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LIFE CYCLE ASSESSMENT OF TRADITIONAL MARKET SOLID WASTE MANAGEMENT IN MALANG REGENCY, INDONESIA

Traditional markets in Malang Regency are divided into four classes with particular classifications. The traditional market solid waste research aims to show the environmental impact of solid waste management efforts using life cycle assessment (LCA) and selected scenarios to reduce solid waste sustainably. The planned management follows four scenarios: Scenario 0 represents the baseline scenario. Scenario 1 assumes that non-composted solid waste recycling is carried out. Scenario 2 assumes that composting takes place. Finally, Scenario 3 assumes that non-composted solid waste recycling and composting are integratively carried out by building a reduced reuse recycle solid waste treatment facility (TPS 3R) near the market. The environmental impact analysis was carried out with various impact categories (carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals, and fossil fuels). The results show that the smallest environmental impact is in Scenario 3 in most classes, namely the scenario where non-composted solid waste was integratively recycled and composted.

1. INTRODUCTION

The sorting, collecting, and transporting systems in solid waste management directly influence the environmental performance of recycling/disposal activities through emissions from the activities involved [1]. Life Cycle Assessment (LCA) is a quantitative cradle-to-grave approach to quantitatively assessing a product system. By conducting a life cycle assessment, decision makers can have data-and fact-based to ground the decision makings. LCA can be used for various purposes, including product design, the

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improvement of production processes, product and process innovation, environmental management system improvement, product or process selection, supplier selection, and communicating environmental information for products manufactured by the company. It can also determine company strategy and make governmental policy decisions. LCA is a quantitative measuring tool for sustainable development [2–5]. LCA consists of 4 stages, namely the determination of goals and limits, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and interpretation of analysis results [6]. LCA is also a tool to assess the environmental impact and use of resources through the life cycle of a product, starting from obtaining raw materials, production processes, and stages of use to solid waste management [7]. The purpose of this study is to analyze the environmental impact of traditional market solid waste management efforts using LCA, as well as the best and most sustainable scenario selections.

2. MATERIALS AND METHODS

The market class is a market categorization that considers several factors, including the number of traders, the market area, potential, and the system for moving goods and people both inside and outside the market. The Malang Regency has 33 officially certified traditional markets [8], as shown in Table 1. The research sample is three markets representing each class. Therefore, there are 12 classes according to the number of samples of non-residential solid waste generation [9] (Fig. 1).

Fig. 1. Map of the sampling locations

Table 1

Traditional markets in Malang Regency and the chosen samples

Class	Market	Sample
1	1.1. Lawang Market 1.2. Kepanjen Market 1.3. Singosari Market 1.4. Gondanglegi Market 1.5. Tumpang Market 1.6. Dampit Market 1.7. Karangploso Market 1.8. Turen Market 1.9. Pujon	1.5. Tumpang Market 1.6. Dampit Market 1.7. Karangploso Market
2	2.1. Wajak Market 2.2. Sumberpucung Market 2.3. Pakis Market 2.4. Sumbermanjing Wetan Market 2.5. Donomulyo Market 2.6. Bululawang Market 2.7. Pakisaji Market 2.8. Wonokerto	2.5. Donomulyo Market 2.7. Pakisaji Market 2.8. Wonokerto Market
3	3.1. Bantur Market 3.2. Ngantang Market 3.3. Watesbelung Market 3.4. Pagak Market 3.5. Ngebruk Market 3.6. Tajinan Market 3.7. Krebet Market 3.8. Jeru Market 3.9. Sumedang Market 3.10. Sumbermanjing Kulon Market 3.11. Bakroto	3.1. Bantur Market 3.4. Pagak Market 3.11. Bakroto Market
4	4.1. Kaligadung Market 4.2. Cungkal Market 4.3. Kromengan Market 4.4. Jabung Market 4.5. Sedayu Market	4.3. Kromengan Market 4.4. Jabung Market 4.5. Sedayu Market

3. RESULTS AND DISCUSSION

LCA was used to analyze the scenarios with the most negligible environmental impact and to assess the environmental impact of conventional market solid waste management initiatives. The following scenarios for using conventional market solid waste control techniques can be planned:

- Scenario 0 is the baseline scenario. Solid waste management is not carried out at the traditional market temporary disposal site (TPS). The solid waste from the TPS is directly transported to the landfill.
- Scenario 1. Non-composted solid waste is recycled at the TPS in cooperation with the solid waste bank while composted solid waste and residue are transported to the landfill.
- Scenario 2. The composting is carried out at the TPS by creating a composting unit, while the dry waste and residue are transported to the landfill.
- Scenario 3. Solid waste recycling and composting are integratively carried out by creating a reduce reuse recycle solid waste treatment facility (TPS 3R) [10], and the residue is transported to a landfill.

The limitation on the use of LCA was the unit of the function used in the life cycle inventory (LCI), namely the solid waste generation, composition, and characteristics of traditional market solid waste. The environmental impact analysis used SimaPro Release 9.4.0.1 application [11].

Life cycle inventory (LCI). Raw materials were composted solid waste for the composting process and non-composted solid waste for recycling. They were calculated based on the solid waste generation and its composition, kg. Additional materials included water for composting activities, fuel for composting machines, plastic chopping machines, and electricity. The chopping machine was also used for composting raw materials and for plastics. Therefore, fuel oil was added as an additional material.

Life cycle impact assessment (LCIA). The impact assessment stage was carried out to determine the impact on the environment obtained from the LCI stage. Characterization was a step to compare the LCI results in each category directly. The method used in conducting the environmental impact assessment was Eco-Indicator 99 (E). The method categorizes environmental impact based on the type of harm caused. The human health category consists of the impacts of carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, and the ozone layer. The category of losses to ecosystem quality consists of the impacts of ecotoxicity, acidification/eutrophication, and land use. The category of loss to resources consists of the impact of minerals and fossil fuels.

Carcinogens are substances contained in pollutants, affecting human health as a trigger for cancer growth. Respiratory organics and inorganics are categories of environmental impacts that correlate with respiratory tract disorders. Climate change is an environmental impact that causes climate change at a certain time. Radiation is an impact produced by energy emitted from particles or waves through space. The ozone layer is an impact that causes depletion of the ozone layer due to organic compounds containing chlorine, carbon, and fluorine. Ecotoxicity is an environmental impact on groundwater, seawater, and soil. Acidification/eutrophication is an environmental impact that

can cause acidification and excessive macronutrient increase in the ecosystem. Land use is an impact on soil caused by resource extraction. Minerals is an environmental impact category related to the availability and quality of minerals. Fossil fuels are environmental impacts related to the availability of fossil fuels.

The results of the environmental impact characterization of each category in the class 1 market of Malang Regency can be seen in Table 2. The lowest impact category of carcinogens in Scenario 3 was 0.023441886 DALY. The lowest impact category of respiratory organics in Scenario 2 was 0.000202306 DALY. The lowest impact category of respiratory inorganics in Scenario 0 was 0.40854641 DALY. The lowest impact category of climate change in Scenario 0 was 0.04712798 DALY. The lowest impact category of radiation in Scenario 3 was 0.00054541 DALY. The lowest impact category of ozone layer depletion was in Scenario 3 at 1.11157E–05 DALY. The lowest impact category of ecotoxicity in Scenario 3 was 90 994.668 PAF·m^{-2}·year^{-1}. The lowest impact category of acidification/eutrophication in Scenario 0 was 3869.4548 PAF·m^{-2}·year^{-1}. The lowest impact category land use in Scenario 3 was 580 197.97 PAF·m^{-2}·year^{-1}. The lowest impact category of mineral in Scenario 3 was 81 026.863 MJ surplus. The lowest impact category of fossil fuels in Scenario 0 was 228 043.51 MJ surplus.

Table 2

The result of environmental impact characterization
of each category on the class 1 market in Malang Regency

Impact category	LC scenario			
	0	1	2	3
Carcinogens, DALY	0.023654826	0.02360241	0.023496203	0.023441886
Respiratory organics, DALY	0.000202308	0.000202638	0.000202306	0.000202423
Respiratory inorganics, DALY	0.40854641	0.40879576	0.40878142	0.4089235
Climate change, DALY	0.04712798	0.047150529	0.047141572	0.047152707
Radiation, DALY	0.000545567	0.00054556	0.000545548	0.000545541
Ozone layer, DALY	1.11363E–05	1.11313E–05	1.11209E–05	1.11157E–05
Ecotoxicity, PAF·m^{-2}·year^{-1}	91 249.477	91 187.287	91 059.51	90 994.668
Acidification/eutrophication, PAF·m^{-2}·year^{-1}	3869.4548	3881.079	3880.3576	3886.969
Land use, PAF·m^{-2}·year^{-1}	580 198.25	580 198.18	580 198.04	580 197.97
Minerals, MJ surplus	81 029.48	81 028.803	81 027.54	81 026.863
Fossil fuels, MJ surplus	228 043.51	228 141.43	228 065.85	228 105.99

The impact category assessment of each class 1 market solid waste management scenario indicated that most of the smallest environmental impacts were in Scenario 3 (non-composted waste recycling and integrated composting). The impact categories of carcinogens, radiation, ozone layer, ecotoxicity, land use, and minerals experienced a decrease in impact value in each waste management scenario. The environmental impact with the highest relative contribution value in the carcinogens, radiation, ozone layer, ecotoxicity, land use, and minerals impact categories were generated by Scenario 0.

The respiratory organics and fossil fuel impact categories had the highest relative contribution value to the environment generated by Scenario 1. Scenario 3 generated the highest relative contribution value in the respiratory inorganics, climate change, and acidification/eutrophication impact categories. Optimizing solid waste sorting can reduce the potential for ozone layer depletion by methane and carbon dioxide gas, as well as the formation of leachate that causes eutrophication [12].

The results of the environmental impact characterization of each category in the class 2 market, Malang Regency can be seen in Table 3. The lowest impact category of carcinogens in Scenario 3 is 0.023394705 DALY. The lowest impact category of respiratory organics was in Scenario 0 of 0.000202398 DALY. The lowest impact category of respiratory inorganics in Scenario 0 was 0.40845216 DALY. The lowest category of climate change impact is in Scenario 0 of 0.047088776 DALY. The lowest impact category of radiation in Scenario 3 was 0.000545461 DALY. The lowest ozone layer depletion impact category is in Scenario 3 at 1.1159E-05 DALY. The lowest impact category of ecotoxicity in Scenario 3 was 90 958,766 PAF·m^{-2}·year^{-1}. The lowest impact category of acidification/eutrophication in Scenario 0 was 3867.5476 PAF·m^{-2}·year^{-1}. The lowest impact category of land use in Scenario 3 was 580 282.98 PAF·m^{-2}·year^{-1}. The lowest impact category of mineral in Scenario 3 was 810 28.576 MJ surplus. The lowest impact category of fossil fuels in Scenario 0 was 227 874.41 MJ surplus.

Table 3

The result of environmental impact characterization
of each category on the class 2 market in Malang Regency

Impact category	LC scenario			
	0	1	2	3
Carcinogens, DALY	0.023489451	0.023465476	0.023418681	0.023394705
Respiratory organics, DALY	0.000202398	0.00020247	0.00020246	0.000202532
Respiratory inorganics, DALY	0.40845216	0.40853303	0.40861263	0.40869351
Climate change, DALY	0.047088776	0.047095193	0.047099509	0.047105925
Radiation, DALY	0.000545476	0.000545472	0.000545465	0.000545461
Ozone layer, DALY	1.1168E–05	1.11657E–05	1.11613E–05	1.1159E–05
Ecotoxicity, PAF·m^{-2}·year^{-1}	91 111.311	91 072.637	90997.44	90 958.766
Acidification/eutrophication, PAF·m^{-2}·year^{-1}	3867.5476	3871.3074	38 74.9905	3878.7503
Land use, PAF·m^{-2}·year^{-1}	580 283.15	58 0283.11	580 283.03	580 282.98
Minerals, MJ surplus	81 029.46	81 029.233	81 028.803	81 028.576
Fossil fuels, MJ surplus	227 874.41	227 900.54	227 910.33	227 936.46

The impact category assessment of each class 2 market solid waste management scenario indicated that most of the smallest environmental impacts were in Scenario 3 (non-composted waste recycling and integrated composting). The impact categories of carcinogens, radiation, ozone layer, ecotoxicity, land use, and minerals experienced

a decrease in impact value in each waste management scenario. The environmental impact with the highest relative contribution value in the carcinogens, radiation, ozone layer, ecotoxicity, land use, and minerals impact categories was produced by Scenario 0. Scenario 1 produced the highest relative contribution value to the respiratory organics impact category. Scenario 3 generated the highest relative contribution values in the respiratory inorganics, climate change, acidification/eutrophication, and fossil fuel impact categories.

Table 4

The result of environmental impact characterization of each category on the class 3 market in Malang Regency

Impact category	LC scenario			
	0	1	2	3
Carcinogens, DALY	0.023468884	0.02345251	0.02341263	0.023396253
Respiratory organics, DALY	0.00020199	0.000202036	0.000202	0.000202043
Respiratory inorganics, DALY	0.40846182	0.40851682	0.40857458	0.40862831
Climate change, DALY	0.047084403	0.047088932	0.047092008	0.04709642
Radiation, DALY	0.000545301	0.000545299	0.000545293	0.00054529
Ozone layer, DALY	1.10293E–05	1.10277E–05	1.10239E–05	1.10224E–05
Ecotoxicity, PAF·m^{-2}·year^{-1}	91 045.975	91 019.103	90 953.955	90 927.08
Acidification/eutrophication, PAF·m^{-2}·year^{-1}	3870.3196	3872.8855	3875.571	3878.0767
Land use, PAF·m^{-2}·year^{-1}	58 0057.54	580 057.51	580 057.44	580 057.42
Minerals, MJ surplus	81 029.342	81 029.184	81 028.809	81 028.65
Fossil fuels, MJ surplus	227 834.51	227 853.21	227 858.69	227 876.76

The results of the environmental impact characterization of each category in the class 3 market, Malang Regency are given in Table 4. The lowest carcinogens impact category in Scenario 3 was 0.023396253 DALY. The lowest impact category of respiratory organics in Scenario 0 was 0.00020199 DALY. The lowest impact category of respiratory inorganics in Scenario 0 was 0.40846182 DALY. The lowest impact category of climate change in Scenario 0 was 0.047084403 DALY. The lowest impact category radiation in Scenario 3 was 0.00054529 DALY.

The impact category of the lowest ozone layer depletion in Scenario 3 was 1.10224E-05 DALY. The lowest impact category of ecotoxicity in Scenario 3 was 90 927.08 PAF·m^{-2}·year^{-1}. The lowest impact category of acidification/eutrophication in Scenario 0 was 3870.3196 PAF·m^{-2}·year^{-1}. The lowest impact category of land use in Scenario 3 was 580 057.42 PAF·m^{-2}·year^{-1}. The lowest impact category of mineral in Scenario 3 was 81 028.65 MJ surplus. The lowest impact category of fossil fuels in Scenario 0 was 227 834.51 MJ surplus.

The impact category assessment of each class 3 market solid waste management scenario showed that most of the smallest environmental impacts were in Scenario 3. The impact categories of carcinogens, radiation, ozone layer, ecotoxicity, land use, and

minerals experienced a decrease in impact value in each waste management scenario. The environmental impact with the highest relative contribution value in the carcinogens, radiation, ozone layer, ecotoxicity, land use, and minerals impact categories is generated by Scenario 0. Scenario 3 generated the environmental impact with the highest relative contribution value in the respiratory organics, respiratory inorganics, climate change, acidification/eutrophication, and fossil fuels impact categories.

Table 5

The result of environmental impact characterization of each category on the class 4 market in Malang Regency

Impact category	LC scenario			
	0	1	2	3
Carcinogens, DALY	0.023473947	0.023448842	0.023367326	0.023405868
Respiratory organics, DALY	0.000201779	0.000201835	0.000201279	0.000201853
Respiratory inorganics, DALY	0.40845298	0.40852174	0.40846597	0.40859872
Climate change, DALY	0.0470878	0.04709309	0.047071007	0.047097868
Radiation, DALY	0.00054531	0.000545307	0.000545045	0.000545302
Ozone layer, DALY	1.10446E–05	1.10411E–05	1.09009E–05	1.10351E–05
Ecotoxicity, PAF·m^{-2}·year^{-1}	91 017.357	90987.15	90 859.809	90 935.309
Acidification/eutrophication, PAF·m^{-2}·year^{-1}	3869.1417	3872.3325	3869.6154	3875.8928
Land use, PAF·m^{-2}·year^{-1}	580 036.89	580 036.85	580 003.65	580 036.79
Minerals, MJ surplus	81 030.146	81 029.798	81 029.253	810 29.211
Fossil fuels, MJ surplus	227 852.23	227 867.36	227 745.68	227 871.93

The results of the environmental impact characterization of each category in the class market 4 of Malang Regency can be seen in Table 5. The lowest impact category of carcinogens in Scenario 2 was 0.023367326 DALY. The lowest impact category of respiratory organics in Scenario 2 was 0.000201279 DALY. The lowest impact category of respiratory inorganics in Scenario 0 was 0.40845298 DALY. The lowest impact category of climate change in Scenario 2 was 0.047071007 DALY. The lowest impact category of radiation in Scenario 2 was 0.000545045 DALY. The lowest impact category of ozone layer depletion in Scenario 2 was 1.09009E-05 DALY. The lowest impact category of ecotoxicity in Scenario 2 was 90 859.809 PAF·m^{-2}·year^{-1}. The lowest impact category of acidification/eutrophication was in Scenario 0 of 3869.1417 PAF·m^{-2}·year^{-1}. The lowest impact category of land use in Scenario 2 was 580 003.65 PAF·m^{-2}·year^{-1}. The lowest impact category of mineral in Scenario 3 was 81 029.211 MJ surplus. The lowest impact category of fossil fuels in Scenario 2 was 227 745.68 MJ surplus.

The impact category assessment of each class 4 market solid waste management scenario showed that most of the smallest environmental impacts were in Scenario 2 (integrated composting). Environmental impacts with the highest relative contribution values in the impact categories of carcinogens, radiation, ozone layer, ecotoxicity, land use, and minerals are generated by Scenario 0. Environmental impacts with the highest

relative contribution values in the impact categories of respiratory organics, respiratory inorganics, climate change, Acidification/eutrophication, and fossil fuels are generated by Scenario 3. The potential impact does not occur quickly but lasts long if waste that is easy and difficult to decompose is still mixed. The composted waste will be decomposed in less than 5 years, while rubber, plastic, and metal waste will take longer and cannot decompose [13].

4. INTERPRETATION OF THE ANALYSIS AND CONCLUSIONS

The inventory analysis and impact assessment findings were combined to produce conclusions and recommendations. The results showed that the sustainable scenario with the smallest environmental impact in classes 1–3 was Scenario 3 carried out by creating an integrated solid waste management program. In class 4 it was Scenario 2 to create a composting program in the market.

Integrated solid waste management by classifying waste types is considered more environmentally friendly. The environmental impact of segregated solid waste can be minimized. Market solid waste management is needed to reduce the contribution of emissions that cause impacts on living things and environmental ecosystems. Mismanaged market waste can be more difficult to control if it is not balanced with proper and effective handling. Traditional market solid waste management can be done by organizing a 3R (Reduce, Reuse, Recycle) based solid waste treatment facility.

In Scenario 3, the environmental impact analysis with LCA had the lowest impact category, namely the scenario where non-composted solid waste was integratively recycled and composted, and the residue was transported to the landfill. Additionally, Scenario 3 had the least adverse environmental effects in most conventional markets.

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