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LIFE-CYCLE ASSESSMENT OF ELECTRIC RICE COOKER: A CASE STUDY

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ABSTRACT

Nowadays, almost every family has one electric rice cooker, thus making electric rice cooker one of the most popular household appliance in our society. If the product is not designed ecologically and is used heavily, then the product may lead to large ecological impact to our environment. To assess a product's environmental impacts, Life Cycle Assessment (LCA) methodology is utilized. However, to the best of the authors' knowledge, for one such technology (electric rice cooker), no complete LCA studies have existed by far. Therefore, the question about the electric rice cooker's environmental performance is still open. This paper presents an LCA study for the complete life cycle of an electric rice cooker with the power 500Watts as the functional unit.

In order to conduct LCA study, the whole life cycle of electric rice cooker was divided into four primary phases: raw materials acquisition, product manufacturing, product utilization and final disposal. To facilitate the data collection and LCA implementation, the whole life cycle system was classified as two subsystems – background system and foreground system. Based on the proposed method, primary data and environmental impact calculation was aided by Simapro7.2 software. In the light of the Ecoindicator-99 methodology, eleven impact categories (Carcinogens, Resp. organics, Resp. inorganics, Climate change, Radiation, Ozone layer, Ecotoxicity, Acidification, Land use, Minerals, Fossil fuels) were used for the classification and characterization of the life cycle impact assessment.

In this paper, the LCA study was found as a very helpful tool to define ecodesign measures for this product. Several measures are suggested to the manufacturers to implement the ecodesign in the future: 1) Use recyclable plastics in the minor parts and hidden components, such as switcher, handle etc.; 2) Reduce the number of different materials in packaging; 3) Avoid incompatible plastics during recycling; 4) Minimize the volume of the heat plate on the premise of meeting the rated heating power.

Keywords - Electric rice cooker, Life cycle assessment (LCA), Ecodesign

NOMENCLATURE

LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
PP	PolyPropylene
PFA	PerFluoroAlkoxy (Teflon)
PA	PolyAmide (Nylon)
PVC	PolyVinyl Chloride
PBT	PolyButylene Terephthalate
Pt	single Point (unit in Simapro software)
Env	*Env*ironment impacts
W	Weight
U	capacity of Use
M	Materials
E	form of Energy
f	*function*

1. BACKGROUND AND REQUIREMENT

In 1945, the Mitsubishi Electric Corporation of Japan was the first company to produce a commercially available electric rice cooker [1]. Since then, electric rice cooker has become one of the most common household appliance in people's daily life, especially in eastern countries where rice is the staple food. Presently, the electric rice cooker in China's urban households has reached the market penetration rate of 100% which implies that every family has at least one rice cooker. Rice cooker manufactures are mainly concentrated in Zhanjiang, Shunde, Zhejiang etc. In China, e.g. only in Zhanjiang, the annual production is over 50 million units per year since 2006, which accounts for nearly 60% of the international market share [2]. Therefore, the electric rice cooker is a very big industry. The large number of the electric rice cooker produced each year potentially has considerable impact to the environment.

However, on one hand, in such industry, manufacturing usually focuses on the quality of the product and the cost. "In order to comply with the environmental regulation, the manufacturers always overlooked the environmental issues or just regarded them as an 'End-of-Pipe' treatment." [3]. Hence, no specific and complete environmental impact assessment or life cycle assessment

(LCA) about this device was done in the past and no published research specifically focused on electric rice cooker to the best of our knowledge, although the LCA of many other kinds of household appliance, such as refrigerator, TV, air conditioner, washing machine, etc. have been assessed [4]. So, conducting a detailed LCA of the electric rice cooker will be meaningful.

On the other hand, such industry is currently facing numbers of problems: 1) market saturation; 2) no major breakthrough in technology; 3) industry matured into aging trend etc. resulting in the fall of the electric rice cooker market for three consecutive years since 2005 [2]. Therefore, developing an environmental friendly product could be a solution to get over the plight. The first step, towards developing an environmentally friendly electric rice cooker, is to perform LCA study of the electric rice cooker.

Furthermore, the government has also been paying more and more attention on sustainability and increasing the eco-awareness in all aspect in the society. For example, in the electric rice cooker industry in China, the Kitchen Appliance Branch of National Standardization Technical Committee was formally established in 2010 [5], in order to draft a new national standard of the electric rice cooker to promote the healthy development of this industry. Under the new national standard, if all the manufacturers upgrade energy efficiency threshold to “energy-saving”, each 10 Watts power consumed by electric rice cookers, with an average 1.5 hours per day, 300 days each year, and one year later, the energy conservation in China will be more than 5,000 million kWh [5]. Therefore, a LCA study of the electric rice cooker will also be socially relevant.

This paper is structured as follows: Section 2 provides a brief introduction of the electric rice cooker which is adopted as the research object in this paper. Section 3 presents the proposed approach for LCA generation. The goad and scope definition, allocation and scenario, and data acquirement method are also presented in this section. The final LCA results and analysis are presented in Section 4. Based on the outcome in previous section, some ecodesign suggestions are provided in Section 5. Finally, closing thoughts and perspective are presented in Section 6.

2. PRODUCT INFORMATION AND MANUFACTURING PROCESS DESCRIPTION

2.1 Product details

The electric rice cooker basically consists of five parts (Figure 1), namely, lid, inner pot, outer pot, heating plate and cable. There are also two accessories, measuring cup and rice spatula, see Figure1. On the outer pot, handle is set for taking cooked rice, the “cook” light and “warm” light shows that whether the cooker is cooking or warming.

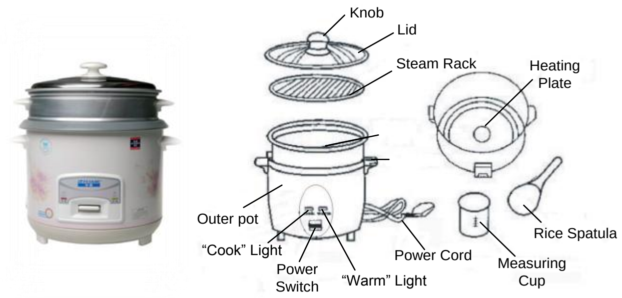

Figure 1 - Electric rice cooker component [6]

In this study, a certain brand of the electric rice cooker was not chosen, but a common structure was taken into consideration as most of the basic electric rice cookers are similar in functionality and operation. Assumed that the electric rice cooker is used for a family of three or four, then a 500Watts electric rice cooker is enough, and the rated capacity is 3.0Lit, which can cook about 0.9Kg rice at one time. The electric rice cooker is around 30cm high and weights average 2.265Kg including packaging box. The mass production is assumed to take place in the Chinese province of Guangdong. Table 1 summarizes the key components and materials used in the electric rice cooker in the study.

Table 1 Key Components and material used in the electric rice cooker in this study [3]

Component	Weight[Kg]	Material
Lid	0.115	Stainless steel/Plastic
Steam Rack	0.105	Fiberglass PP
Inner Pot	0.34	Aluminum alloy/PFA(Teflon)
Outer Pot	0.715	PA-66/Steel
Heat Plate	0.42	Aluminum alloy
Power Cord (110cm)	0.135	Cu/PVC/PBT/PB
Measuring Cup	0.02	PP55
Rice Spatula	0.02	PP55
Packing Box	0.315	Carton board
Others*	0.08	PP/ Quality carbon steel / Magnetic material
Total	2.265	
*: e.g. Knob, handle, spring, and magnet.		

2.2 Manufacturing process

Understanding the whole production process of the electric rice cooker can provide us a pre-knowledge and solid basis for the later life cycle assessment. From the process, we can know what kind of materials, what process and what kind of transportation the electric rice cooker uses so that we can input the required data information into the LCA generator. A simplified process flow chart for manufacturing of pot and assembly the electric rice cooker is shown in Figure 2. Workers first process aluminum billet into aluminum disks which will be stamped to form the exterior pot for the electric rice cooker. Then, press the aluminum disk into the form for the cooker's outer pot. After metal punching, chrome plating or spray decoration procedure follows in order to shiny or decorate the exterior of outer pot. The inner pot is made from higher grade aluminum and coated with Teflon for a non-stick surface.

The cooker's heating element is die cast on site from lower grade aluminum alloy. After all the parts are manufactured, the electric rice cookers are then partially assembled. Following assembly, each electric rice cooker is tested for quality assurance prior to packaging. Legs are screwed into the bottom of the electric rice cooker before the final packaging. And in the end, the electric rice cookers are packaged and then transported to the destination [7].

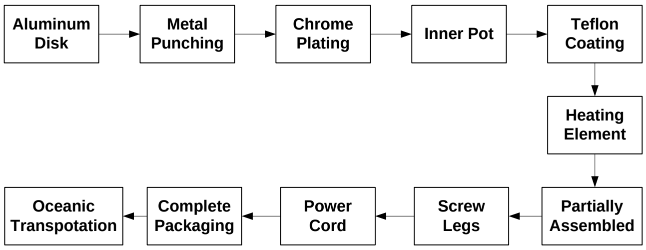

Figure 2 - Electric rice cooker pot manufacturing, assembly and packaging process

3. LCA STUDY

3.1 Goal & scope definition

LCA research is meaningful and has many advantages in the product development, especially, “the outputs of a LCA study can give the product designers guidance to improve the environmental performance of a product, and to help a decision-maker establish short-term goals as well as long-term goals for the improvement.”[8]

So, the goal of this study is going to conduct a integrated LCA to investigate the direct or indirect environmental performance, identify hot spots in relation to an electric rice cooker for improving environmental performance, and then try to suggest ecodesign measures to the manufacturers so that could reduce environmental costs of consumption and wastes when produce this product.

The scope of the study is thus a traditional LCA from cradle to grave, i.e. from the extraction of the various resources used in the production of such an electric rice cooker to the final dismantling and recycling or disposal activities at the end of the life time of such a product.

The life cycle impact assessment (LCIA) of electric rice cooker here therefore provided an accurate description of processes and procedures of electric rice cooker production that can be considered as a basis for future evaluations of the life cycle of household appliance products in a broader sense.

3.1.1 Function and function unit

A 500 Watts electric rice cooker was chosen as a product in the LCA study because this type is about 7-cup capacity and suitable for a family of 3 or 4, thus is the most popular one in the market. The function unit was defined as “The complete life cycle of a 500 Watts electric rice cooker; produced in China, used during 5 years, 2.5h/day”. Although the technical life time of an electric rice cooker maybe longer than five years, most family prefer to change a new one after a long time use. So, five-year is a reasonable life time for our study.

3.1.2 Product system and system boundary

The whole processes of the electric rice cooker system, from cradle to grave, are included in the final inventory calculation, e.g., production and transportation of the raw materials, manufacture and transportation of the components, electric rice cooker assembly, production distribution/transportation, use phase/maintenance/repair and waste management. Figure 3 shows the LCA process boundary of the electric rice cooker.

In addition, all the tools, service medium and other product used in the life cycle of electric rice cooker are investigated in the LCA. However, the non energy consumption tools, especially the tools for assembling and disassembling such as wrench, screwdriver etc. will not be calculated in the system boundary.

3.2 Allocation and scenario

In the practical manufacturing, it is rarely that there is only one material input and only one product output in the production process. Most of the component manufacturing process is multi-output process. So, allocation problems occur. The primary disposal method for household appliance including electric rice cooker is recycling, and mainly is the open-loop recycling, which means that the recycling of a product is used as the materials for other product manufacturing. Therefore, the study basically focuses on the allocation on the open-loop recycling.

In this specific study, the “cutoff” method was applied [9]. By the way of this method, each product is assigned only the burdens directly caused by the product. As a consequence, raw material product and waste disposal are allocated to those products actually linked to these processes, whereas recycling is allocated to the downstream product. This is the simplest allocation method since no data from outside the investigated product’s life cycle is required.

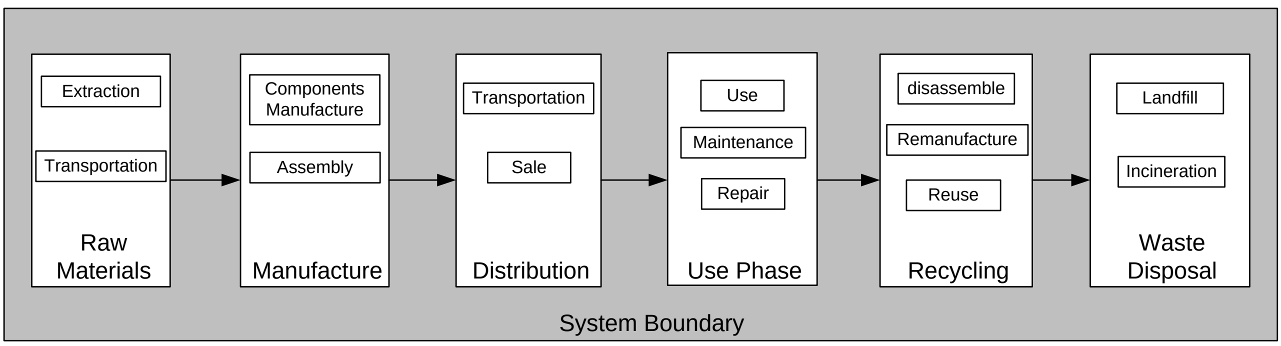

Figure 3 - LCA process boundary of the electric rice cooker

3.3 Data sources and gaps

Due to product complexity and some uncertainty, including the confidentiality and the complete lack of the first hand materials from the companies producing this type of electric rice cooker, the detailed information of the main data is hard to collect. Therefore, there are some data gaps in the study, especially the data in the production process stages.

To facilitate the data collection and the process of LCA, the life cycle system is divided into two systems – background system and foreground system [9]. A detailed system classification is shown in Figure 4.

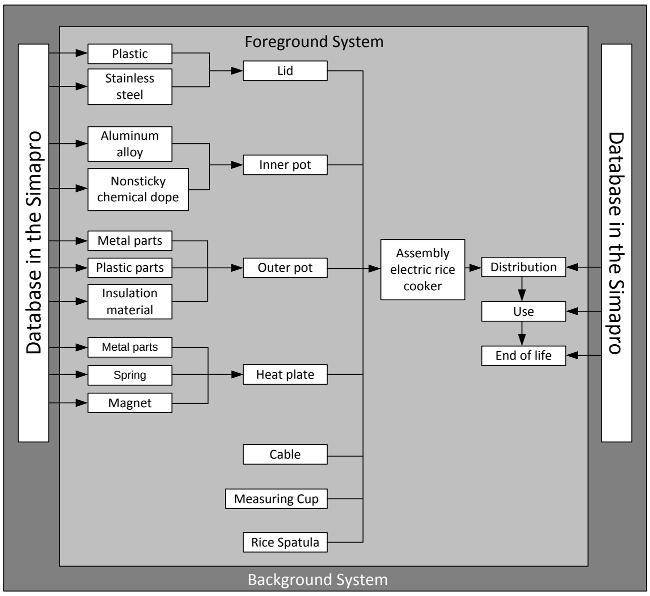

Figure 4 - System divided into background and foreground system [12]

The raw material extraction, the material production, and the energy production systems are defined as the background system. And all the databases used in background systems are included in the SimaPro7.2 [10] software which is adopted in this study, e.g., eco-invent v2, US LCI database, industry data etc [11]. Process of components manufacturing, assembly, transportation, and process within the company or factory are defined as the foreground system. As to the data for this system, information from various international patents, internet recourse and relevant literatures are chosen in order to further detail the composition of this electric rice cooker. Waste management is also defined as foreground system. The treatment to the end-of-life of the electric rice cooker is firstly separate it into large assemblies such as the lid, heat plate, inner pot, housing, measuring cup, rice spatula, power cord manually, and then to be recycled. The paper board and expanded polystyrene in the packaging material are usually recycled as well. Other components such as the electrical cable, LED lamps etc. are incinerated or land filled.

3.4 Life cycle assessment methodology

In the study, as for the impact assessment, Eco-indicator 99, the well known Dutch LCIA methods were used. It primarily take the following types of environment impact into consideration: Acidification/Eutrophication, Eco-toxicity, Land use, Carcinogens, Climate change, Radiation, Ozone layer, Resp. organics/inorganic, Fossil fuels, Minerals. The environment damage related to those impacts is categorized as three types: Human Health, Ecosystem quality and Resources [12]. Those environment impacts are directly calculated in the Simapro 7.2 based on the mathematical model imbedded in the software. The mathematical model is dominated by certain parameters, such as weight of the product, capacity of use, energy consumption and materials, in different process stage in Figure 3. Assuming that one electric rice cooker has *n* number of parts that are processed through *m* different processes. Then, each part *i* may bring some environment impacts at each process stage *j*, which can be expressed as the follows:

$$Env_{ij} \propto f_j\left(W_i, U_i, E_i, M_i\right),\ i = 1, 2...n \text{ and } j = 1, 2...m$$

where *Env* means the environment impacts; *W, U, E, M* denote the weight of the part that is processed in a particular process, capacity of use, form of energy and materials, respectively. A simplified energy and carbon weight relationship for different process stages of a general product life-cycle can be found in [13].

Furthermore, the parameters may be interrelated in many of the process stages. Therefore, in SimaPro 7.2 a linear relationship is utilized. Environmental impact data is incorporated for each process type based on a functional unit, e.g. 1kg of a particular material processed. In order to compute the environmental impact of particular process, the environmental impact data is appropriately multiplied by the ratio of mass of the material processes to the functional unit used in incorporating the data in Simapro 7.2.

4. LCIA RESULTS

In the detailed analysis of the electric rice cooker LCA by using the Simapro 7.2, the electric rice cooker was divided into five parts due to the maximum limit to the subassembly in the demo version. And we also assume that the electric rice cooker is shipped from Guangdong province of China to west coast of United States by oceanic shipping. So the distance is about 15000 Km [14]. In addition, as discussed above, most of the electric rice cookers will be recycled except some small parts, such as the electrical cable used in the heating system, the LED lamps and so on. Therefore, we assume that 95% materials of the electric rice cooker will be recycled and 5% will be sent to disposal. After setting all the initial calculation conditions, we can figure out the whole inventory and assess the life cycle of the electric rice cooker by Simapro 7.2. The following are the detail result of my analysis.

In Table 2, the detail information of the 11 impact categories was obtained. It is clearly shown that the use phase account for a large proportion in the whole 11 impact categories since the five-year tenure of use. The information from Table 2 tells that in all the 11 impact categories, the scores of the disposal are all negative value except the ecotoxicity impact, which means that most of these impacts are beneficial to the environment.

Figure 5 shows the result of the whole life cycle of the electric rice cooker after the characterization and weighting calculation of the 11 environment impacts

Table 2 Scores of each phase in the 11 impact categories

Impact category	Unit	Total	Electric Rice Cooker	Electricity, at grid, US/US	Disposal_Electric Rice Cooker
Total	Pt	69.4	1.21	68.7	-0.499
Carcinogens	Pt	0.989	0.616	0.413	-0.0399
Resp. organics	Pt	0.0558	0.000146	0.0557	-7.03E-05
Resp. inorganics	Pt	30.8	0.176	30.8	-0.187
Climate change	Pt	9.65	0.0512	9.64	-0.0436
Radiation	Pt	-0.000501	0.000807	0	-0.00131
Ozone layer	Pt	4.83E-6	1.69E-05	5.69E-07	-1.27E-05
Ecotoxicity	Pt	0.311	0.0121	0.255	0.0439
Acidification	Pt	2.96	0.0158	2.95	-0.00862
Land use	Pt	-0.00179	0.003	0	-0.00478
Minerals	Pt	-0.0384	0.0507	0	-0.0891
Fossil fuels	Pt	24.7	0.281	24.5	-0.168

indicator based on the assessment methodology—Ecoindicatior-99. In Figure5, in each phases of the life cycle, the impact to Resp. inorganic is most significant, and next is the consumption of the fossil fuels and the impact to climate change.

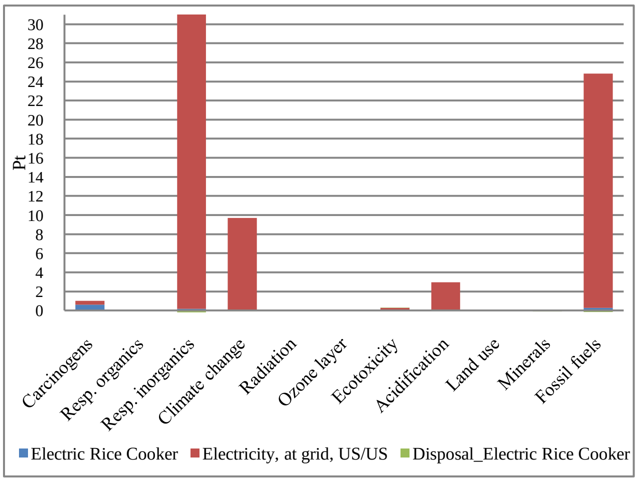

Figure 5 - Bar chart of the 11 environment impacts category

Figure 6 shows the result after the combination of the 11 categories into three main environment impacts—human health, ecosystem quality and resources. It can be seen that the impact of the life cycle of the electric rice cooker to the human health is greatest, and the resources follows.

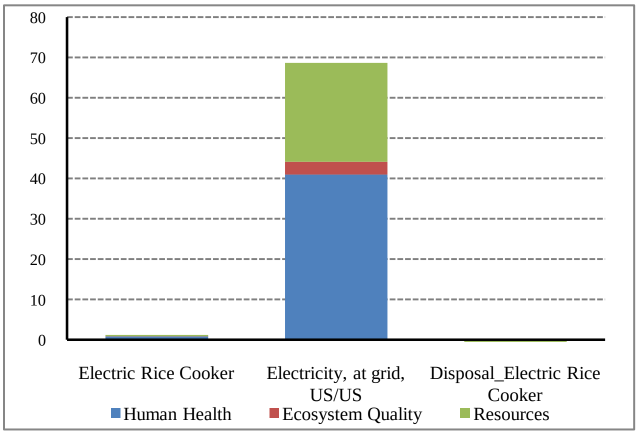

Figure 6 - Three main environmental impacts

It is convenience to acquire the environmental impact assessment result of the each phases of the life cycle of the electric rice cooker. Figure 7 is namely the result of the environmental impact assessment in produce phase. In the picture, it shows that in the aspect of carcinogen, the power cord and outer port make a great contribution, and the heat plate is in the third place. While in the fossil fuels aspect, the impact produced by outer pot and heat plate is much more.

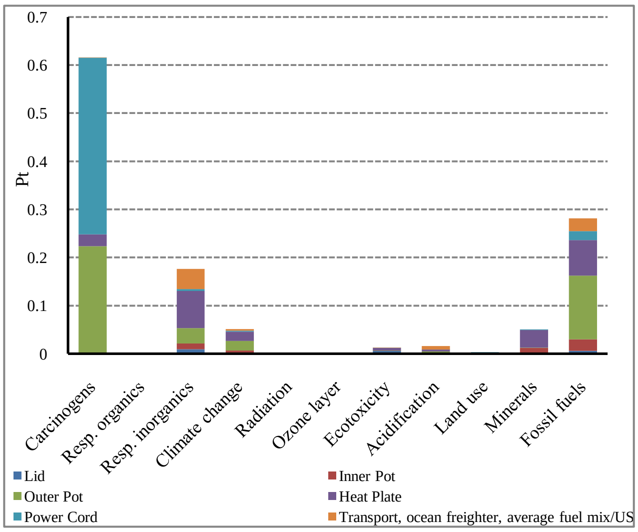

Figure 7 - Result of the environmental impact assessment in produce phase

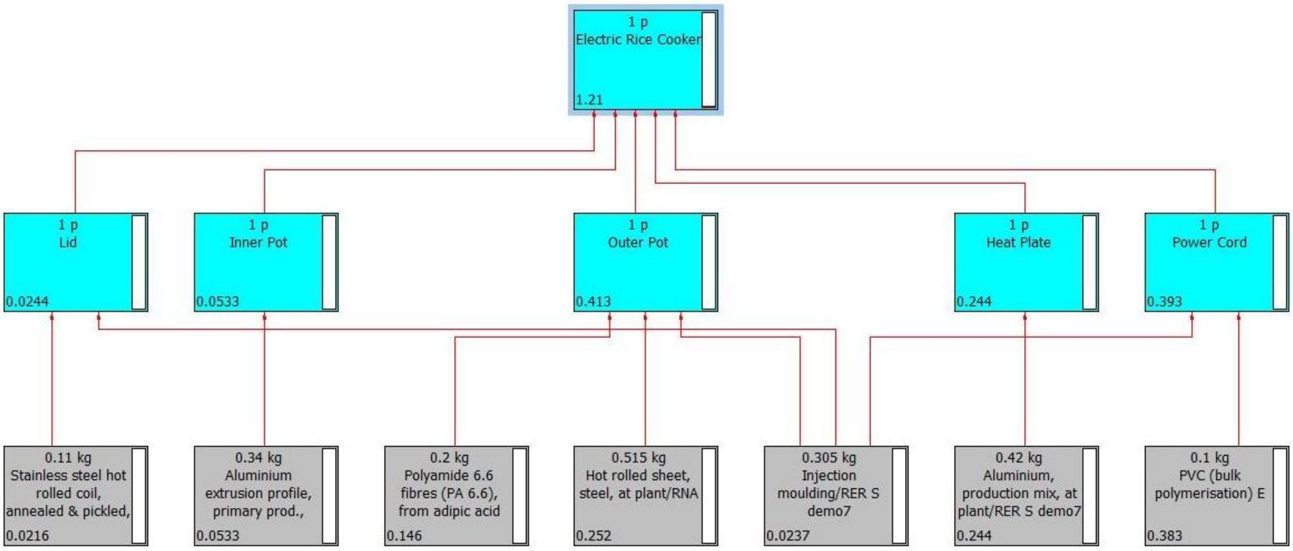

Figure 8 - Specific constitution of the environmental impact score in production or manufacturing phase created in Simapro 7.2 software.

In Figure 8, a specific constitution of the environmental impact score of the electric rice cooker in produce phase was shown. The total score of the produce phase of the electric rice cooker is 1.21 in which the score of outer pot is 0.413, and the score of power cord is 0.393. Based on such specific analysis, designers may conveniently recognize which subassembly is the most significant impact factor so that could make an improvement when design the product.

The "single score" function can be used as well to clearly describe each part's impact to the environment. As shown in Figure9, the Environmental impact is primarily generated by the outer pot, power cord and heat plate.

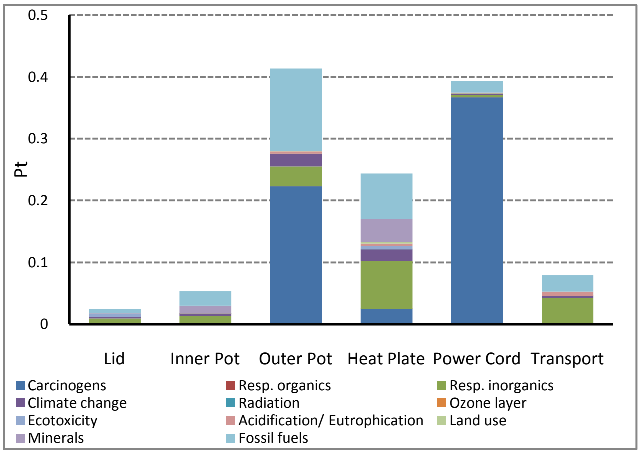

Figure 9 - single score of each component's impact to the environment

Besides all the analysis stated above, the proportion of the consumption of every material and energy in the environmental impact score in produce phase can also be acquired, as shown in Figure 10 Based on this analysis result, the designer can compare the different environmental impact produced by different materials, so that could facilitate the design method and then save the design time.

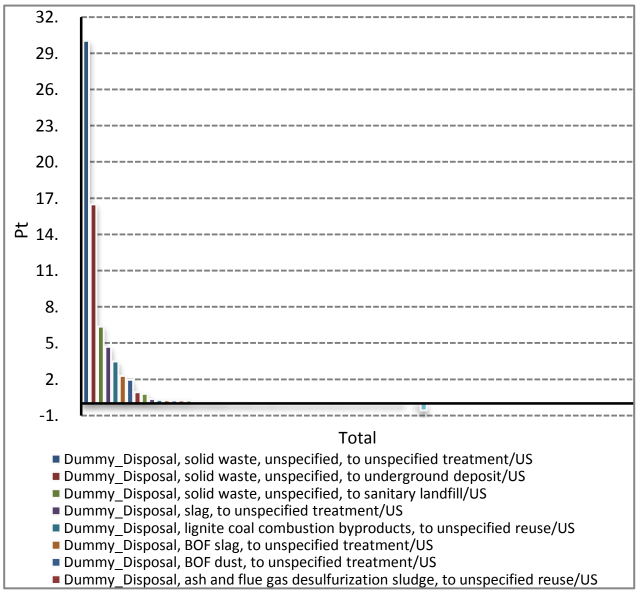

Figure 10 - The proportion of every material and energy consumption

Ecoindicator-99 scoring reflects the integrated environmental attribute of the electric rice cooker. This score provides a basis of reference for improving the environmental attribute of the electric rice cooker. Based on the Ecoindicator-99 environmental impact score of the product, we can then determine the main factor that impacts the environment, and can also know which material, which process or which phase make a great contribution to the environmental impact in the whole life cycle so that we can investigate different directions for the product's re-design.

5. ECODESIGN SUGGESTIONS

While carrying out the LCA study, as well as after the results were obtained, several ideas arose on how to improve the electric rice cooker from an environmental point of view. Since the use phase has large amount of impact to the environment, several refinements may help in reducing the environmental impacts without compromising other functions. These refinements include (a) resource efficient design and (b) modifying consumer use pattern. Resource efficient design may include greater energy efficiency, better heat capture, etc. Consumer use pattern can be modified to reduce environmental impacts by suggesting the consumers to turn off the power as soon as the rice cooker switches to warm mode and not to open the lid. This is because the temperature in the pot is still very high and can keep cooking the rice by using the excess heat of the heating plate.

In the production phase, the following measure should be taken. 1) Use recyclable plastics in the minor parts and hidden components, such as switcher, handle etc. 2) Reduce the number of different materials in packaging. 3) Avoid incompatible plastics during recycling in the packaging. 4) Minimize the volume of the heating plate on the premise of meeting the rated heating power. These suggestions should be further investigated by the design and manufacturing teams.

Distribution phase depends on the locations of the manufacturing plant and consumer base. Since modifications to manufacturing plant location require large investment, any suggested changes will have associated large investment. End-of-life phase will be able to provide a positive impact to the environment by use of recyclable materials and reusable parts.

6. CONCLUSION AND PERSPECTIVE

A LCA study was carried out on an electric rice cooker. The study covered complete cradle-to grave cycle. The result shows that:

1). the impact to Resp. inorganic is most significant, as shown in Figure 5;

2). and the next is the consumption of the fossil fuels and the impact to climate change, as shown in Figure 5;

3). the use phase has large impact on the environment out of different stage of the life-cycle of a rice cooker. This is due to electricity consumption during the five-years of use. This might also be due to the assumptions made in this paper regarding consumer usage of rice cooker;

4). the production phase has the second largest impact on the environment out of different stages of the life-cycle of a rice cooker. The impacts from this phase were dominated by the outer pot, power cord and heating plate - responsible for about 87% of the impact of this life stage. These numbers are subject to some uncertainty due to the assumptions regarding materials and process related data used in production of the rice cooker;

5). Last but not the least, in the end-of-life phase, substantial environmental benefits are attainable through a modern recycling system and waste management.

From the LCA results themselves, but also from the detailed product analysis that an LCA requires, several ecodesign measures were proposed to the manufacture. However, some of the advices should be further discussed with the engineer and designer to make sure the feasibility.

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