# Kansei engineering application in redesigning carica packaging to support local-small industry in Central

*by* Manik Mahachandra

# The influence of product design on environmental impacts using life cycle assessment

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# The Influence of Product Design on Environmental Impacts Using Life Cycle Assessment

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**Abstract.** In Indonesia, as a tropical country, fans become one of the electronic products with quite high level of consumption. The high amount of fan consumption potentially increases the number of e-waste, by which throughout its life phase, electronic products generate many environmental impacts. Environmental impacts in each life phase are very influenced by the design stage. Life cycle assessment is able to identify the eco-cost value of each product so that the product with lowest environmental impact can be selected. In the present study, various design of fans, i.e. stand fan and alternative designs were evaluated. The findings showed that redesign of product in environmental perspective could reduce environmental impact.

## INTRODUCTION

Interest in environmental sustainability and its relationship with product innovation is not something new. The design of a product affects the subsequent stages, such as material requirements, manufacturing process, energy consumption, and activity at the product disposal stage [1]. Similarly [2] claimed that 80% of the cost of development, production, and usage of the product is determined in the early design stage. In the early stages of product development, it is important to reduce costs and environmental impact [3]. The design stage also becomes a key stage in product life cycle in applying sustainability concept [4].

According [5] suggested that electronic products generate many kinds of impact to environment. A number of natural resources are required in manufacturing process phase, electrical energy is required in the usage phase, and an impact on human health and ecosystem quality is assessed in disposal or end of life phase, especially when the waste is not managed properly. Increasing public awareness and government regulation on environmental protection have challenged product designers to consider environmental aspects of product design goals [1].

Fans become the electronic products that have high demand in Indonesia. Based on the questionnaire, the life time of fans did not match the expectation of consumers. In addition, it is relatively complicated to repair a broken fan. About 63% of respondents stated that it was difficult to replace the broken components of a fan. This situation encouraged them to buy a new fan (24%). Frequently, the damage of one vital component, such as the motor, can cause a fan for not functioning properly, even though the other components are still in good condition. Consequently, the life time of the fan tends to be shorter than the standard. Furthermore, the increase of waste volume may also cause economic loss and adverse impact on the environment [6]. In fact, e-waste is deemed hazardous because this waste contains toxic that endangers human health as well as environment.

Life Cycle Assessment (LCA) is a standardized methodology to measure and analyze the environmental impacts of the product system along the production chain [7]. It has the ability to find out important issues from environmental aspects [8]. Furthermore, it is currently the most representative tool for analyzing and calculating the consumption of resources and environmental impacts throughout the product life cycle [9]. It is often used to compare product alternatives related to environmental impacts, hence it would be easier to find out which alternatives are the most environmentally friendly [10].

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However, LCA requires detailed data on product development that is not available in the early stage of conceptual design. To overcome this problem, eco-design concepts have been raised to help product designers in reducing environmental impacts by providing assistance for them to make better decisions in the early design stage [4]. Eco-design, as a product concept that integrates the aspects of environmental protection at the product design stage, is the best way to improve product performance in respect to environmental protection.

LCA has been widely used to evaluate environmental impacts on electronic products, among others on consumer electronics [9], air conditioning system [11], TV CRT [5], hetric lamp [12], desktop computer [13], electronic media [14], video projectors [15] and electronic tablets [16].

The purpose of this LCA discussion was to find out which phases have significant environmental impact from the fan production process, as well as to figure out the eco-cost value of the fan product which currently widely used, and then to compare its environmental impact value and its eco-cost value with alternative fan products. The present study will investigate the role of product designer in reducing environmental impact.

## METHODOLOGY

### Life Cycle Assessment (LCA)

LCA calculation is used to identify activities that have negative impact on environmental quality and human life quality. LCA can be used to evaluate whether a design or a process improvement of a product is able reduce its impact on the environment. This method results in the definition of an environmental profile for the assessed product/process/service by quantifying the environmental effects on different categories, while only indirect or intermediate effects on humans can be assessed. The impact categories analyzed in the present study were: abiotic depletion (AD), acidification (AC), eutrophication (EP), global warming (GW), ozone layer depletion (OD) and photochemical oxidants formation. Meanwhile, the LCA inputs included the type of material used in units of mass, the energy used for the production process, and the fan supporting product components brought in from suppliers in units of mass.

Calculation of the Life Cycle Assessment (LCA) method was performed using SimaPro v 7.1.8 software with the aim of knowing the value of the environmental impact of the fan product. The LCA calculation stages include:

i. Goal and Scope. The scope of the LCA assessment is the product life cycle only at the production and assembly stages of the product

ii. Life cycle inventory (LCI). This stage identifies input and output data for each stage of the evaluated production process. Life Cycle inventory is calculated based on the number of 1000 units/batch.

iii. Calculation of LCIA. The calculation of LCIA covers the calculation of characterization, normalization, weighting, and single score value.

iv. Calculation of Eco-cost. The calculation of Eco–Cost value is conducted using eco-cost 2012 method with Eco-Invent V3 2014 data base, published in Ecocostvalue.com. According to Volgtlander (2010), Eco-Cost is a cost that must be spent to reduce environmental pollution adjusted to the ability of the earth (earth carrying capacity). Eco-cost is a measure that describes the amount of environmental burden from a product on the basis of managing the waste.

The calculation of LCA in the present study ignored data regarding consumption of paint for iron components, packaging from suppliers, and modes of transportation during distribution due to unavailability of accurate information from the company. To maintain the validity of input data, it was assumed that the data was the same for all types of fans discussed in this study, so the results of the comparison would not be affected.

### Case Study

The present work aimed to have environmental analysis of the fan manufacture. The objectives were to identify: (1) the LCA study to detect the environmental ‘hot spots’ of the fan, (2) the reduction of its environmental impact with alternative design. The SC Company, located in Tangerang, Indonesia, produces “Electric Home Appliances”, since 1976, especially the production of fans. The types of fans include wall fans, desk fans, and stand fans. Components are supplied from several suppliers of steel, electronics, and packaging.

The product being studied was fan product with the highest demand level (stand fan) and alternative products. This product system had a material composition of 20.45% of PP, 4.33% of ABS and 75.22% of other materials.

The calculation of environmental impacts with the Life Cycle Assessment method in this study was limited to the production process inside the factory. The scope of the LCA assessment was limited to the phase when the fan product was ready to be distributed to consumers or to the distribution center.
Stages to make a unit of stand fan are as follows:

1. **Part Production with Molding Injection Process**. Molding is the process of shaping fan components that are made of plastic, for example motor covers, bodies, and others.
2. **Part Assembly Process.** The assembly process is a component assembly process at several workstations. The tools used in work stations are electric solder, screw drivers, and some other manual equipment.
3. **Quality Inspection Process.** The quality checking process includes the checking of in-line production and out-line production. The in-line production inspection process occurs while the product is still in the production line. This process consists of checking the condition of the motor, switch, cable connection, and other part of the connections. Checking of out-line production is carried out after the product has been assembled and packed. The packaged product will be tested by sampling and reassembling all packaged components and then turning it on and making sure all components and fan unit works properly.
4. **Packaging & Warehousing.** Product packaging uses cardboard cartons corresponding to the type of product. The product will then be stored and distributed.

## Collection Data Method

Primary data collection was carried out by observation and in-depth interview related to fan production process while secondary data was obtained by performing documentation study.

## THE RESULT OF STUDY AND ANALYSIS

### Stand Fan: Existing Design

**Goal and Scope.** The aim was to determine the environmental impact of fan production process and its eco-cost value. The scope of LCA assessment was in gate to gate. The input was material and energy consumption. The calculation method used SimaPro software with Eco-cost 2012 v 1.00.

**Life Cycle Inventory.** Life cycle inventory of existing stand fan can be seen in Table 1 (material data) and Table 2 (electricity data).

**TABLE 1**. LCI of existing fan: material data

| Name of Part | Quantity | Name of Part | Quantity |
|---|---|---|---|
| **Injection Molding Process** | (gram) | **Component from supplier** | (gram) |
| Switch Box (PP) | 107.5 | Motor (Copper wire & steel) | 1119.0 |
| Switch Box Cover (PP) | 41.3 | Front Guard (steel) | 491.6 |
| Base (PP) | 249.3 | Rear Guard (steel) | 499.6 |
| Front Motor Cover (PP) | 28.7 | Stand Pipe (steel) | 201.0 |
| Rear Motor Cover (PP) | 85.8 | Slide Tube (steel) | 16.7 |
| Blade (PP) | 114.5 | Screws (steel) | 1188.0 |
| Blade Spinner (PP) | 10.5 | Capacitor | 28.0 |
| Guard Mark (PP) | 14.1 | Lower Base (mix fiber) | 2001.0 |
| Pipe Bushing (ABS) | 16.9 | Piano *Switch* (mix) | 44.0 |
| Adjusting Bushing (ABS) | 24.0 | AC cord (cable) (meter) | 12.0 |
| Neck (ABS) | 37.7 | | |
| Neck Support (ABS) | 3.3 | | |
| Guard Ring Stabilizer (ABS) | 56.3 | | |

Life Cycle Impact Assessment in LCA calculation consisted of 4 (four) stages, namely: characterization, normalization, weighting, and single score calculation. Characterization included identification and classification of substances derived from LCI into predetermined heterogeneous impact categories. The normalization stage was a procedure of homogenizing units for all impact categories by multiplying the characterization values by "normal" values. The Weighting Stage was used to convert the normalization value from each impact category to the same unit. Single score calculation was executed to determine the contribution of each fan production process to the environmental impact caused. The result of eco-cost calculation is shown in Table 3 and 2 single score calculation is presented in graph in Fig. 1.

**TABLE 2**. Life cycle inventory of existing fan: electricity data

| Name of Parts | Quantity |
|---|---|
| **Electricity for Injection Molding** | **Watt hour** |
| Injection Molding | 2310100 |
| Chiller | 143 |
| **Electricity for Assembly Process** | **Watt hour** |
| Solder | 214 |
| Screw Driver | 73920 |
| Press | 44733 |
| Testing Machine | 770 |
| Solder | 120 |

**TABLE 3.** The result of eco-cost calculation of existing fan

| Impact category | Unit | Total | Supplier Part | Molding for SNQ- 16 | Electricity |
|---|---|---|---|---|---|
| Total | Euro | 14,062.18 | 13,312.39 | 722.99 | 26.80 |
| Climate change | Euro | 3,136.79 | 2,617.85 | 501.32 | 17.61 |
| Acidification | Euro | 3,351.05 | 3,284.68 | 64.95 | 1.41 |
| Eutrophication | Euro | 12.45 | 11.04 | 1.36 | 0.04 |
| Photochemical oxidant formation | Euro | 187.55 | 185.94 | 1.54 | 0.07 |
| Fine dust | Euro | 309.19 | 287.68 | 20.55 | 0.97 |
| Human toxicity, cancer | Euro | 996.74 | 863.66 | 126.51 | 6.57 |
| Eco-toxicity | Euro | 42.23 | 39.70 | 2.40 | 0.12 |
| Metals Depletion | Euro | 1,154.19 | 1,154.19 | 0.00 | 0.00 |
| Waste | Euro | 4,872.00 | 4,867.65 | 4.35 | 0.00 |

***Source: SimaPro Software.***

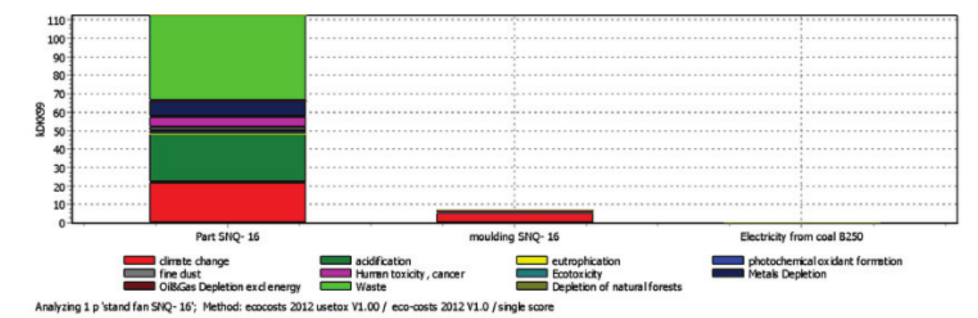


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**FIGURE 1.** Single score calculation of existing fan.

## Stand Fan using modularity concept

The development of product design with modularity concept is based on its ability to reduce environmental impacts [17] and to optimize the supply chain network [18]. The modular design has the potential to reduce the amount of waste because damaged fans can be repaired by replacing only the damaged components so that they do not need to be disposed. Based on the survey, the most frequent damaged components were the fan motors and the blades. The data was obtained from 64 respondents with the criteria of possessing damaged fan. In the modular design, if motor of a fan is damaged then it can be repaired while other components can be reused. This can reduce the amount of waste disposed into landfills.

### *Goal and scope*

LCA calculation was to determine the environmental impact when the motor component was damaged and discharged to landfill. The scope of calculation was the fan motor. Input of LCA analysis was materials of the motor. Output of LCA was the environmental impact indicators when a damaged motor is discharged to landfills.

### *Life cycle inventory*

Life cycle inventory of fan motor is presented in Table 4.

**TABLE 4.** LCI of fan using modular concept (motor)

| Process | Type of Material | Need/unit (gram) | Need/batch (kg) |
|---|---|---|---|
| Material | Copper Wire | 300 | 300 |
| | Steel | 819 | 819 |
| | Capacitor 1,2 Uf | 32 | 32 |
| | Cable | 0.4 meter | 400 Meter |

Source: Data processing.

### *Life cycle impact assessment (LCIA)*

The result of LCIA calculation shows that the environmental impact of the fan motor component was 78% due to the use of copper material for the coil inside the motor. The use of capacitors contributed to an impact of 18.3%, and the cable components accounted for 1.64% of the impact value. The result of the single score calculation for fan motor components is shown in Table 5 and Fig. 2.

**TABLE 5.** LCIA calculation for stand fan using modular concept

| Impact category | Unit | Total | | Capacitor | | Iron | | Copper | | Cable | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Unit | Euro | Unit | Euro | Unit | Euro | Unit | Euro | Unit | Euro |
| Climate change | kg CO2 eq | 5,958 | 804 | 2,665 | 360 | 835 | 113 | 2,253 | 304 | 206 | 28 |
| Acidification | kg SO2 eq | 282 | 2,333 | 67 | 554 | 7 | 61 | 206 | 1,700 | 2 | 18 |
| Eutrophication | kg P eq | 1 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Photochemical oxidant formation | kg NMVOC | 5 | 44 | 4 | 42 | 0 | 0 | 0 | 0 | 0 | 1 |
| Fine dust | kg PM2.5 eq | 2 | 46 | 1 | 41 | 0 | 0 | 0 | 0 | 0 | 4 |
| Human toxicity, cancer | CTUh | 11 | 400 | 9 | 323 | 0 | 3 | 0 | 0 | 2 | 75 |
| Eco-toxicity | CTUe | 0 | 9 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 3 |
| Metals Depletion | euro | 272 | 272 | 259 | 259 | 0 | 0 | 0 | 0 | 13 | 13 |
| Waste | MJ | 402,081 | 4,753 | 0 | 0 | 79 | 1 | 402,092 | 4,752 | 0 | 0 |

Source: SimaPro Software.

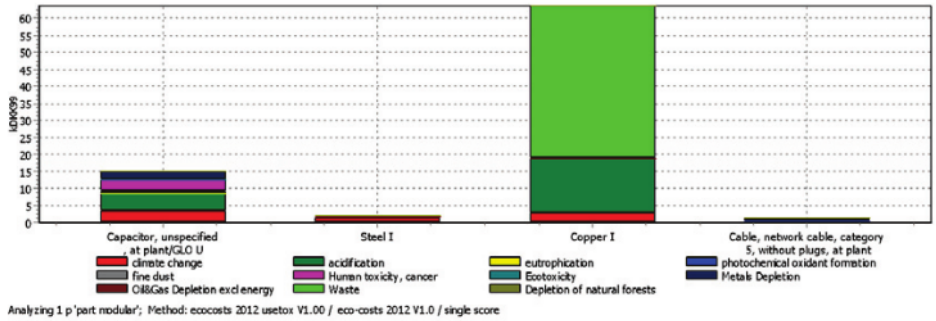


**FIGURE 2.** Single score calculation for stand fan using modular concept (motor).

## Stand fan with multi-location design

Alternative product with the multi-location concept was developed based on the function of the fan on their location. An alternative product of multi-location fan combines 3 (three) types of fan products: stand fan, wall fan, and desk fan in a 3-in-1 fan.

### *The Goal and Scope*

The goal of the LCA assessment was to determine the environmental impact of the multi-function fan production process. The inputs LCA were material and energy consumption for the production process. The output of LCA calculation was in the form of eco-cost value derived from the fan production process.

### *Life cycle inventory*

LCI contains input and output data of the fan production process. Table 6 and 7 show the inventory data of materials and energy required for the multi-location fan.

**TABLE 6.** LCI of stand fan with multi-location design (material)

| Name of Part | Kg/Batch | Name of Part | Kg/Batch |
|---|---|---|---|
| **Molding Process** | | **Assembly Process** | |
| Switch box (ABS) | 167 | Screw JP/MS 5 x 18 (Steel) | 3 |
| Switch box cover (ABS) | 75 | Screw JT/TS 4 x 10 (Steel) | 43 |
| Base (ABS) | 84 | Screw JP/TS 4 x 12 (Steel) | 59 |
| Pipe Bushing (ABS) | 17 | Screw JP/MS 4 x 12 (Steel) | 31 |
| Adjusting Bushing (ABS) | 24 | Screw JT/TS 3 x 8 (Steel) | 5 |
| Neck (ABS) | 38 | Screw JP/MS 8 x 32 (Steel) | 14 |
| Neck Support (ABS) | 3 | Screw JT/TS 3 x 12 (Steel) | 3 |
| Sliding Base (ABS) | 195 | Screw JT/TS 4 x 20 (Steel) | 2 |
| Sliding Base Bracket (ABS) | 85 | Screw JT/TS 4 x 16 (Steel) | 72 |
| Guard Ring Stabilizer (ABS) | 56 | Front Guard (Steel) | 492 |
| Front Motor Cover (PP) | 29 | Rear Guard (Steel) | 500 |
| Rear Motor Cover (PP) | 85 | Lower Base (Mix) | 2,001 |
| Guard Mark (PP) | 14 | Base Plate (Steel) | 124 |
| Blade Spinner (PP) | 11 | Stand Pipe (Steel) | 201 |
| Blade(PP) | 115 | Slide Tube (Steel) | 17 |
| | | Motor (Copper wire, steel) | 1,087 |
| | | Piano Switch (Mix) | 44 |
| | | AC cord (Mix) | 62 |
| | | Capacitor (Mix) | 32 |

| **TABLE 7.** LCI of stand fan with multi-location design (energy) | |
|---|---|
| **Machine Used** | **Total Power (kwh)** |
| Injection molding Process | |
| Injection Molding Machine | 2487.5 |
| Chiller Machine | 0.5 |
| Subtotal | 2488.0 |
| Component Assembly Process | |
| Solder Machine | 0.1 |
| Screw Driver Machine | 99.0 |
| Press Machine | 44.0 |
| Testing Machine | 0.9 |
| Subtotal | 144.0 |

Source: Company's Data.

*Life cycle impact assessment*

The output of SimaPro software for energy consumption during multi-location fan production is shown in Table 8.

**TABLE 8.** Environmental impacts in unit and euro of multi-location fan

| Impact Category | Unit | Total | | Molding | | Part | | Electricity | |
|---|---|---|---|---|---|---|---|---|---|
| | | unit | euro | unit | euro | unit | euro | unit | euro |
| Climate change | kg CO2 eq | 25,328 | 3,419 | 6,693 | 903 | 18,479 | 2,495 | 157 | 21 |
| Acidification | kg SO2 eq | 403 | 3,325 | 12 | 102 | 391 | 3,222 | 0 | 2 |
| Eutrophication | kg P eq | 3 | 13 | 1 | 2 | 3 | 11 | 0 | 0 |
| Photochemical oxidant formation | kg NMVOC | 19 | 189 | 0 | 3 | 19 | 186 | 0 | 0 |
| Fine dust | kg PM2.5 eq | 11 | 323 | 1 | 34 | 10 | 287 | 0 | 1 |
| Human toxicity, cancer | CTUh | 28 | 1,005 | 4 | 136 | 24 | 861 | 0 | 8 |
| Eco-toxicity | CTUe | 1 | 42 | 0 | 3 | 1 | 40 | 0 | 0 |
| Metals Depletion | euro | 1,154 | 1,154 | 0 | 0 | 1,154 | 1,154 | 0 | 0 |
| Oil & Gas Depletion excl energy | kg oil equ | 413,055 | 0 | 1,339 | 0 | 411,716 | 0 | 0 | 0 |
| Waste | MJ | 25,328 | 4,882 | 6,693 | 16 | 18,479 | 4,866 | 157 | 0 |

Source: SimaPro Software.

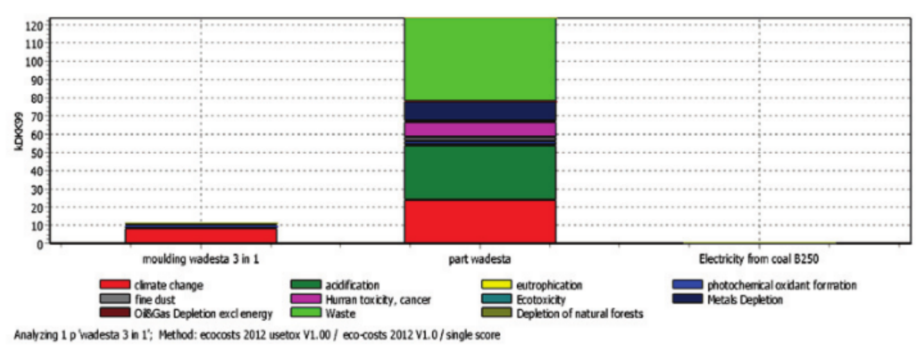


**FIGURE 3.** Single score calculation of multi-location stand fan.

The single score value classified environment impacts based on its processes. The single score calculation of the multi-location fan is shown in Fig. 3. Comparison of eco-cost values between existing fan stands, modular and multi-location is shown in Table 9. From table 9, it can be seen that the lowest eco-cost was obtained by the fan with a modular concept. It is because the modular fan is designed to be easily replaced when the motor is damaged. Thus, it is assumed that when the product is damaged, the only item discarded is the motor component, not all components of the stand fan.

**TABLE 9.** Comparison of environmental impact between existing design with alternative design

| Impact category | unit | existing | modular | Multi-location |
|---|---|---|---|---|
| Total | Euro | 14,062 | 8,663 | 14,353 |
| climate change | Euro | 3,137 | 804 | 3,419 |
| acidification | Euro | 3,351 | 2,333 | 3,325 |
| eutrophication | Euro | 12 | 3 | 13 |
| photochemical oxidant formation | Euro | 188 | 43 | 189 |
| fine dust | Euro | 309 | 45 | 323 |
| Human toxicity, cancer | Euro | 997 | 400 | 1,005 |
| Eco-toxicity | Euro | 42 | 9 | 42 |
| Metals Depletion | Euro | 1,154 | 272 | 1,154 |
| Waste | Euro | 4,872 | 4,753 | 4,882 |

## CONCLUSION

Based on the results of the LCA calculation with the Simapro software 2012 v.1.00, it was revealed that product design affected the impact of the product on the environment, in which modular designs had a smaller impact. In general, the fan products have a great impact on the category of waste, eco-toxicity and climate change.

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