

Water footprint and life cycle assessment of concrete roof tile and brick products at PT. XYZ

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Abstract. PT. XYZ is an Indonesian company engaged in manufacturing concrete roof tile and paving block. The company has not paid attention to the environmental and human health aspects of their production activity, where there is so much water used and discarded during the production process and no water treatment for the wastewater produced. Therefore this topic proposed in order to determine the resulting impacts from the production processes of concrete roof tile and brick at PT. XYZ on the environment and human health. The impact on the environment and human health were identified through water footprint assessment (WFA) and life cycle assessment (LCA). Through the WFA accounting, it is known that the amount of water needed to produce a concrete roof tile is 21.384 L which consists of 16.433 L blue water and 4.951 L grey water, whereas for a brick is 10.496 L which consists of 10.48 L blue water and 0.016 L grey water. With ReCiPe midpoint (H) method, it is known that the dominant impact categories generated in one batch production processes of concrete roof tile and brick are natural land transformation, marine eco-toxicity, freshwater eutrophication, and freshwater eco-toxicity, where those impact categories represent the average of 75.5% from overall impact category for concrete roof tile and brick products.

Keywords – water footprint, life cycle assessment, roof tile, brick

1. Introduction

Along with the increase of the development in Indonesia, the concrete roof tile and brick industries are also increasing. On the other hand, Indonesia as a member of United Nations shows serious commitment to successfully implementing sustainable development goals 2015-2030. The government direct industrial activities will be to apply the principle of sustainability [1]. In sustainable manufacturing concept, there are 3 aspects, one of which is an environmental aspect, where this aspect is the most resistant to implement in a real action or in the activities [2].

In order to apply the concept of sustainable manufacturing for the environmental aspect, the company must know the environmental impacts arising from their production process. The environmental impacts of the production process can be identified in several ways, such as by conducting LCA and WFA. By using technology, not only the environmental impact, but the impact on human health can also be identified simultaneously. WFA is a four-phase process that quantifies and maps green, blue and grey water footprints, assesses the sustainability, efficiency, and equitability of water use and identifies which start magic actions should be prioritized in order to make a footprint sustainable [3]. The four phases in WFA are setting the goals and scope, accounting, sustainability assessment, and response formulation. WFA only focuses on water consumption, so the impacts on the environment and human health can only be seen in terms of water use and wastewater discharge. LCA is a tool for identifying or comparing the whole life cycle, or cradle to grave, environmental impacts of the creation, marketing, transport and distribution, operation and disposal of specific human artifacts [4]. Based on ISO 14040, LCA has four phases that are performed in sequence, namely the goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and interpretation. Through LCA, it can be seen the overall environmental impact caused by the production process, where those impacts can be linked to the impact on human health. Given the importance of considering the environmental aspect, so this topic was proposed to PT. XYZ, where the company has not pay attention to the environmental and human health aspects of their production activities. It can be seen from the amount of water used and discharged in their production activities and the absence of



water treatment for the wastewater generated. The purpose of this case study is to determine the resulting impacts from the production processes of concrete roof tile and brick on the environment and human health. Thus, the company can realize about those aspects and make significant improvements in their daily activities. The research focused on brand X flat for concrete roof tile and concrete brick because those products are in common use that always in production line every month. The paper is structured as follows. Firstly, the introduction and methods used for this paper start from preliminary research are described. Secondly, the result and discussion about water footprint assessment and life cycle assessment are analyzed and finally, a conclusion is drawn, to sum up, all of the discussion.

2. Methodology

Preliminary research first conducted in PT. XYZ to see the condition of the company, e.g. by observing the processes occurring in each production line and the varieties of the products, continued with the selection of the products to be studied. The selected products for further study are type X flat concrete roof tile and concrete brick. From the observation, it is also known that the problem expressed in the company is the lack of attention paid to the environmental and health aspects. The general data consist of the company background, product type, and production processes. Meanwhile, the specific data consist of data needed for WFA and LCA. The data were collected through interview, direct observation and measurement, references, and water testing in the research laboratory. The data will then be processed to then be analyzed. In the WFA, data processing is done by mapping the water used and calculating the blue and grey water. Bluewater refers to groundwater, whereas grey water refers to the volume of freshwater that is required to assimilate a load of pollutants based on natural background concentrations and existing ambient water quality standards [5]. In the LCA, data processing is done using the software and ReCiPe midpoint (H) method. The analysis carried out based on the data processing, where the results from WFA and LCA will be analyzed related to the impacts on the environment and human health. In the end, the result analysis and discussion then summarized in the conclusion to answer the purpose of this research.

3. Results

The first two phases from WFA, which are setting goals and scope and accounting will be discussed in this section, whereas the next two phases will be discussed in Section 4.

3.1. Setting Goals and Scope

The objective of WFA is to determine the amount of water used in the production process of concrete roof tile and brick in PT. XYZ. The functional unit is a concrete of roof tile and brick for the labor-intensive home industry. The further goal is to assess the sustainability of the production process in terms of water use with regard to the environmental and human health impacts. The scope of this study is the water use calculation will only be made to the operational water footprint. In water footprint itself, the calculation only limited to direct water footprint. This calculation is conducted only on blue and grey water, while the use of green water ignored. In the calculation of grey water, the pollutant that will be used in the calculation is total dissolved solids (TDS).

3.1.1. WFA Accounting

Calculation of the blue water based on the amount of water used during the production process. Meanwhile, the grey water calculation use equation below, where the amount of c_{effl} , c_{act} , and c_{nat} obtained from the water testing result and c_{max} based on government rule RI No.416/MENKES/PER/IX/1990.

$$WF_{proc, grey} = \frac{(Effl \times c_{effl}) - (Abstr \times c_{act})}{c_{max} - c_{nat}} \quad (1)$$

Where:

$WF_{proc, grey}$: Grey water footprint of a process (volume)

Effl	: Effluent volume (volume)
C_{effl}	: Concentration of the pollutant in the effluent (mass/volume)
Abstr	: Water volume of the abstraction (volume)
C_{act}	: Actual concentration of the intake water (mass/volume)
C_{max}	: Maximum acceptable concentration (mass/volume)
C_{nat}	: Natural concentration in the receiving water body (mass/volume)

The process of stirring one tile requires 0.8 L of water. In the soaking process, the immersion bath used has a volume of $2\text{ m} \times 5\text{ m} \times 1.5\text{ m}$, so the volume of water needed to soak is 15 m^3 and number of tiles in one-time soaking are 960. Therefore, water quantity used to soak one tile is 15.625 L. In addition, for the painting process of one tile takes 0.02 kg of paint and 8 ml of water. So blue water footprint to produce one flat concrete roof tile is 16.433 L. The result of grey water footprint accounting is 4.951 L, where greywater generated in the soaking process. Thus, the total water footprint per concrete roof tile is 21.384 L.

One brick paving block requires 0.25 L of water for the stirring process. In the watering process, watering is done for one pile or one batch of brick paving blocks with size $1\text{ m} \times 6\text{ m}$ and stack height is 10 bricks. Number of bricks for each square meter are 44 pieces. Data of one batch of brick are as follows: area of 1 batch of brick = $1\text{ m} \times 6\text{ m} = 6\text{ m}^2$, height of 1 batch of brick = 10 bricks, and paving blocks of brick per $\text{m}^2 = 44$ pieces. Therefore, the number of paving blocks of bricks per batch is $6\text{ m}^2 \times 44\text{ pieces} / \text{m}^2 \times 10 = 2640$ pieces. Based on the results of the interview process, it is known that the process of watering is once a week, but for first three days will be twice a day and the rest of four days is once per day. Thus total number of watering per week is 10 times with each duration of 3.5 hours, which is equal to 27,000 L per batch and the water discharge = $3/14 = 0.214\text{ L} / \text{sec}$. After knowing number of paving blocks for one batch and water used for sprinkling process per batch of brick, it can be calculated amount of water usage per brick for the watering process, which is 10.23 L / piece (27,000 L: 2,640 pieces). This amount is used in the calculation of water footprint paving block brick. Thus, the total blue water footprint for the production of one brick is 10.48 L.

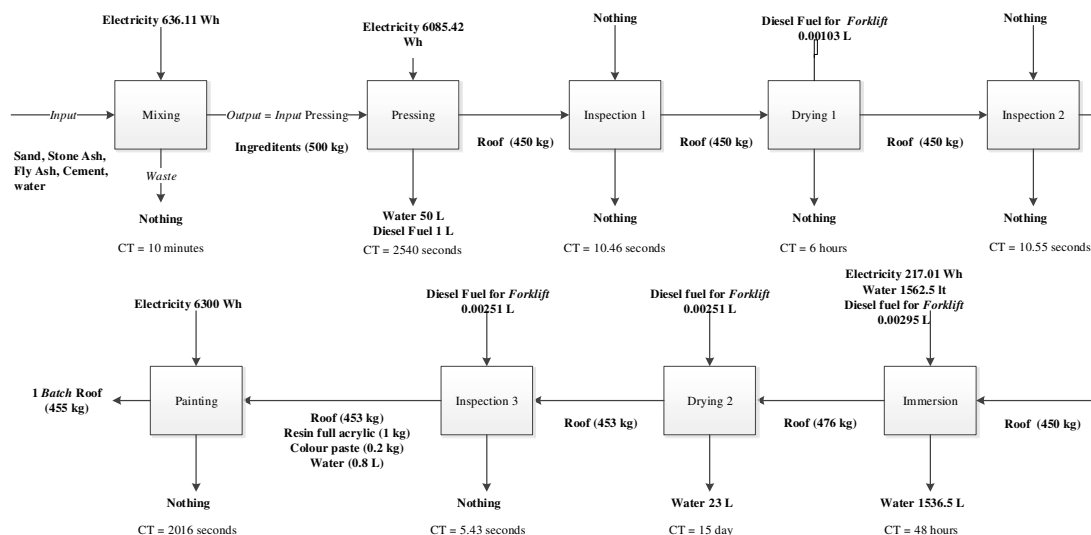


Figure 1. Generic Unit Processes of Concrete Roof Tile

3.2. Life Cycle Assessment

The first two phases from LCA, which are goal and scope definition and LCI will be discussed in this section, whereas the next two phases will be discussed in Section 4.

3.2.1. Goal and Scope Definition

The purpose of this LCA is to determine the environmental impact of the production process of concrete roof tile and brick at PT. XYZ. This result will be used as a reference to discuss the further impacts on human health. The system boundary of this study is the activities of the production process or gate-to-gate. It can be interpreted that word gate-to-gate means the gate of the plant, which means that all the data gathered are from the internal factory. Other data such as the mileage or gasoline usage in the transportation is not calculated.

3.2.2. Life Cycle Inventory

LCI is the straight-forward accounting of everything involved in the “system” of interest. It consists of detailed tracking of all the flows in and out of the product system, including raw material, energy by type, water, and emissions to air, water, and land by specific substance [6]. Functional units used in this study are one batch of concrete roof tile with 455 kg mass and one batch of brick with a mass of 290 kg. The summary result of LCI data in the form of generic unit processes for concrete roof tile and brick can be seen in figure 1 and 2 respectively. The generic unit processes will then be used in LCIA phase as the database that will be used in SimaPro.

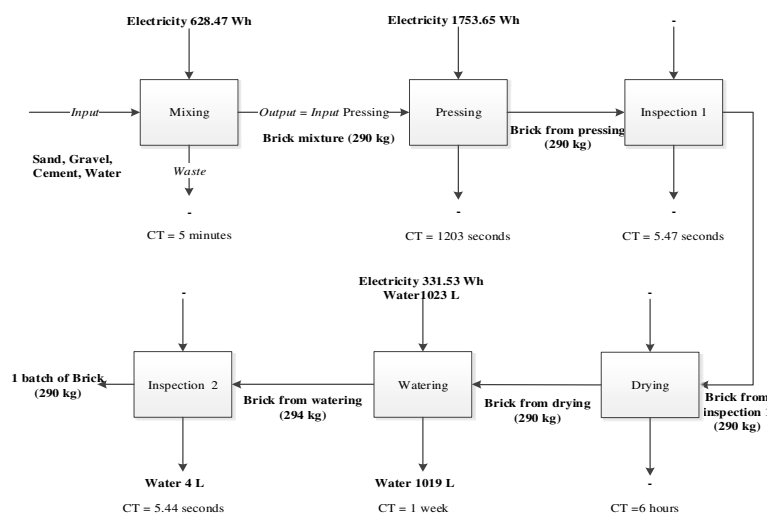


Figure 2. Generic Unit Processes of Brick

4. Discussion

In this section, the results of the two accounting assesment will be discussed.

4.1. WFA Accounting

In this assessment, the results are discussed based on the two phases of the WFA accounting, they are sustainability assessment and response assessment.

4.1.1. Sustainability Assesment

The discussion is focused mainly on the impacts on the environment and human health from the water used and discharged as waste. First, the discussion will focus on the amount of water used in the production process. In this section, a comparison will be made between the water use in production activities and the state of the amount of water in PT. XYZ area itself, which is Tangerang. The state of

the total amount of water in an area can be seen from the Water Stress Index (WSI) of that area. WSI is an indicator that aims to compare the total water usage by the amount of water that actually available for use [7]. The map that showed the state of WSI in Java according to the World Resources Institute can be seen in Fig. 3 [8].

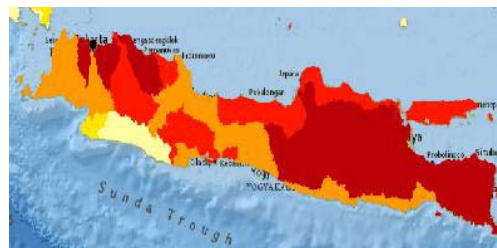


Figure 3. Water Stress Index in Java

Based on Fig. 3, it can be seen that the area of Tangerang has been marked with a black pin, where the color of the region is orange which means the value of WSI classified as medium to high with the percentage value of 20-40%. On the other hand based on the results of water footprint accounting, it is known that the amount of water needed in the production process is very large. Thus when compared to the value of WSI in Tangerang, the amount of water usage is quite dangerous. This is because the value of WSI in Tangerang is very vulnerable to lead to water scarcity. It can be seen from Fig. 4 and 5 that shows the approximate conditions of WSI in Java in 2020 and 2040 if economic development is considered stable.

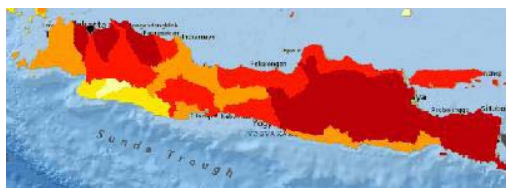


Figure 4. Water Stress Index in Java 2020



Figure 5. Water Stress Index in Java 2040

Based on Fig. 4, it can be seen that there is a change in WSI for Tangerang area, which is to be a red or relatively high percentage of 40-80% by value. Subsequently, in 2040, the value of WSI for Tangerang area is getting worse and marked with dark red color or classified as very high percentage above 80%. Therefore, the company must minimize the use of water in its production activities. If company continue to use water with the same amount of no improvement, then the company will always give bad impact on the environment in terms of water use and the company will become a supporter of water scarcity in Tangerang area. When viewed in terms of the impact on human health, the large amount of water use has made the availability of clean water decreases, so the number of people who can not get access to clean water increases. As a result, humans will use contaminated water which a cause a variety of illnesses and even death. The waste waters come from roof tile pressing and soaking processes and brick watering process, whereas the water used comes from water from the reservoir. A number of pollutants contained in water reservoirs and wastewater from the water testing results can be seen in Table 1. The water testing result is generated by the research lab, where the sample is collected, tested and the results are finally tabulated in table 1. Based on Table 1, it can be seen that indicators of turbidity, TDS, pH, organic substance, chloride, and sulfate need to be considered because it shows increased results in the wastewater. Even if all of the results are still below the standard, but the increasing amount signifies the addition of pollutant resulting from the production process. The increase in a number of pollutants if accumulated with pollutants contained in the wastewater disposal can ultimately harm people and environment.

Table 1. Water Testing Result.

	Unit	Water from Reservoir (Cact)	Water from Pressing (Cefft)	Water from Soaking (Cefft)	Water from Watering (Cefft)	Standard (Cmax)
Turbidity	NTU	3.56	6.54	9.16	3.3	25
TDS	mg/L	160.6	201	599	163.3	1500
pH	-	7.56	10.09	11.57	7.75	6.5 - 9
Iron	mg/L	0.23	< 0.07	< 0.07	< 0.07	1
Manganese	mg/L	< 0.058	< 0.058	< 0.058	< 0.058	0.5
Hardness	mg/L	111.1	70.7	16.16	121.2	500
Nitrate	mg/L	8	< 1.33	1.7	6.7	10
Nitrites	mg/L	0.036	0.032	0.021	0.007	1
Organic substance	mg/L	< 1.99	3.16	3.16	2.21	10
Chloride	mg/L	6.2	18.86	37.72	5.96	600
Sulfate	mg/L	2	57	6	8	400

4.1.2. Response Formulation

PT. XYZ should build water treatment plant (WWTP) for treating the generated wastewater to enable reusing of the water due to the high volume of water needed in the production process of concrete roof tile and brick. In addition, the water treatment also can make the wastewater discharged into the environment does not pollute and harm the environment or human health. Moreover, the brick watering process that uses a lot of water should not be done in an outdoor venue, but a semi-outdoor so it can minimize evaporation which causes the brick to dry faster and require more water.

4.2. Life Cycle Assessment

The next two phases from LCA are LCIA and interpretation that will be discussed in this section. The LCA was done by using software with ReCiPe midpoint (H) method. The ReCiPe method was chosen because this method gives a complete impact categories result, compares with the other methods [9]. Meanwhile, midpoint method was used to know the root problems of the existing processes.

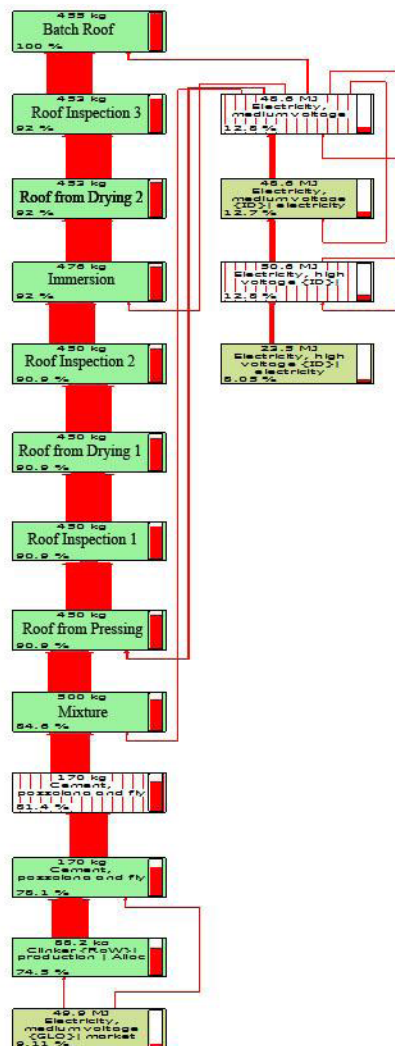


Figure 6. Network Diagram of Concrete Roof Tile

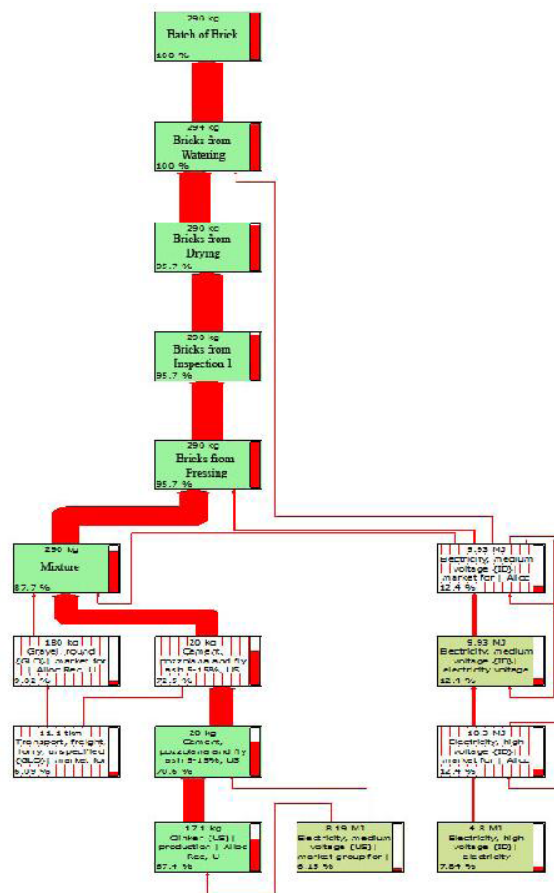


Figure 7. Network Diagram of Brick

Based on the network diagram in figure 6 and 7, it can be seen that the great contribution of the environmental impact in the production process is starting from the clinker node that used in cement and fly ash production, where cement and fly ash used as raw material in concrete roof tile production. This can be seen from the thickness of the flow line between nodes. The thicker the flow line between nodes indicates that the greater the contribution of that node to the indicator produced. Furthermore, through the impact assessment results, it can be seen the resulting impact on the environment of the production process.

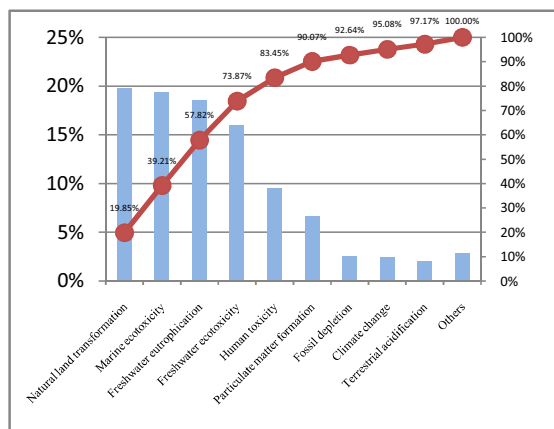


Figure 8. Pareto Impact from Roof Tile Production by PT XYZ Tangerang, Indonesia

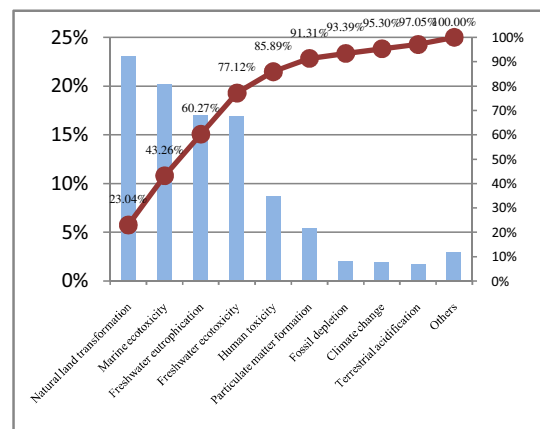


Figure 9. Pareto Impact from Brick Production by PT XYZ Tangerang, Indonesia

Figure 8 and 9 illustrate four categories of the impact that is dominant and represent 74.13% of the total impact. The four impact categories are the natural land transformation, marine ecotoxicity, freshwater eutrophication, and freshwater ecotoxicity. Next, there will be tracking of the specification per substance and process that led to each of these impacts. The most influence substance on the natural land transformation is the raw material from the forest. The the most influential substance for marine ecotoxicity and freshwater ecotoxicity are similar, which are nickel and copper. The most contribute substance to freshwater eutrophication is phosphate. In addition, processes or components that provide the greatest contribution to the natural land transformation is onshore well, oil/gas. As for the three other impact categories, a component that has the largest contribution is spoil from lignite mining.

5. Interpretation

This section will discuss the four dominant assessment of environmental impact categories from LCIA result. The natural land transformation itself means a number of natural lands that are changing and occupied or used within a certain timeframe [10]. Based on the prior explanation it is known that the most influential components for natural land transformation are onshore well and gravel. Onshore well is used as a source of fuel that is required in the manufacturing process of materials used, where onshore which is derived from the intensive forest area. Gravel is used as a raw material of tiles and bricks manufactures, where gravel come from areas that are not specific or unknown. Onshore well and gravel caused natural land transformation because the mining process of these two components can cause changes in natural land used. Natural land transformation does not have a direct impact on human health. However, changes in the natural land as for example forest land which is then used as the mine site is the one who later may cause harm to human health. For example are the poor quality of oxygen, the increase of natural heat, and drought because trees are felled. Ecotoxicity is a toxic effect on chemicals that can harm the environment, including the non-human organism, population, or community [11]. Based on the foregoing, it is known that the most contributing component is spoil from lignite mining. Lignite mining waste contains many heavy metals include copper and nickel. Lignite is used as input to the electrical energy used in the production process. Marine and freshwater ecotoxicity certainly could have negative impacts on human health. The substance of copper at not really high doses in the human body can cause the typical symptoms of food poisoning such as headaches, nausea, vomiting, and diarrhea. At high doses, it can cause serious problems such as acute renal failure and liver damage [11]. Direct exposure to nickel can cause an allergic reaction in the form of skin infections, whereas the high nickel content in the body can be carcinogenic or cause cancer [12]. Freshwater eutrophication refers to an overgrowth of aquatic plants or algae because of many nutrients in freshwater ecosystems such as lakes, reservoirs, and rivers [13]. The substance that causes

this impact category is phosphate. Phosphate rock and mineral sediment are natural sources of phosphorus in terrestrial and aquatic ecosystems, where phosphorus is one of the main triggers for freshwater eutrophication. Phosphate rock itself can be generated from the spoil from lignite mining. Excess nutrients in the water can cause algae to grow rapidly or also called as algal blooms. These algal blooms harmful to humans because it produces the high growth of bacteria and toxins that can cause diseases if humans make direct contact with contaminated water, eating contaminated fish or shellfish, or drinking contaminated water [14].

6. Conclusion

Based on WFA, the amount of water used to produce a concrete roof tile is 21.384 L, whereas for a brick is 10.496 L, where the amount of water used is consist of blue and grey water. The use of large amounts of water may negatively impact the environment in the form of water scarcity in Tangerang so that humans can be infected with illness and even death due to contaminated water uses. In addition based on water testing results, wastewater discharged from the plant showed increase amount for the indicators of turbidity, TDS, pH, organic substance, and sulfates from water that was in use, where those indicators can give many negative impacts on the environment and human health. Based on the LCA result using ReCiPe midpoint (H), it is known that there are four categories of environmental impacts that dominate the production process of concrete roof tile and brick, they are natural land transformation, marine ecotoxicity, freshwater eutrophication, and freshwater eco-toxicity, where each impact category can also provide direct or indirect effects on human health. Therefore, the company should conduct water savings in a way that was already explained in response formulation phase in WFA. In addition, the company also should reduce the use of cement as raw material that has negative impacts on the environment and as a replacement can use waste such as bottom ash and bagasse and also use renewable energy for generating electricity. Moreover, there are few suggestions for future research such as conducting WFA and LCA for the other variant of concrete roof tile and paving block, the calculation of greywater can use another type of pollutants other than TDS. Also, the next research can be about the standard amount of water use which is the most effective and efficient in the eco-friendly production process of concrete roof tile and brick, doing research on the difference in the amount of water needed for the brick production when dry and rain season, extend the scope of LCA research, and conduct life cycle costing to provide information to companies on the link between the environmental impacts produced with the financial aspects.

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