffee husk waste [5]. Previous research [6] showed that the average emission by the ground coffee industry located in Surabaya has contributed SO₂ of 2.53 tons/year, CO₂ of 4.6 tons/year, and NO_x of 0.97 tons/year to the environment.

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Life Cycle Assessment (LCA) is one of the environmental management techniques used to evaluate environmental sustainability, energy used, environmental audits, and environmental impact assessments [7]. LCA is a method of analysing the entire cycle from the production process to waste treatment by looking at the costs, energy used, and environmental damage, starting from taking raw materials to becoming products [8]. LCA supports the process of assessing the costs and benefits associated with environmental innovations to reduce environmental impacts. However, energy efficiency policies usually focus on the medium or macro scale, while interventions are usually taken at the micro scale [9].

LCA analysis had been carried out by several researchers. Evaluation of the environmental impact of the paper product supply chain [10] proposed 2 alternatives for reducing the impact to the environment, i.e. replacing the transportation mode for product distribution from trailers to trains and replacing the optical brightening agent (OBA) bleach with H₂O₂. LCA analysis on the supply chain activities of a small scale dairy industry [11] had been carried out to observe the impact of supply chain activities. The results of this study provide an alternative to converting biogas on cattle farms to reduce the impact of supply chain activities on the environment. LCA analysis had also been carried out in the soybean production process in the State of Rio Grande do Sul, South Brazil [12]. Recommendations for reducing the impact on the environment were proposed by reducing the use of pesticides, providing freedom of association, and increasing stakeholders in the community. The results of all previous studies indicate the environmental impact of the production process in the agricultural industry and the alternative recommendations to reduce the impact on the environment [10,11,12].

This study was conducted at CV. XYZ which is located at Jalan Raya Seririt - Singaraja (Pemaron). Buleleng Regency. Bali Province, Indonesia. CV. XYZ is a producer which process dry coffee beans into ground coffee with the brand “Kopi PQR”. The high productivity of coffee in Indonesia increasing the coffee business. A lot of research on coffee had also been done. Most of the research on coffee focused on the quality [13,14], consumers’ satisfaction [15,16], and the coffee business chain [17,18]. Only a few research had been done by considering the impact of coffee business to the environment, meanwhile a lot of coffee business have impact on environment and the waste can be recycled to be another product [19]. The impact of coffee business on environment also happened at CV. XYZ. CV. XYZ has been using a lot of technology in the coffee production process, both traditional and modern, but the use of this technology has not been optimal to reduce the impact of the process to the environment and more cost was spent. The “Kopi PQR” production process had to be improved to reduce environmental impacts. Identification and evaluation of the environmental impact of the “Kopi PQR” production process needs to be done to minimize the impact. This study aimed to evaluate the environmental impact of the ground coffee production process, identify potential environmental contaminants from the ground coffee production process, and determine improvement strategies from evaluating ground coffee processing in order to create green manufacturing. This study assumed that the technology and energy used in the “Kopi PQR” production process had not changed.

2 Methods

2.1 Analysis of Life Cycle Assessment (LCA)

LCA data processing began with the creation of a Life Cycle Inventory (LCI) by calculating input and output in all stages of the “Kopi PQR” production process. The data at this stage were raw material requirements, emissions, solid waste, liquid waste, and gas

waste from the entire process. Obtained data then grouped according to the stages of production processes to be analysed using SimaPro 8.20 software. The LCI calculation used the Environmental Design of Industrial Product (EDIP) method of the software. The impact assessment data obtained from the LCI was then used at the Life Cycle Impact Assessment (LCIA) stage.

The LCIA stage was used as the basis for selecting improvement alternatives. LCIA analysis can relate the emergence of an impact to the use of a particular product or product life cycle. This stage started from identifying the quantity of emissions released by the system to the environment and their contribution to the environment. The criterion in the impact assessment was to compare the highest total accumulated impact on one process with another. LCI and LCIA calculations were carried out in accordance with the database on SimaPro 8.20 software [20].

Checking and evaluating the LCIA results was then carried out at the Life Cycle Interpretation stage. The interpretation on the system answered the objectives and scope of the LCA that had been previously defined. Further analysis was then carried out on the results of the Life Cycle Interpretation related to the “Kopi PQR” production process activities that had the greatest impact on the environment. Several high impact values for the environment were chosen to be the basis for improvements in reducing the impact on the environment.

2.2 Analytical Network Process (ANP)

ANP is a method that considers the relationship between the same objectives with other. The relationship is based on the same 2 types of perspectives, for example: finance with finance, business processes with business processes [21]. ANP was used to determine the priority weight for improvement alternatives to reduce the biggest and most significant impact on the environment using Super Decision software. The criteria used in weighting are benefit, opportunity, cost, and risk (BOCR). Opportunities typically capture expectations about positive spin-off, future profits, and revenue from future positive developments, whereas benefits represent current revenue or profits from positive developments that are relatively certain. Risks are supposed to capture the expected consequences of future negative developments, whereas costs represent (current) losses and efforts, as well as the consequences of relatively certain negative developments [22].

The formulation of sub-criteria for each criterion was carried out through discussion with expert respondents after determining the criteria. The determination of the sub-criteria considered environmental and social aspects of society for achieving the objectives of this study. The questionnaire was given to the Manager of CV. XYZ as an expert respondent who understands the entire “Kopi PQR” production process. The assessment was done to determine the interdependence between criteria in one group (inner dependency) and between groups (outer dependency) and to do pairwise comparison of the importance between the criteria, between the sub-criteria in a criteria, and between the sub-criteria across criteria. The importance scale of pairwise comparison is shown in Table 1 [23]. The results of the assessment from expert respondents were then analysed with Super Decision software to obtain one alternative improvement with the highest weight. These alternative improvements can certainly provide an increase in the performance of CV. XYZ economically and productivity.

Table 1. The importance scale of pairwise comparison.

Scale	Definition	Explanation
1	Equal importance	Two criteria / sub-criteria contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one criterion / sub-criterion over another
5	Strong importance	Experience and judgment strongly favour one criterion / sub-criterion over another
7	Very strong importance	An criterion / sub-criterion is favoured very strongly over another
9	Strong importance	The evidence favouring one criterion / sub-criterion over another is of the highest possible order of affirmation
2, 6, 4, 8	Intermediate values between adjacent scale values	

3 Results and discussion

CV. XYZ is a company which process dry coffee beans into ground coffee with the trademark “Kopi PQR”. The ground coffee is packed using plastic and paper packaging of various sizes. The products are marketed throughout Bali, Lombok, and several regions in Java based on orders. CV. XYZ produces 3 types of coffee, i.e. regular coffee, premium coffee, and 2in1 instant coffee (a mixture of sugar and ground coffee).

Regular coffee is a type of ground coffee packaged in plastic containers with sizes of 40 g, 50 g, 100 g, 200 g, 250 g, and 500 g. Premium coffee consists of super Robusta ground coffee, super Arabica ground coffee, *luwak* coffee, pea-berry coffee, Robusta and Arabica mixed coffee, and original ground coffee. The 2in1 instant coffee was produced by mixing 500 kg of regular coffee with 250 kg of sugar cane.

3.1 LCA of “Kopi PQR”

The scope of LCA of “Kopi PQR” consists of the entire “Kopi PQR” production process starting from receiving and storing raw materials to packaging the finished product. “Kopi PQR” production consists of three processes, i.e. the regular coffee production process, the premium coffee production process, and the 2in1 instant coffee production process. “Kopi PQR” produces 1800 kg of various sizes and types of products in 1 day of production.

3.1.1 Life Cycle Inventory

The LCI calculation process used the SimaPro 8.20 software database by entering input and output. The input were material and energy used in the “Kopi PQR” production process. The output data were the results of the production process, i.e. emissions and solid waste. Liquid waste and gas waste were not considered due to data limitations. All types of production process of “Kopi PQR”, i.e regular coffee production process, premium coffee production process, and 2in1 instant coffee production process, were analysed based on the aggregate production.

The capacity of the regular coffee production process in 1 day was 3600 kg of coffee beans which used 145.33 kWh of electrical energy. Regular coffee production process also used energy from firewood. The weight of firewood used was 2500 kg/day. The products were packed using Low-density *polyethylene* (LDPE). The need of LDPE to pack the product was 1 roll/day. The weight of LDPE was 3 kg per roll. The work days of regular

coffee production process were 24 days in 1 month. LCI input of regular coffee production process is shown in Table 2.

Table 2. Input of regular coffee production process.

Material and energy	Database in SimaPro 8.20	Quantity in a month
Coffee beans	Coffee Bean	86400 kg
Packaging (LDPE)	<i>Polyethylene</i> , LDPE, granulate, at plant/RER	720 kg
Electrical energy	Electricity, medium voltage {AU} market for Alloc Def, U	3487.92 kwh
Firewood energy	Wood and wood waste, 9.5 MJ per kg	570000 MJ

The production process for premium coffee was almost the same as the regular coffee production process. Premium coffee production process used 60 kg sorted coffee beans per day. The electricity used for this process was 22.9 kWh/day. Liquefied petroleum gas (LPG) was used 6 kg in a day with 1 kg of LPG equivalent to 13.6 kWh of electrical energy. “Kopi PQR” premium coffee products were packed using LDPE as primary packaging and kraft paper as secondary packaging. The need of LDPE to pack the product was 0.167 roll/day. The weight of LDPE was 3 kg per roll, meanwhile the weight of paper kraft was 1 kg for packaging premium coffee mad from 120 kg coffee beans. The work days of premium coffee production process were 24 days in 1 month. LCI input for premium coffee is shown Table 3.

Table 3. Input of premium coffee production process.

Material and energy	Database in SimaPro 8.20	Quantity in a month
Coffee beans	Coffee Bean	1440 kg
Primary packaging (LDPE)	Polyethylene, LDPE, granulate, at plant/RER	12 kg
Secondary packaging (Kraft paper)	Kraft paper, unbleached {GLO}	12 kg
Electrical energy	Electricity, medium voltage {AT} market for Alloc Def, U	549.6 kWh
LPG energy	Heat, central or small-scale Alloc Def, U	1958.4 kWh

The 2in1 instant coffee was produced by mixing 500 kg of regular coffee with 250 kg of sugar cane using a 500 kg capacity mixer machine. The electric power used was 7500 Watt for the mixer and 1300 Watt for the packaging machine. The products were packed using LDPE. The need of LDPE to pack the product was 1 roll/day. The weight of LDPE was 3 kg per roll. The work days of 2in1 instant coffee production process were 24 days in 1 month The LCI input for 2in1 instant coffee can be seen in Table 4.

Table 4. Input of 2in1 instant coffee production process.

Material and energy	Database in SimaPro 8.20	Quantity in a month
Ground coffee	Regular coffee	12000 kg
Sugarcane	Sugar, from sugarcane	6000 kg
Packaging (LDPE)	Polyethylene, LDPE, granulate, at plant/RER	72 kg
Electrical energy	Electricity, medium voltage {AU}	429,6 kWh

3.1.2 Life Cycle Impact Assessment (LCIA)

Impact assessment is used to evaluate the impact of the damage caused by its impact characteristics. The use of this analysis is useful as a consideration in improving environmental performance [24]. Each process input is calculated using the Environmental Design of Industrial Product (EDIP) method to help examine the impact. The input of production process data were integrated using SimaPro 8.20 software to compare the value or impact on each process before calculating the LCIA. The result of the data integration showed that the quantity ratio of regular coffee to premium coffee to 2in1 instant coffee was 1:1:3.5.

The contribution of each process contained in a system is known in the network process. Network Process was obtained from the results of data analysis using the EDIP method on SimaPro 8.20 software. The results of the analysis were in the form of a series of production processes for various types of “Kopi PQR” products. Figure 1 shows the identification of the Impact Assessment that assesses the production process of “Kopi PQR” according to the scope of the LCA. The arrows on the process indicate the flow of materials and energy in the “Kopi PQR” production process within the scope of the LCA. The arrows on network processes have different thicknesses. The thicker the arrow line, the greater the resulting impact [10]. The green line shows the process of reusing waste that can produce renewable products or energy to reduce environmental impacts [20].

The impact assessment was then carried out using SimaPro 8.20 software. The impact assessment consists of characterization, normalization, weighting, and single score calculation. Characterization is a large assessment of the substance that contributes to the impact category. Characterization aims to assess the level of impact contribution of each impact category of the product [8]. The characterization results showed that the highest impact category value from all categories were global warming in the entire production process with a value of 1.3×10^7 g CO₂, chronic water eco toxicity with a value of 4.8×10^7 m³, water acute eco toxicity with a value of 4.8×10^6 m³, and human toxicity air with a value of 1.1×10^{10} m³.

Normalization was carried out with the aim of equalizing the overall calculated impact category value. Figure 2 shows a graph of the normalization value of the “Kopi PQR” product. The X axis is the normalization of impact value, meanwhile the Y axis is the impact category. The combination of the impact category values from the whole process resulted in the three highest impact category values, i.e. human toxicity soil with a value of 149.29, eco toxicity water acute with a value of 165.97, and eco toxicity water chronic with a value of 136.55.

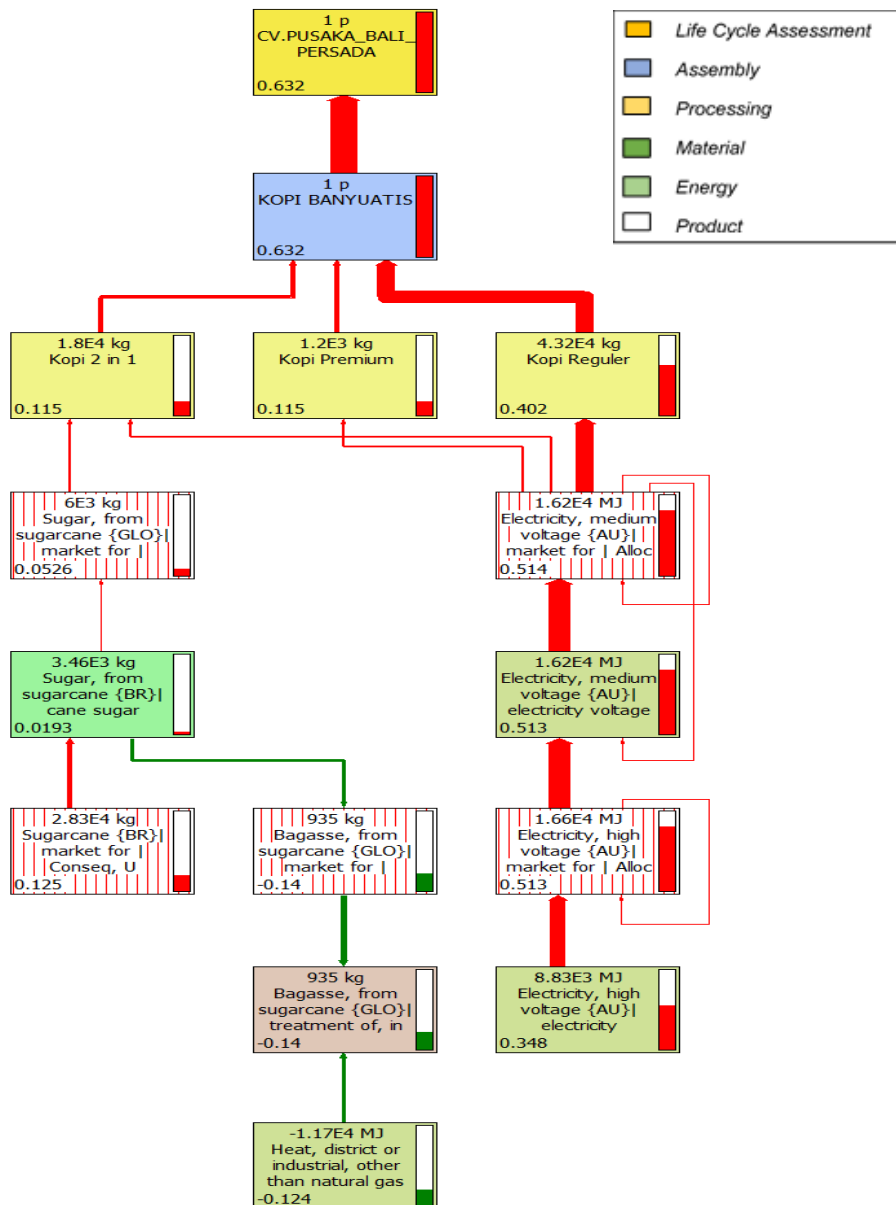


Fig. 1. The result of network process.

Weighting aimed to get results that were in accordance with the interests of improving the “Kopi PQR” production process. The increase in the value of each impact category occurs in weighting because there was a direct weight from the SimaPro 8.20 software database. Weighting also aimed to simplify comparisons and facilitate interpretation. The Simapro 8.20 software uses Point (Pt) units to show the resulting impact. The Pt unit used in the environmental indicator method is defined as a dimensionless value. A value of 1 Pt means one thousandth of the one-year environmental burden of the average European population [20].

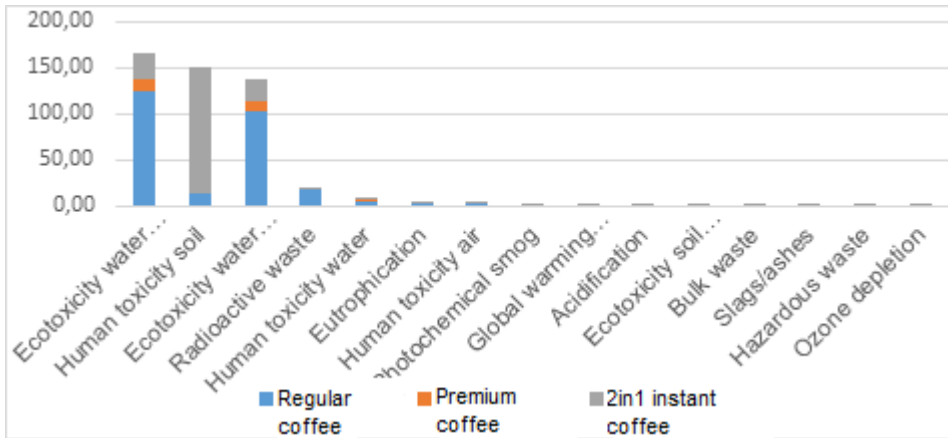


Fig. 2. The result of normalization.

The results of the weighting values indicated that the highest impact category value was human toxicity soil for each type of product with a value of 16.37 Pt for regular coffee, 0.79 Pt for premium coffee, and 161.98 Pt for 2in1 instant coffee. The eco toxicity water acute value for each product was 135.88 Pt for regular coffee, 14.69 Pt for premium coffee, and 31.99 Pt for 2in1 instant coffee. The eco toxicity water chronic value for each product was 122.86 Pt for regular coffee, 13.25 Pt for premium coffee, and 27.75 Pt for 2in1 instant coffee. Figure 3 shows a graph of the weighting value of the “Kopi PQR” product. The X axis is the value of resulting impact (weight), meanwhile the Y axis is the impact category.

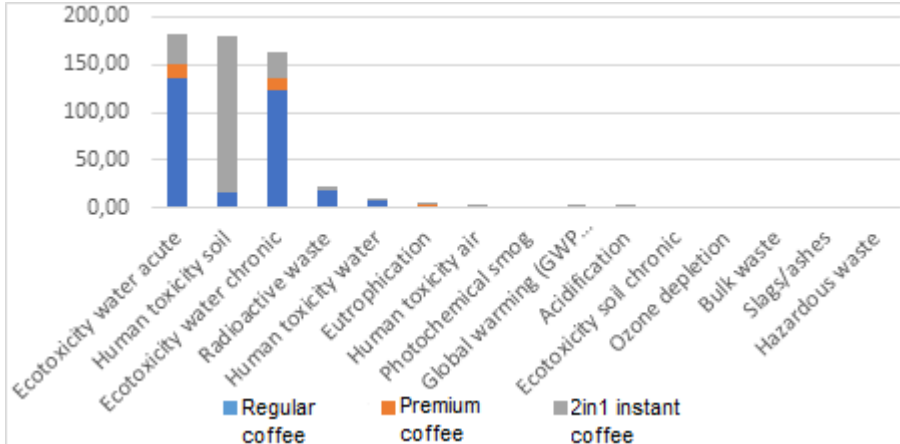


Fig. 3. The result of weighting.

The last stage of the LCIA is the calculation of a single score to determine which part of the scope exactly had an impact on the environment. The single score in Figure 4 shows that the total impact value of the whole process was 0.575 kilo-Point (kPt). The regular coffee production process had the greatest impact on the environment in acute water eco toxicity with a value of 0.136 kPt and chronic water eco toxicity with a value of 0.123 kPt. The 2in1 instant coffee production process had a high impact on the environment on human toxicity soil with a value of 0.162kPt. The high environmental impact on eco toxicity water acute and eco toxicity water chronic was caused by the use of LDPE for “Kopi PQR” packaging. Plastic has a fairly large contribution today to environmental impact. Plastic element is harmful to the aquatic environment. It can kill underwater habitats in a short

time [10]. Meanwhile, human toxicity soil was obtained from waste of coffee powder that fly then fall to the ground during grinding. Coffee powder has a pH of 4-6. The level of acidity of the coffee can be harmful to surrounding plants that cannot stand acidity [3].

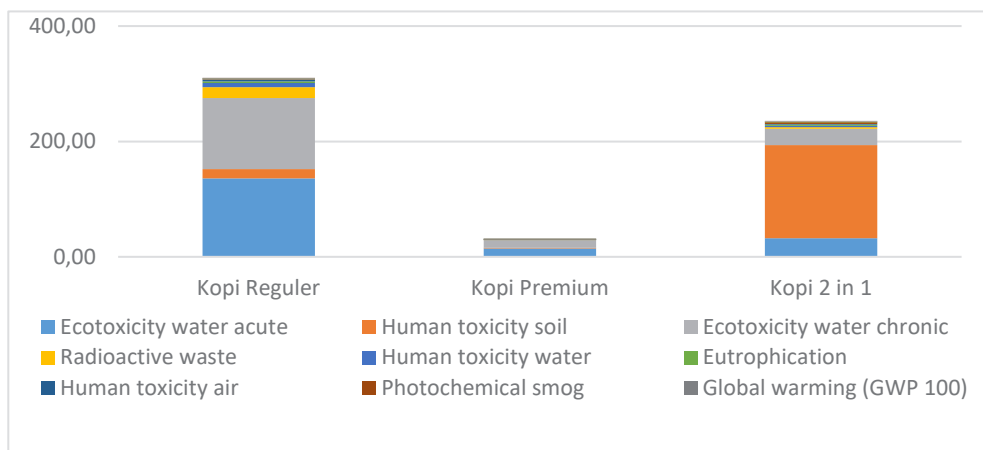


Fig 4. The result of single score calculation.

3.1.3 Life Cycle Interpretation

Determination of improvement recommendations based on the results of LCA analysis was carried out at this stage. The results of the LCA analysis in this study indicated that the regular coffee production process and the 2in1 instant coffee production process had the largest contribution to the impact on the environment. The impact was caused by the accumulation of ground coffee that was flying and falling to the ground. The use of plastic also had a significant impact on the production process of “Kopi PQR”

The improvement recommendations to reduce the impact of “Kopi PQR” production process to the environment were replacing plastic packaging from LDPE to be biodegradable. The replacement of plastic from LDPE to be biodegradable for “Kopi PQR” packaging can provide a significant reduction in impact to the environment. Biodegradable plastics can be decomposed quickly with lighting, hydrolysis, oxidation, and microorganisms activities.

Recycling the coffee powder waste was also another recommendation for CV. XYZ in reducing the impact of “Kopi PQR” production process to the environment. Coffee powder waste can be recycled to be an air freshener which can be done by partnering with perfume manufacturers. CV. XYZ can also choose companies of essential oils extraction to recycle the coffee powder waste to be coffee oil extraction. This essential oil can be used as a flavouring in foods, including candies, cakes, and puddings [25].

3.2 Determination of the best recommendation using ANP

The selection of the best recommendations to reduce the impact of the “Kopi PQR” production process on the environment was carried out at this stage. Recommendations given to CV. XYZ to reduce the impact of the “Kopi PQR” production process on the environment was the replacement of plastic packaging from LDPE to be biodegradable (R1) and recycling coffee powder waste (R2).

The selection of the best recommendations was done by weighting the recommendations based on the criteria and sub-criteria. Those criteria and sub-criteria were determined based on the discussion with the Head of Production Division of CV. XYZ. The

criteria used were benefit, opportunity, cost, and risk. The sub-criteria for each of these criteria are shown in Table 5.

Table 5. Criteria and sub-criteria of weighting the recommendations.

Criteria	Sub-criteria	Description
Benefit	Environmentally friendly (S1)	Minimizing the impact of the “Kopi PQR” production process on the environment
	Product quality (S2)	Improving the quality of “Kopi PQR” products
	Company image (S3)	Increasing the public’s positive perception of the company
Opportunities	Productivity of the company (S4)	Improving the productivity of the company
	Business opportunity (S5)	Creating an opportunity of a new business
Cost	Production cost (S6)	Cost incurred in production
	Energy (S7)	Energy used in production
Risk	Availability (S8)	The availability of resources
	Unpreparedness (S9)	The preparedness of resources

The interdependence between criteria in one group (inner dependency) and between groups (outer dependency) were then determined by giving a questionnaire to the Manager. of CV. XYZ as expert respondents. Figure 5 is the ANP Model of the relationship between sub-criteria and criteria using the Super Decision software.

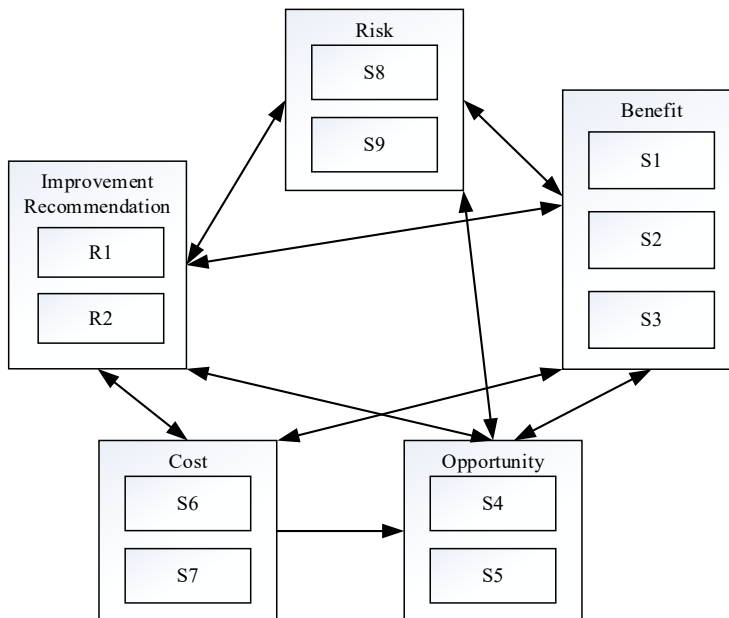


Fig. 5. The model of ANP.

Pairwise comparisons were made between criteria, between sub-criteria in one criterion, and between sub-criteria in different criteria. The results of pairwise comparisons (Table 6) showed that recycling of coffee grounds was the highest priority recommendation for improvement with a weight value of 0.712, while the replacement of LDPE packaging into biodegradable only had a weight value of 0.288. Therefore, the best recommendation for improvement for CV. XYZ to reduce the impact of the “Kopi PQR” production process on the environment was recycling the coffee powder.

Table 6. The result of pairwise comparison using Super Decision software.

Recommendation	Criteria	Sub-criteria	Weight	Final weight of recommendation
Replacement of LDPE packaging into biodegradable	Benefit	S1	0.627	0.288
		S2	0.094	
		S3	0.279	
	Opportunities	S4	0.750	
		S5	0.250	
	Cost	S6	0.750	
		S7	0.250	
	Risk	S8	0.833	
		S9	0.167	
Recycling of coffee ground	Benefit	S1	0.651	0.712
		S2	0.072	
		S3	0.277	
	Opportunities	S4	0.125	
		S5	0.875	
	Cost	S6	0.750	
		S7	0.250	
	Risk	S8	0.250	
		S9	0.750	

4 Conclusion

The production process of "Kopi PQR" had several impacts on the environment, i.e. eco toxicity water acute, eco toxicity water chronic, and human toxicity soil. The regular coffee production process had the greatest impact on the environment in the form of acute water eco toxicity with a value of 0.136 kPt and water chronic eco toxicity with a value of 0.123 kPt. The 2in1 instant coffee production process gave a high impact value on human toxicity soil with a value of 0.162 kPt. These impacts resulted from the use of plastic packaging that was difficult to be decomposed and the accumulation of coffee powder waste.

Recycling of coffee powder waste was an improvement recommendation to be prioritized by CV. XYZ in reducing the impact of its production process on the environment. Some resources have to be prepared and procured to be able to implement these recommendations. Future LCA research should use a database that is more appropriate with the conditions of the agro-industry in Indonesia.

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