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# A Sustainable Approach of Toaster by Using Simplified Life Cycle Assessment: A Case Study

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***Abstract***
*Toaster is considered the main appliances in every household worldwide. Thus, it is necessary to analysis its life cycle and figures out which phase affects the environment and how its impacts could be alleviated. Simplified Life Cycle Assessment (SLCA) was conducted for the entire life cycle of Toaster considering raw materials phase, manufacturing phase, usage phase, End of life (EOL) and transportation. According to SLCA results, the Polypropylene scored the highest SLCA points (approximate 0.2117) among the materials used in the Toaster. This can be expected as it contributes to the major weight of Toaster. Copper scored the second-highest SLCA points (0.1318) because of its environmental impacts resulted from raw material extraction processes such as mining. This paper also pointed out that the hot spot analysis during the manufacturing phase has resulted from plastic injection moulding. In the life-cycle of Toaster, the obtained results of SCLA indicated that the usage phase had the highest SLCA points among all phases. This can result from the high consumption of electricity. After performing the sensitivity analysis, it is evidenced that replacing the conventional fossil fuel to renewable wind power would have a less environmental impact during the life-cycle of the Toaster.*

***Keywords***: *Life Cycle Assessment; Hot spot; Sensitivity Analysis*

## 1. INTRODUCTION

The life cycle assessment method is a tool that been employed to assess the products environmental impacts. However, it usually requires time and particular data to run an entire life cycle assessment for a product (Biswas *et al*., 1995). For this reason, a Simplified/ Streamlined Life Cycle Assessment (SLCA) is employed in this study to estimate the environmental impacts at the early product development stage in terms of the SLCA scores or Environmental Performance Indicators (EPI) by multiplying a set of input data with corresponded SLCA drivers and points. SLCA methodologies were conducted for Toaster entire life to obtain a sustainable product. A SLCA is depended on a group of technology that applied various industrial products. This will have divided products into groups according to their environmental behaviour with four phases the material phase, the manufacturing phase, the usage phase and the disposal phase. In addition to SLCA, SIMAPRO software also utilized in the results.

## 2. GOAL AND SCOPE DEFINITION

The primary goal of Life Cycle Assessment (LCA) guidelines (ISO 14041, 1998; ISO 14042, 2000; ISO 14043, 2000) is to determine the energy and resources consumption and environmental impacts incurred by the entire life cycle of the Toaster (Cradle-to-Grave). The results obtained can be used by product designers and decision-makers for the better choice in design, materials selection, manufacturing process or transportation options. Streamlined/Simplified LCA (SLCA) in the early stage of product development due to full LCA is time and cost consuming. The environmental impacts resulted from selective materials for the Toaster and its entire life cycle phases are examined by SLCA methods.

### 2.1. Functional Units and System Boundaries

First of all, the appropriate system boundary and functional units are essential for LCA. The functional units for Toaster are the usage and frequency of use for its whole life cycle, which is 3 years (2 uses/day, each use takes 3 minutes, 7 days per week, 50 weeks/year). The wattage for the Toaster is 780 watts. The LCA of the Toaster will be conducted using SLCA drivers. The system boundaries (Figure 1) include raw material extraction phase, manufacture phase, usage phase and end of life (EOL) of the Toaster. The transportation also included in the LCA. The treatment options for the discarded Toaster at the end of life are recycling and landfill.



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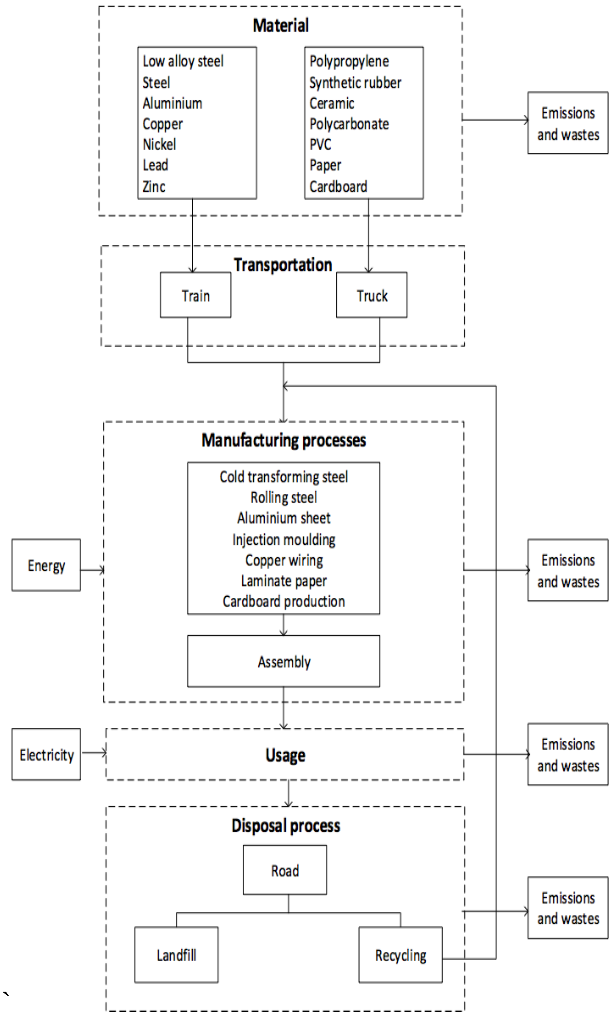


Figure 1 System boundary for Toaster

## 2.2. Assumptions and limitations

The design phase was excluded from the Life Cycle Assessment (LCA) due to considerable less significant to the energy and resources consumed in the product life cycle. The system boundaries only included the raw material extraction phase, manufacture, usage and disposal phase. The wastes and emission associated with the manufacturing process and disposal of the Toaster are outside of the system boundaries. The injection moulding was assumed as the prime manufacturing process of the Toaster. Only selected compartments of Toaster were included for the analysis, which are housing, lid, heating mechanism and cables. The plastics/bubble wraps and container boxes for Toaster packaging were excluded. SLCA has its limitations in variable multi-input multi-output systems and also average inventory data used. The average data might not be directly reflecting the actual environmental impacts in the life cycle of the Toaster. The streamlined tool only highlights the hot spot during product development rather than provides quantitative estimates of environmental impact. It addressed the consideration needed during the design phase to reduce the environmental impacts, energy and cost-efficiency.

## 3. INVENTORY ANALYSIS

The product Net weight is 2.1 kg, certain materials and process are excluded. The Lifetime is 3 years (It is estimated that the product is discarded when no longer works). The Frequency of use is 780 watts for 2 uses/day (each use takes 3 minutes), 7 days/week, 50 weeks/year. In term of the logistic, all the materials are located in Australia, the metals are supplied from Perth. The plastics are sourced from Melbourne and then the product is distributed to Sydney. The assembly process is produced in Sydney and requires 0.35 MJ/kg of the product. Finally, the End of Life (EOL) product is disposed of at the disposal site. The distance to the disposal site is estimated at 70 km. The disposal routes include



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90% recycling and 10% landfill for steel, 80% recycling and 20% landfill for other metals, 100% recycling for paper and cardboard, and 100% landfill for the other materials. The weight and processes of the following material are utilized as listed below. Required data were sourced from (Nga *et al*., 2013; NSW resource and energy, 2018; Vinyl Council Australia, 2019).

**Table 1 Material Types and Weight for Toaster**

| Material type | Weight, kg | Material type | Weight, kg |
|---|---|---|---|
| Lowalloy steel | 0.5 | PVC | 0.1 |
| Steel | 0.3 | Copper | 0.06 |
| Polypropylene | 0.6 | Nickel | 0.0008 |
| Synthetic rubber | 0.0005 | Lead | 0.004 |
| Aluminium | 0.07 | Zinc | 8.00E-05 |
| Ceramic | 0.005 | Paper | 0.05 |
| Polycarbonate | 0.016 | Cardboard | 0.4 |

**Table 2 Manufacture Processes**

| Process | Unit,kg |
|---|---|
| Cold transforming steel | 0.8 |
| Rolling steel | 0.8 |
| Aluminum sheet | 0.07 |
| Injection moulding | 0.716 |
| Copper wiring | 0.060 |
| Laminate paper | 0.05 |
| Cardboard production | 0.3 |

## 4. IMPACT ASSESSMENT

### 4.1. Existing LCIA Methods

Many LCIA methods can be used for assessing the environmental effects, the existing LCIA methods include Eco-indicator 99, EPS 2000, CML 2 baseline2000 and Cumulative Energy Demand.

**4.1.1. Eco-indicator 99:** Eco-indicator 99 is the successor of Eco-indicator 95. Both methods use the damage-oriented approach. The default Eco-indicator 99 method is the Hierarchist version with an average weighting set (average of the full panel). In the Eco-indicator 99 method, the impact category indicator results are calculated in the Characterization step. Then, they are added to damage categories. Normalization and weighting are performed at the damage category level (endpoint level in ISO terminology). The damage categories are normalized on a European level (damage caused by one European per year) (Goedkoop and Spriensma, 2001). (There are three damage categories:

- Human Health (unit: DALY= Disability-adjusted life years; this means different disability caused by diseases are weighted).
- Ecosystem Quality (unit: PDF×$m^2$ year; PDF= Potentially Disappeared Fraction of plant species).
- Resources (unit: MJ surplus energy Additional energy required to compensate for lower future ore grade).

**4.1.2. Environmental Priority Strategies (EPS) 2000**: The EPS system is mainly aimed to be a tool for a company's internal product development process. In the EPS default method, the impact categories are identified from four damage categories (Steen, 1999) :

- Human health (Unit: ELU/Person Year)
- Ecosystem production capacity, (Unit: ELU/kg or $H^+$).
- Abiotic stock resource (Unit: ELU/kg).
- Biodiversity (Unit: ELU).



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Weighting is made through valuation. Weighting factors represent the willingness to pay to avoid changes. The environmental reference is the present state of the environment. The indicator unit is ELU (Environmental Load Unit).

**4.1.3. CML 2 baseline 2000**: The CML 2 baseline method is a problem-oriented approach. The baseline indicators are category indicators at the middle point level. For each baseline indicator, normalization scores are calculated for the reference situations: the world in 1990, Europe in 1995 and the Netherlands in 1997. Grouping and weighting are considered to be an optional step. No baseline recommended rules or values are given for these steps (Guinée, 2001). The impact categories used in CML baseline method are:

- Abiotic depletion
- Global warming
- Ozone layer depletion
- Human toxicity
- Fresh water aquatic ecotoxicity
- Marine aquatic ecotoxicity
- Terrestrial ecotoxicity
- Photochemical oxidation
- Acidification
- Eutrophication

**4.1.4. Cumulative Energy Demand:** Cumulative Energy Demand is used to assess the primary energy consumptions or flows throughout the entire life cycle of a good or service. The method has the characterization and weighting steps. There are five impact categories which are calculated in a unit of MJeq (Mega joules equivalent) (CML,2013) : Non-renewable fossil, Non-renewable nuclear, Renewable biomass, Renewable wind, solar, geothermal and Renewable water.

### 4.2. Method used by the SLCA driver database

The available databases of SimaPro software were used and assessed using the Eco-Indicator 99 (unit: points). Thus, the SLCA drivers can be applied by a designer to calculate the Environmental Performance Indicator through the VSSM (the Valuation of Social Cost and Simplified Life Cycle Assessment Model). Here are the equations on how to calculate the environmental impact by using the provided SLCA drivers.

Total Environmental Impact (TEI) = SLCA DRIVERS × INPUT DATA

= SLCA Driver for material × Material weight (kg) + SLCA Driver for process × Material weight (kg) + SLCA Driver for usage × Lifetime energy consumption (MJ) + SLCA for EOL options × Material weight (kg) + SLCA for transportation used in all stages × travel distance (km)

## 5. INTERPRETATION

According to data in previous inventory analysis and SLCA drivers, the results of Toaster SLCA points can be calculated and they are shown below as two bar charts (cradle to gate and cradle to grave).



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### 5.1. Cradle to gate results

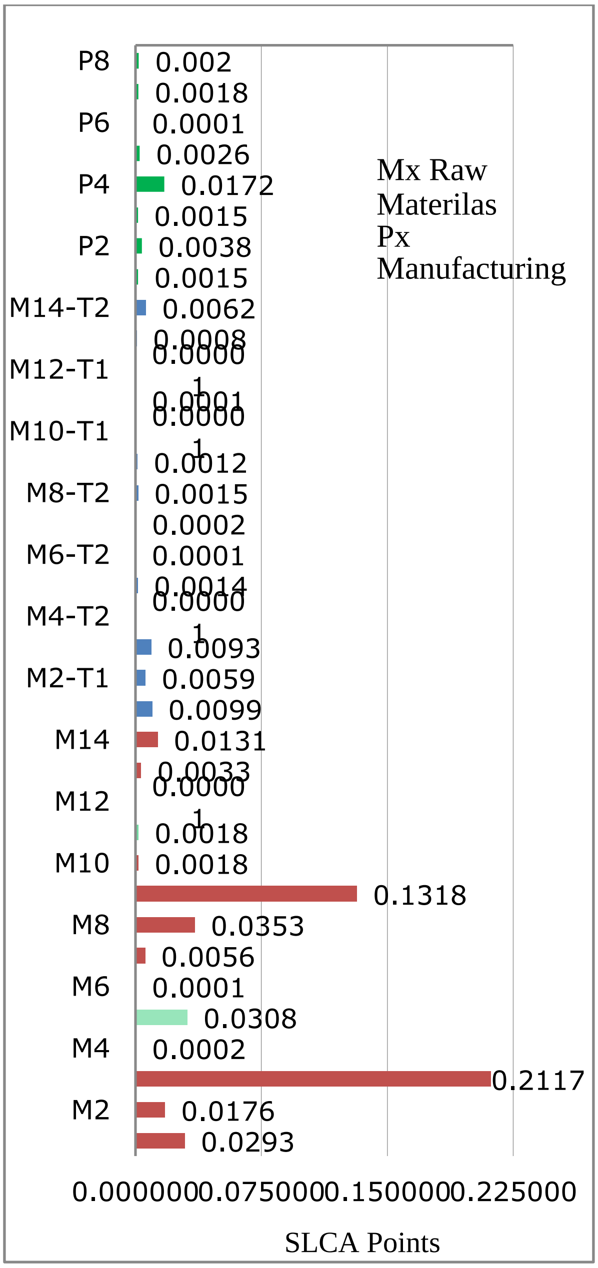


Figure 2 Toaster results from cradle to gate

Before discussing results in this Figure 2, certain abbreviations are used in this chart, they are:

**Table 3 Nomenclature for bar charts in Figure 2**

| | | | | | |
|---|---|---|---|---|---|
| M1 | Low alloy steel | M14 | Cardboard | P1 | Cold transforming steel |
| M2 | Steel | M9 | Copper | P2 | Rolling steel |
| M3 | Polypropylene | M10 | Nickel | P3 | Aluminium sheet |
| M4 | Synthetic rubber | M11 | Lead | P4 | Injection moulding |
| M5 | Aluminium | M12 | Zinc | P5 | Copper wiring |
| M6 | Ceramic | M13 | Paper | P6 | Laminate paper |
| M7 | Polycarbonate | T1 | Train | P7 | Assembly |
| M8 | PVC | T2 | Truck | P8 | Cardboard Production |

As it can be seen in Figure 2, in the raw material stage, M3 which is polypropylene contributes the highest points, approximately 0.212. This is because the major material of this Toaster is



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polypropylene which is 0.6 kg. Although there is only a little portion of copper in this Toaster, its SLCA point is the second-highest among these 14 materials. The reason is that serious environmental impact such as erosion could have happened during copper mining. That is why the SLCA driver of copper is the highest among these 14 materials for about 2.20. When it comes to transportation stage, all these SLCA points are relatively low. Low alloy steel transported by train is the highest point, which is 0.009896. Another result close to low alloy steel is polypropylene transported by the truck which is 0.009273. These two contribute the highest point in the transportation stage is mainly because these two materials are the major part of this Toaster, one is 0.5 for low alloy steel, the other one is 0.6 for polypropylene. For manufacturing processes stage, injection moulding has the most environmental impact point (Thiriez and Gutowski, 2006) . This is due to the significant energy consumption of the injection moulding process as well as the large portion of polymer material in this product.

### 5.2. Cradle to grave results

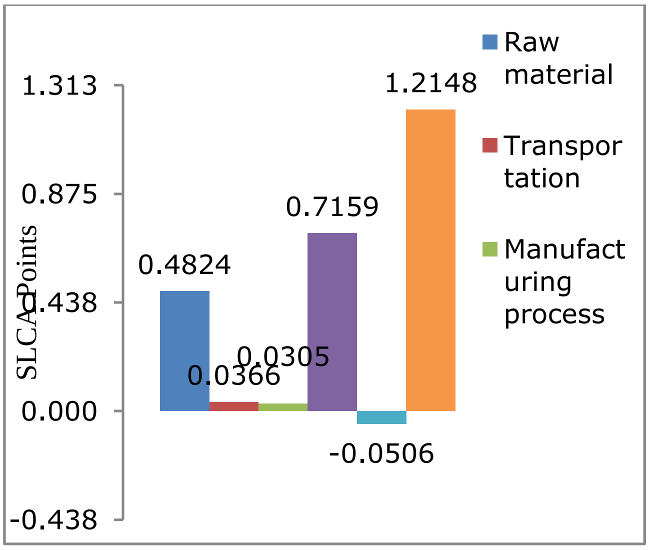
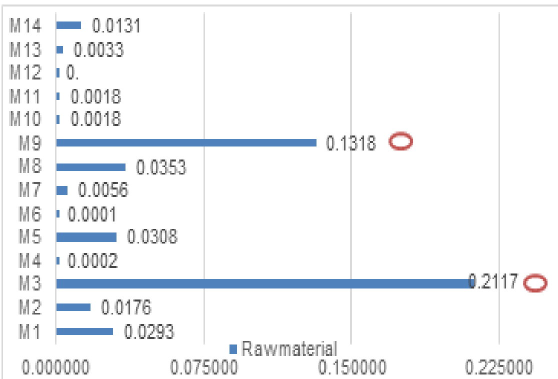



Figure 3 Toaster LCA results from cradle to grave

Figure3 demonstrates the total SLCA point of each stage from raw material to end of life and the total environmental impact of this Toaster. From this Figure, it can be seen that the usage stage contributes to the highest part of the whole product life cycle. This could be accounted for the energy inefficiency in Australia. Another interesting value is the point of the end of life stage, which is a negative value. This is mainly because 90% of steel and 80% of other metal could be recycled.

### 5.3. Hot spots analysis

To determine which activities have a high contribution for each life cycle stage as well as the entire life cycle, it is necessary to generate SLCA results from each life cycle stage and form bar charts. Therefore, five charts have been made to reveal the environmental impact from cradle to grave. The red circle represents the hot spot activities.



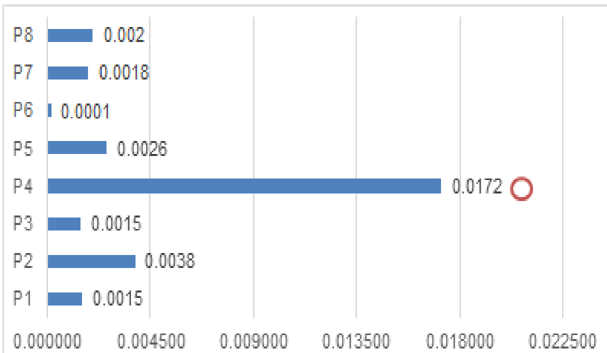






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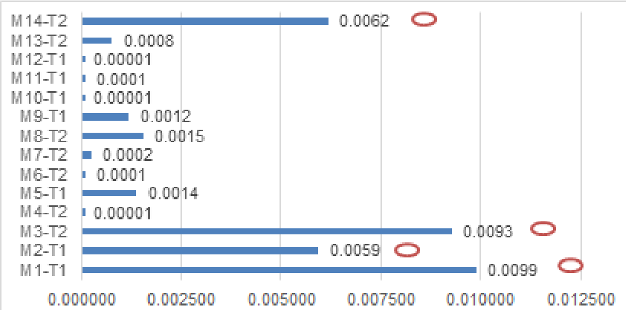
Figure 4 SLCA results for raw material

Figure 5 SLCA results for manufacturing process stage



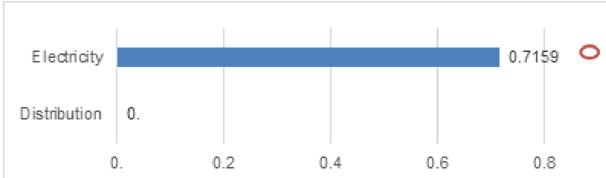




Figure 6 SLCA results for transportation

Figure 7 SLCA results for usage

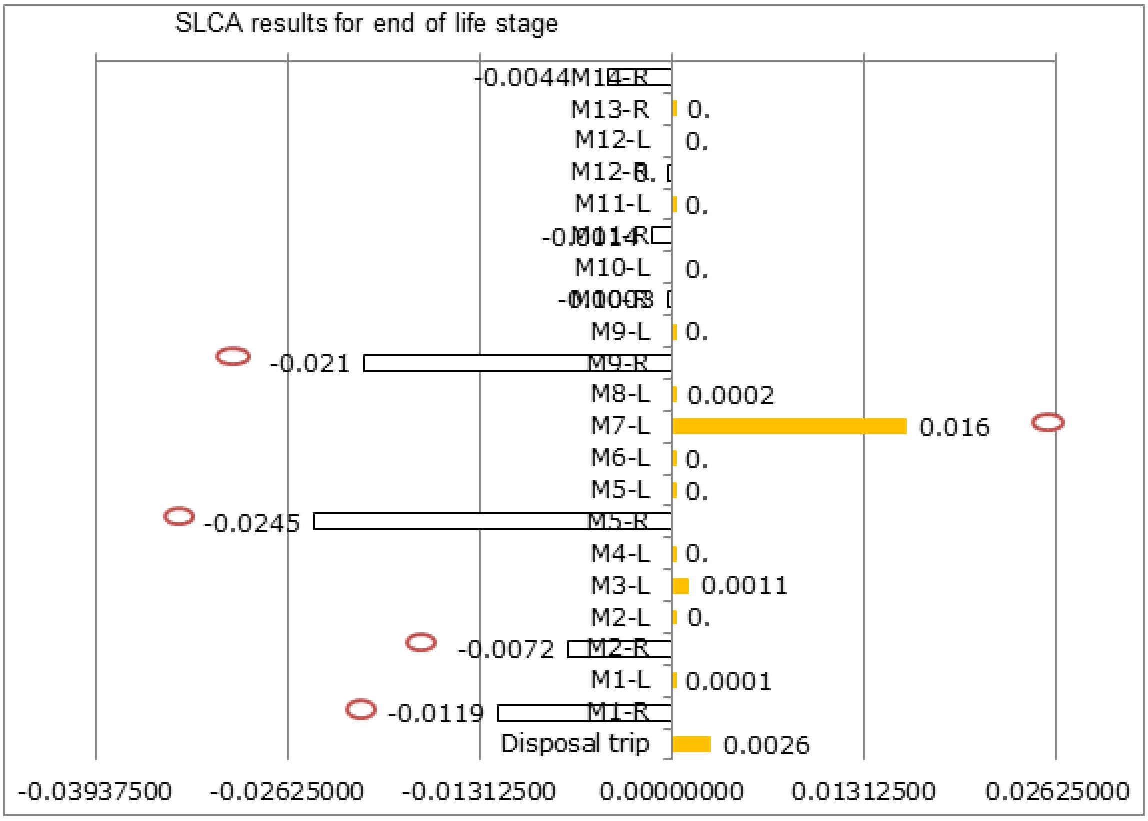



Figure 8 SLCA results for end of life, R(recycle), L(landfill)

Figure 4 shows that the hot spots of raw material would be M3 (Polypropylene) and M9 (Copper). The main reason for polypropylene to be the hot spot is that it contributes to almost 30% of Toaster net weight. For copper, although it only contributes 3% of the total weight of the product, the significant energy consumption, as well as the environmental impact during copper mining, would cause it to be another hot spot following polypropylene. Figure 5 demonstrates the results of SLCA in transportation stage. M1-T1, M2-T1, M3-T2 and M14-T2 are the activities that have a high contribution (Williams, 2013). This is because M1, M2, M3 and M4 contribute almost 86% of product weight.

As it can be seen in figure 6, during the manufacturing processes, the hot spot is P4 injection moulding. Not only because all polymers (34% of product net weight) have to go through injection moulding, but also the energy embedded in this manufacturing process is significantly high (NSW resource and energy, 2018).

During the usage phase Figure 7, the hot spot would be the electricity consumption. As for the end of life stage, Figure 8, the hot spots are recycling M1, M2, M5 and M9 as well as landfilling M7. To be



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more specific, M5 (Aluminium) have the highest negative value of recycling. That is not only because the energy consumption is relatively high during aluminium mining, but also it can be recycled for almost 80% of the total aluminium during product disposal.

### 5.4. Sensitivity analysis

The sensitivity analysis of LCA is widely used in the manufacturing industry to comparing the current procedure and the alternative one. The analysis of the impact of variations of the whole life span of the Toaster is based on the previous cradle to grave calculation, which including the manufacturing process, transport, the type of electricity of usage and the disposal phases of the Toaster. According to the cradle to grave result, the total point of SLCA is 1.215, and the heaviest one is the usage point which is 0.716. This sensitivity analysis will focus on analysing and comparing the current and the alternative scenario of the electricity type as it has the most significant impact on the life cycle of the Toaster. The analysis will be conducted under the VSSM Model (the Valuation of Social Cost and Simplified Life Cycle Assessment Model) and will follow the same assumption and constrains made in the previous sections. In the usage phase, it only includes the type of electricity used through the lifetime of the Toaster. As the Toasters are mainly sold in Sydney, so the SLCA driver selected for the energy usage of the Toaster is G1 Asia/Australia with 0.0024 points per MJ. During the three years' lifetime, the Toaster used three minutes once for twice per day seven days of 50 weeks annually. Therefore, the total energy consumption = $0.78kW \times 0.05hr \times 2 \times 7 \times 50 \times 3 \times 3.6 = 294.84MJ$

From the VSSM model, G1 Asia/Australia has a relatively low point among the energy per region with the US, South America etc. However, compared to the electricity by countries in Europe, the SLCA points of G13.1 electricity wind power plant Grenchenberg S is only 0.0005 which is 20% of the G1 points. According to the New South Wales major electric power generation station, around 1.4% (NSW resource and energy, 2018) of the electricity is generated from a wind turbine in NSW, the major source of NSW electricity comes from coal and steam power plants. Undoubtedly, the conventional coal-burning power plant has a much more environmental impact than the renewable clean energy power plant. The choice of electricity consumed by Toaster users is assumed sourcing from wind power due to its sustainability. This assumption is made upon the fact that the wind farm grows a large trend of NSW electricity resources in the future. Approximately 30% of the approved planning power station is sourced from wind and even 78% of the planning power station is sourced from wind turbines (NSW resource and energy, 2018).

If the major source of electricity used by Sydney residents is wind power, then the SLCA driver for usage phase is $0.0005 \times 294.84 = 0.1474$ points. Comparing this result with the current result, $(0.716-0.1474)/0.716 = 0.794 \times 100 = 79.4\%$ of the impact of energy has been improved by using wind power.



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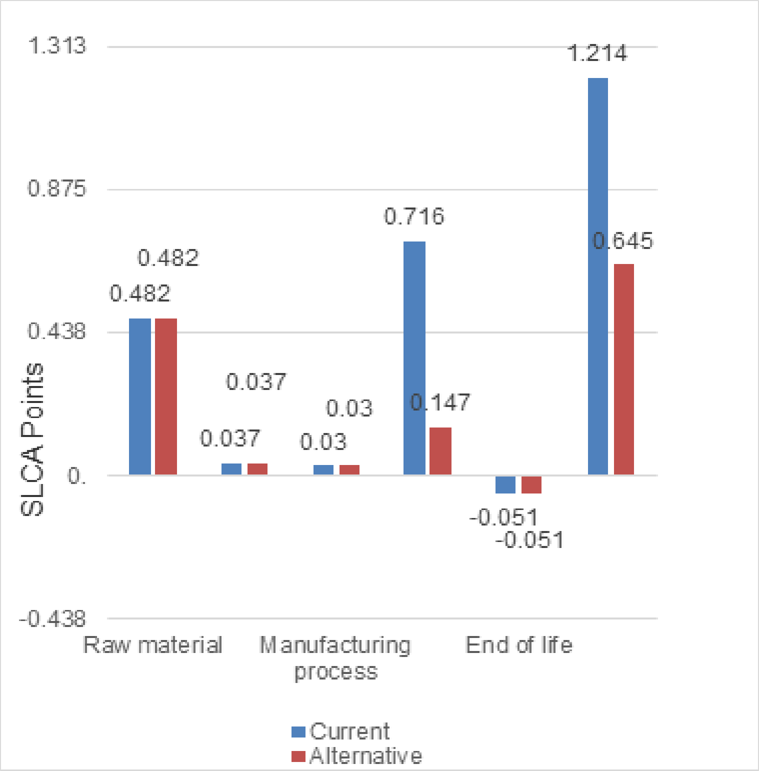


Figure 9 Comparing SLCA point of current and alternative scenario

From Figure 9, it is clear that under an alternative scenario, the total eco-points reduced 47% from the original situation. The energy of usage impact used to have 59% of the total points which reduced to only 22.7% of the total score. On the other hand, when the resource of energy using by the Toaster users transferred from conventional fossil fuel to renewable wind power, the less environmental impact would be made through the life-cycle of the Toaster. To realize this target, it requires not only the government promoting more renewable power station planning but also the users' knowledge of choosing clean energy. The relatively low efficiency and unstable wind speed constrain the capacity of the current wind power stations.

## 6. CONSLUSION

In this paper, Life Cycle Assessment of a Toaster was presented using the SLCA method and the results from hot spot analysis were discussed. The usage phase had the highest environmental impacts during the product life cycle due to electricity consumption. Carrying out the sensitivity analysis proved that the alternative energy resource of wind power could reduce up to 47% of the total environmental impact compared current energy resource of Australia.

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### Author Contributions

All authors contributed substantially to all aspects of this article.

### Conflicts of Interest

The authors have no conflict of interest to declare.

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