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Ecological and Health Risks in the Life Cycle of Notebook Computers: A Review

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Abstract

This study was conducted to synthesize the impacts on the environment and human health laptop usage. Research results show that the production and use of portable machines causes ozone depletion, global warming acidification, eutrophication, carcinogenicity, respiratory effects, ecological toxicity, and depletion of resources among many other impacts. Currently, notebook computers are very commonly used, Majority of users are not aware of the harmful effects of all processes related to notebook computers from the time of manufacture, use and disposal. Measures to handle notebook computers after disposal are ineffective, and pose many risks to the environment. Many recyclable and reusable materials have not been used effectively. Therefore, it is necessary to raise user awareness and strengthen the capacity of collection, treatment, reuse and recycling. From the research results, it shows the potential assessment and planning to develop an appropriate collection and treatment system to recycle the flow of harmful materials and e-waste found disused laptops. This becomes necessary in the context of resources being gradually depleted. The results provide important information for manufacturers, users and environmental managers to pay more attention to the effective use and management of notebook computers after use

1. Introduction

Life Cycle Assessment (LCA) is a commonly used method to addresses environmental issues and their potential impacts throughout the product's life from raw material extraction through production, to use and its end-of-life disposal processes.[1-3].

In the current period, laptops are widely used in daily life for study, work and entertainment. It is considered an electronic device that represents information and communication technology with a short innovation cycle and rapid development in both hardware and software [4]. However, electronic devices in general and laptops in particular have complex structures. The production process requires diverse material composition such as plastic, glass, aluminum, steel, copper, gold, silver, etc., some chemicals and they generally consumes a lot of energy [2,3, 5-7]

Moreover, frequent use of laptops without ensuring appropriate lighting and time duration also causes many harms to users' eyesight and sleep[8-9]. In addition, hazardous materials such as heavy metals and flame retardants arising from the disposal and end-of-life management of these devices pose risks to the ecosystem and human health [10-11]. From the impacts in each of these individual stages, this study was conducted to synthesize the environmental and health risks arising from laptops.

The research results provide important information for manufacturers, users and environmental managers to pay more attention to the effective use and management of notebook computers after use.

2. Materials & Methods

This research is carried out by the collection of secondary data from domestic and foreign documents and scientific articles on the impacts in each period of laptops. ScienceDirect and Google Scholar are the two main databases research uses to search and collect data. Some of the keywords used in the search are laptop, life cycle assessment of laptop, impact of laptop, laptop battery manufacturing process, laptop integrated circuit manufacturing process, impact of heavy metal, recycling laptop, impact of e-waste, circular economy for e-waste, etc.

After careful search and selection, the data is aggregated to determine the material composition as well as the ecological and human health risks in each stage of the laptop's life cycle.

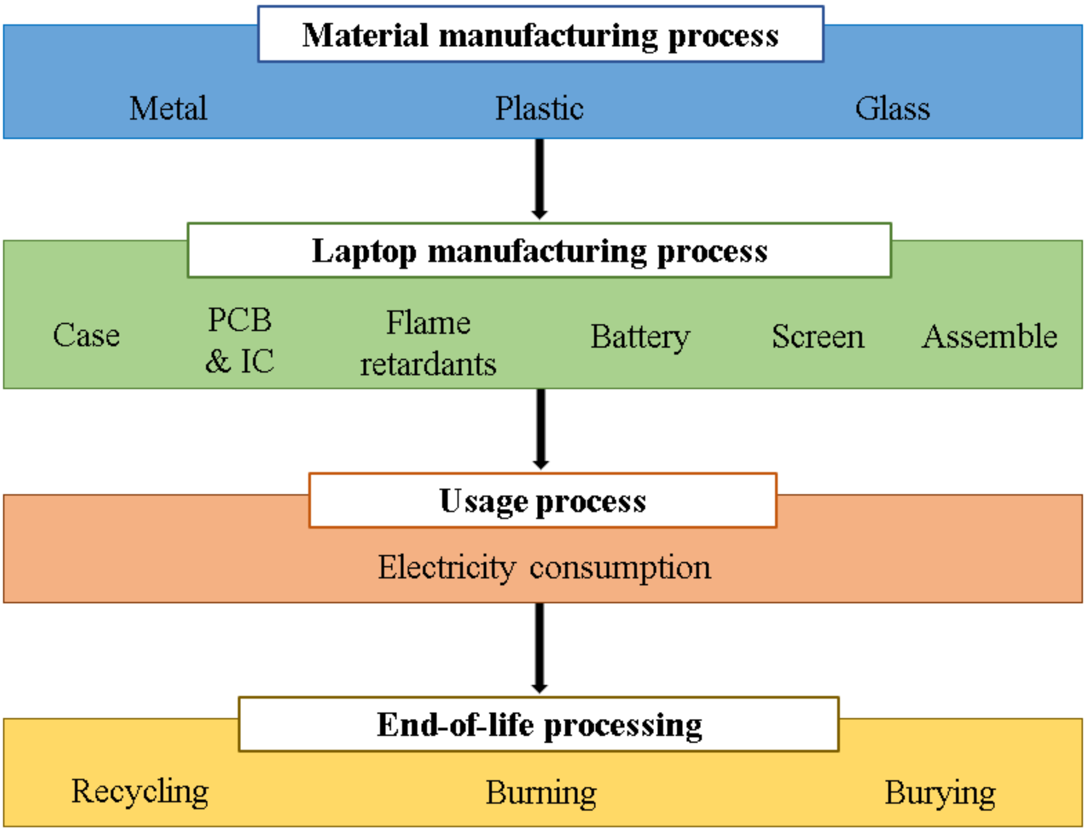

Figure 1. Stages in the laptop life cycle

3.0 Results and Discussions

3.1. Demand for materials used for laptop production

The impact of laptops arises in many stages, from production, transportation to waste disposal. In particular, the manufacturing process of notebook computers requires a variety of material requirements [12-14]. From plastic, glass, base metals such as copper, aluminum, steel, etc. to precious metals such as gold, silver, etc [2,3,5]. According to Andre et al.[15], gold, silver, palladium, platinum, indium, cadmium, lead, tantalum, tin, and copper are the metals with the most significant contributions to the impact on laptop metal resource usage.

In addition, Epoxy, Paladium, Neodymium, Nickel are also used to produce computer batteries. Details of the material composition variation of a typical laptop are presented in Table 1.

Table 1. Composition and weight of materials for the manufacture of notebook computers

Materials	**Material weight per laptop** (gam)	**Material ratio in each laptop (%)**
ABS	373	9.87
PC	406	10.74
Other plastics	343	9.08
Glass	300	7.94
Copper	270	7.15
Aluminum	512	13.55
Steel	871	23.05
Gold	0.36	9.53×10^{-3}
Silver	1.4	0.04
Epoxy	244	6.46
Paladi	0.06	1.59×10^{-3}
Nikel	0.99	0.03×10^{-3}
Zinc	0.1	2.65×10^{-3}
Neodymi	0.02	0.53×10^{-3}
Tin	9.3	0.25
Lead	6.1	0.16
Other	442	11.69
Total	**3.779**	

(Source: Deng *et al*., 2011)

3.2. Production stage

Manufacturing is a major contributor to the impact of a laptop's entire lifecycle, primarily on carbon emissions [5]. The LCA assessment for the Actina 244C10 notebook found that manufacturing (including extraction and processing of raw materials) contributed 37% of the total impact. Some of the major impacts are ecotoxicity, acidification/eutrophication, land use and impacts on mineral resources and fossil fuels [1,3]

In addition, the impact calculation results of the Dell Inspiron 2500 laptop manufacturing process also show that the total energy demand in the material production phase is 280 - 665 MJ and CO_2 emissions in this periodis 16 - 41 kg [2]. In particular, the energy used to mine and process precious metals is higher than that of other metals, especially gold. For Dell Inspiron 2500 laptop, the manufacturing phase ranks as the most critical with 62-70% contributing to total lifecycle impact.

In terms of production stages, integrated circuits (ICs) and liquid crystal displays (LCDs) are the components that contribute the most to the impact of the entire manufacturing process[13]. While Andre et al.[15] argues that the impacts on climate change and human toxicity are caused mainly by the manufacturing process of the case and printed circuit boards. And similar results were also observed in the study for HP laptop with a 14-inch screen [5]. In addition to the motherboard and screen, the battery is also one of the components that contribute to 95% of the carbon footprint of the laptop manufacturing process [16].

3.2.1. Producing laptop cases

Laptop cases are manufactured from a variety of materials, including fossil resins, aluminum, magnesium alloys and, more recently, biomaterials. Each type of material causes different impacts, typically carbon emissions and global warming potential [17]. In addition, there are a number of other effects such as smoke, acidification, eutrophication, carcinogenicity, respiratory effects, toxicity to the ecosystem and fossil fuel depletion. For the production of aluminum laptop cases, ecotoxicity has the highest impact score, followed by global warming potential and impact on fossil fuel depletion [11]

As for laptop cases manufactured from magnesium alloy, the casting process contributes greatly to climate change risks due to the use of perfluorinated compounds and SF_6. These studies suggest that in order to solve the problem of fossil fuel depletion, besides increasing the recycling efficiency to recover materials from the final product, the research and development of biomaterials also needs to be improved.

3.2.2. Manufacture of printed circuit boards and integrated circuits

In the production of notebook computers, the production stages of semiconductors, printed circuit boards and silicon microchips use a lot of energy [2,18]. A printed circuit board (PCB) is an electrical circuit board that uses a printing method to shape conductive circuits and component connection points on an insulating substrate. In particular, the semiconductor manufacturing process of a laptop uses a total energy of 247-405 MJ and emits 21-33 kg of CO_2. Lower emissions are silicon chip production with 5.3 kg CO_2/laptop[2]. As for printed circuit boards, the manufacturing process not only contributes to energy use and CO_2 emissions, but also has an impact on the use of precious metals. One of the precious metals used in the manufacture of microchips and connectors is gold. Despite its very small weight, it causes about 80% of toxic effects on humans and impacts on reserve resources. In addition, there are contributions of metals such as zinc, arsenic and chromium [15]

As an indispensable component in electronic devices,is the integrated circuits (ICs), which also has one of the highest global warming potentials of the manufacturing process. Moreover, the integrated circuit manufacturing process not only consumes large amounts of energy and materials, but also uses a wide range of chemicals and requires high purity gases. Typically, it takes 1.27 kWh of electricity and high purity substances such as N_2, H_2, O_2, H_2O_2, sulfuric acid, phosphoric acid to produce a mold with a size of 1 $cm^{2[}$ [19]. In particular, the gases generated from this process are extremely potent and long-lived greenhouse gases (Sulfur hexafluoride, Perfluoroethane, Tetrefluoroethane, Perfluorpropane). In which, the highest emission factor is Sulfur hexafluoride (SF_6), which is a gas with a very high global warming effect, approximately 22,000 times higher than the equivalent amount of CO_2. In addition, under conditions prolonged exposure to fire or heat, Trifluormethane has a very high risk of fire and explosion and can cause coma in high concentrations. As for the microchip manufacturing process, the biggest impact comes from the high use of energy [5]

3.2.3. Battery production

Batteries are the primary source of power for many types of electronic devices, including laptops. As the consumer electronics market is promoted, the demand for the production of this type of battery also increases. In there, lithium batteries are commonly used. The production of batteries puts a lot of pressure on natural resources, not only lithium but also other heavy metals such as lead, cadmium, copper, cobalt, nickel, etc. Besides, the process of metal exploration, mining and production is also a cause of environmental pollution [20]. Especially, after the battery is no longer in use, it will be disposed of in landfills. An estimated 90% of lithium batteries globally will end up in landfills [21]. Ending its life in landfills without being recovered, reused or recycled not only wastes large amounts of valuable materials, but also releases heavy metals into soil and groundwater. Most of the components in batteries are pollutants that can have a strong impact on the environment and human health due to the common feature of bioaccumulation [22].

However, each type of material will cause effects on many different parts of the body. Specifically, Lithium causes changes in the development of invertebrates, at the same time interferes with nucleic acid synthesis, and is highly toxic to plants due to its high accumulation in soil [23]. More seriously, the accumulation of Cadmium in the body can cause kidney diseases and even cancer [24-25]. In addition to causing cancer, lead metal causes cardiovascular disease and affects the nervous system, kidneys, and other organs[24-25]. Meanwhile, copper causes liver, stomach, and nerve damage [24]. In addition, nickel can disrupt ionic homeostasis and high oxidative stress in terrestrial plant and mammalian systems [26]

3.2.4. Production of flame retardants

In the composition of notebook computers, there are many different types of flame retardants such as APP, ATH, ATO, DecaBDE, DOPO, RDP, TBBPA, ZHS, ZS. However, there are three types of flame retardants with strong toxicity for ecology and humans, including DecaBDE (Decabromo diphenylether), TBBPA (Tetabromobisphenol A) and ATO (Antimony trioxide). The production process of all three types of flame retardants has an impact on the air and water environment. In particular, DecaBDE also affects the soil environment and causes higher toxicity to humans than other substances. While ATO and TBBPA are more toxic to freshwater, marine and terrestrial ecology [27]

3.2.5. Manufacturing and assembling LCD screens

The emissions generated from the LCD panel manufacturing process are mainly nitrous oxide, acid gas and fluoride gas (Liu et al., 2016). In which, the composition of fluoride gas includes BF_3, HF and NF_3 with the ratio 1:5:25. The research results performed on HP 14-inch screen laptops show that the proportion of fluoride emissions in the screen manufacturing process is 1.75E−6 kg, 8.6E −6 kg and 4.3E −5 kg, respectively. In addition, many studies have also demonstrated that LCD modules have the largest contribution to the carbon footprint of LCD panel production[28-29]

3.3. Usage period

As the results of the LCA studies conducted on laptops show that the usage stage and the production stage have a huge contribution to the total life cycle impact. In particular, the impact is caused mainly during the use phase from electricity consumption. They account for up to 60% of the total lifecycle impact of the Actina 244C10 [3] and between 30 and 38% of the total impact of the Dell Inspiron 2500 [2]. During its 2.9-year lifespan, the Dell Inspiron 2500 computer consumed 1,781 MJ of power and emitted 159 kg of CO_2. Besides electricity consumption and CO_2 emissions, the process of using laptops also causes negative impacts on users' health. According to Chang et al.[8], the use of light-emitting devices right before sleep affects the human circadian clock. Specifically, they will block the release of the hormone melatonin - a hormone that aids sleep, making it take longer for users to fall asleep, reducing feelings of sleepiness at night and reducing wakefulness in the next morning. Visual health effects caused by improper use [9]. It is very important to adjust the brightness down to an appropriate level for a low-light working environment to avoid creating a contrast in brightness between the screen and the surrounding working environment. At the same time, placing the light source as the screen close to the observer's eyes is also the cause of the symptoms of visual fatigue.

3.4. End-of-life processing

Although a type of hazardous waste, but the current situation of e-waste treatment in developing countries is still inadequate and poses many potential risks to the environment and public health. Most of the treatment of e-waste only focuses on material recovery without paying attention to the environmental impacts generated. The main processing stages are dismantling and separating to get base metals such as copper, lead, or plastic or aluminum casings. The treatment process is usually done manually in recycling craft villages, so the recovery efficiency is low and has no significant value compared to the total value contained in an electronic device. In addition, some parts of the computer in general contain hazardous materials such as flame retardants, tin-lead solder or even mercury. These substances, when leaked, not only pollute the environment but also increase the risk of cancer or, more seriously, cause death to those exposed [13]. The study by Thao et al.[30] has also recorded the accumulation of heavy metals As, Zn, Cu, Cr and Co in the hair and nails of elderly people who participate in collecting and storing e-waste recycling of craft villages. For the environment, the most prominent impact is the pollution of heavy metals Cr, Fe, Pb, Hg, Ni in soil and groundwater samples in the recycling area[6,30]. The release of dioxins, flame retardants and furans from the combustion of e-waste containing plastic materials and flame retardants were also found [27,31].

4. Conclusions

During its life cycle, laptops cause many environmental impacts such as ozone depletion, global warming potential, acidification, eutrophication, carcinogenicity, respiratory effects, ecological toxicity, resource depletion. Besides, it also effects on users' health such as vision impairment, sleep disturbances. The reality of dealing with this type of waste shows that we are wasting huge number of resources when only rudimentary manual treatments are applied to recover basic materials.

Therefore, it is necessary to evaluate the potential and plan to build an appropriate collection and treatment system to recycle the precious materials present in electronic waste in general and laptop computers in particular in the context of the current depletion of resources.

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