4.11 Personal Computer Life Cycle Assessment Study: The Case of Western Australia

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The alarming growth of the information and communication technology (ICT) during the last decade has increased the awareness of environmental impacts associated with the use of personal computers (PC).Energy and materials use and e-waste disposal during the life cycle of ICT products need to be assessed in order to minimize the environmental impacts of ICT devices, particularly personal computer. This research utilizes a life cycle assessment (LCA) tool to identify the process (or processes) or "hotspot(s)" requiring mitigation strategies. The LCA of the PC's takes into account all the stages from raw material extraction and production, manufacturing, transportation and use to disposal (cradle to grave). A desktop computer has been disassembled to develop a detailed life cycle inventory to carry out a LCA analysis. The LCA is constructed by SimaPro software version 7.3 and express with greenhouse gas and demand energy life cycle assessment method. The LCA shows that the use and manufacturing stages is the largest contributor to embodied energy and carbon footprint. In the manufacturing stage, LCA have been identified that the production of monitor is the greatest significantly in producing carbon footprint and embodied energy.

Keywords: personal computer; life cycle assessment; environmental impacts.

1 INTRODUCTION

The revolution of information and communication technology during the last decade has generated massive production, mass consumption and mass disposal of ICT devices, particularly the personal computer (PC) use in Western Australia and across the world. On the other hand, the public awareness of environmental impacts of the use of PC has increased. The disposal of e-waste is increasing not only because of fact that the product life cycle of PC is becoming shorter (3 years), but also due to the innovation of a wide variety of products, including model, size, and the high system level integration [20]. The manufacturing stage of the PC requires large amount natural resources, such as chemicals (e.g. nitric acid) and use stage consumes huge amount of electricity causing global warming. It is a crucial that e-waste is managed in an environmentally friendly manner (e.g. recycling, reducing). Otherwise, it will cause health hazard, such as cancer and respiratory problem [13]. This because PC contains some hazardous and valuable materials, brominates flame retardants, tin and lead such as printed circuit board (PCB) [15]. The Western Australian (WA) State Government has a policy of "Towards Zero Waste".

The existing waste management model of WA includes recycling, that only covers waste management at the end of the product's life, but it does not take into account the some important environmental impacts, such as global warming and embodied energy consumption associated with the raw material extraction, production, use and disposal of PC. The LCA of PC takes into account recycling and remanufacturing strategies during the life cycle stages. The LCA consist of stages including raw material extraction and production, manufacturing, transportation, use and the disposal/recycling of end of life (EoL) product. Most of studies find that the most common method to evaluate the environmental impacts is life cycle assessment (LCA). [7,10]. The LCA of PC product and monitor has been carried out since 1990 [1,8,13]. In addition, LCA has been applied to determine the environmental impacts associated with other ICT devices, e.g. mobile telephone. The LCA of PC is more important than the LCAs of other electronic products because it has the shortest life span compared to other devices, (e.g. TV life time 7-10 years) [16].In addition, PC contains some additional rare earth materials, such as, gold, lead, and mercury, which are finite and limited and produces hazardous waste. Nevertheless, the literature so far reviewed did not carry out the LCA analysis of PC for assessing the environmental impacts of electronic products in Western Australia, but this research mainly focuses on two major environmental impacts: global warming and embodied energy, which are important for Western Australian context.

Then, the paper determines the "hotspots" causing the most environmental emissions. Finally, cleaner production strategies have been applied to restructure the PC supply chain resulting reduced global warming impact and embodied energy consumption.

2 METHODOLOGY

Life Cycle Assessment (LCA) has been used to evaluate the environmental impacts throughout the life cycle of PC. The LCA follows ISO 14040 guidelines [8], which consist of following steps: i) goal/scope, ii) life cycle inventory, iii) life cycle impact assessment, and iv) interpretation. Once the hotspots have been identified, cleaner production strategies, such as modification product, substitution of input products, and modification technology, will be applied to reduce the life cycle environmental impact [18].

2.1 Goal and Scope

The goal of this LCA is to reduce the environmental impact of PC in Western Australia using cleaner production strategies.The functional unit is to determine the global warming and embodied energy consumption of the disposal of PC which in fact determine the system boundary. The system boundary of

PC takes into account the global warming the entire life cycle of PC including raw material extraction and production, manufacturing (e.g. assembly), distribution and transportation (from production site to end user), use (functional life span), and end of life recovery (e.g. reuse, recycle and disposal operation).

2.2 Life Cycle Inventory

Life cycle inventory is based on the estimation of materials content in three main of components: control processor unit (CPU), monitor and keyboard with life span is assumed of 5 years.

Raw material extraction and production : The amount of materials required to produce a PC was measured by disassembling a PC , which was collected from the Curtin University's information technology department and the energy consumption for producing PC was sourced from journals, annual report from published by international institutions, such as USEPA and UNEPA [1,5,9,12,15,17,19]. The percentage distribution of materials content for computer components was obtained from different sources [1,5,9,12,15,17,19] to carry out a mass balance. Table 1 show the raw materials which is used to produce each component parts of PC's.

Table 1.Raw material of Typical Personal Computer

Raw materials	Mass (Kg)	%
E-glass	0.43	1.54
Epoxy	0.31	1.12
TBBPA	0.36	1.30
Cooper/cu	1.09	3.98
Aluminium	1.04	3.77
Iron	0.28	1.02
ABS	3.87	14.01
Steel	8.97	32.47
PVC	0.24	0.87
Ferrite	0.40	1.43
Zinc	0.06	0.22
Sodium	1.05	3.86
Calcium	0.23	0.83
Lead	1.08	3.93
Chromium	1E-03	0.001
Silver	1E-03	0.003
Gold	1E-03	0.002
Kaolin	0.58	2.12
Magnesium	0.06	0.23
Titanium/ti	0.03	0.1
zirconium/zr	0.07	0.24
antimony/sb	0.04	0.13
Yttrium	1.4E-03	0.01
Nickel	0.06	0.21
Silica	5.18	18.77
Beryllium/Be	1.6E-05	5.9E-05
Palladium/Pd	2.1E-05	7.4E-05
Silicon	0.42	1.53
Strontium	0.49	1.76
Potassium	0.70	2.55
Barium	0.49	1.79
Borosilicate glass	0.05	0.17
Cadmium	8.2E-07	2.9E-06
Sum	27.62	

Manufacturing Stage: Table 2 show energy consumption by different processes of PC manufacturing, which were source from different literatures [3,4,7,11,12,16].

Table 2.Energy consumption by manufacturing process of PC

Manufacturing Processes	Energy Intensity (MJ/Kg)
Injection Molding	19
Drilling (Milling)	1.3-2.6
Machining	5.3-7.5
Die Casting	14.9
Iron Casting	19-29
Galvanizing	29
Winding Wire	142
Al Casting	55
CRT manufacturing	3.169 MJ/cm2
Assembly PC	340

Distribution and Transportation: The emissions associated with the different modes of transportation from manufacturer to the computer shop in WA were taken into account. A PC was assembled in Malaysia and was then shipped to Perth, when the nautical distance between Malaysia and Perth is 4000 km. The PC was delivered to the local distributor by a 28 tonne truck, when the average distance travelled between these two points was 35 km. Finally, the PC was sent to the end user, Curtin University, located 30 km away from distributor. For each mode of transportation, tkm (tonne x km travelled) was calculated, for example, 0.02762 tonne * 4000 km = 110tonne*km) as emission factor for transportation is based on tkm, which are available in LCA software.

Consumer Use: As PC is mostly used by the business sector (65 %) [2], the PC use has been considered in this business sector. The lifetime of the PC has been considered as 5 year for the business sector. It is assumed that it operates 8 hours/day and 5 days a week. The power consumptions of a monitor and the control unit that include the keyboard are 104.5 W and 39.1 W respectively [21]. Using this information, the power consumption during use stage of PC in the business sector has been estimated to be 1.38MWh.

Disposal or End of Life: About 65 % of the end of life PC goes to land fill, 22 % goes for incineration and 15 % is recycled [1,5]. In order to reduce the impact of end of life PC's, this study has developed an environmentally scenario to reduce the disposal of PC. Some typical scenarios are; reuse, recycling, remanufacturing/refurbishment, and reducing/repair

2.2 Life cycle impact

This study uses greenhouse protocol method and cumulative energy demand method to assess the life cycle environmental impacts and embodied energy [14]. The inputs from the inventories are linked to relevant emission databases in the simapro 7.3 software to calculate the associated environmental inputs of a PC. Finally, life cycle assessment has been used to carry out the environmental impact. Then it assessed the carbon footprint and embodied energy to find the 'hotspots" for the environmental improvement.

3 RESULT AND DISCUSSION

The carbon footprint and embodied energy consumption have been determined by using LCA analysis then 'hotspots" have been determined to apply cleaner production (CP). .

3.1 Embodied Energy

The raw material extraction and production, manufacturing stage, transportation and distribution, use stage contributes and end of life (E-O-L) consume 4534 MJ (21.8 %), 7889 MJ (38.1%), 45 MJ (0.2154 %), 8237 MJ (39.7 %) and 37 MJ (0.18 %) respectively (Table 3). The use and manufacturing stages consume the largest portion (39.7 % and 38.1 %) of the total energy. Therefore, the inputs used in the manufacturing stage have been investigated in order to determine the "hotspots" for applying CP strategies.

Table 3. Embodied Energy of life cycle PC

Life cycle of PC	Embodied Energy (MJ)	Carbon Factor (KgCO2eq)
Raw material Extraction	4534 (21.8 %)	829.85 (27.5 %)
Manufacturing	7889 (38.1 %)	975.6 (32.33 %)
Transportation	45 (0.22 %)	2.82 (0.09 %)
Use	8237 (39.7 %)	1207.32 (40 %)
EoL	37 (0.18 %)	2.16 (0.07 %)

3.2 Carbon footprint

The carbon footprint of raw material extraction and production, manufacturing, transportation and distribution, use and end of life stages generate 829.9 $KgCO_2$ (27 %), 975.6 $KgCO_2$ (32.33 %), 2.8 $KgCO_2$ (40 %) and 2.2 $KgCO_2$ (0.07 %) respectively (Table 3). Similar to the embodied energy analysis, the use and manufacturing stages have been identified as hotspots, contributing the most of the GHG emissions. Then, use of energy intensity inputs, such as steel production, electricity use, may be some possible causes of these impacts.

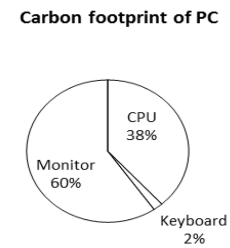


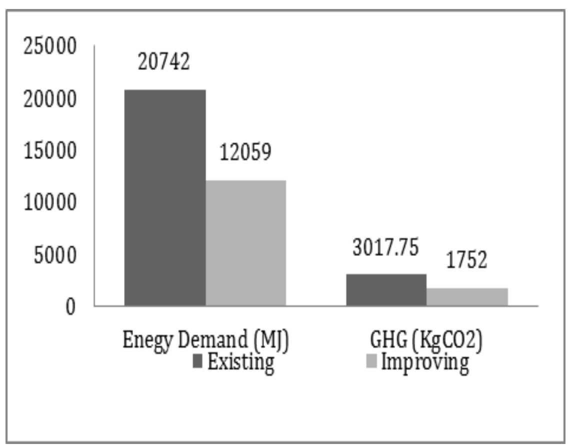
Figure1. Carbon footprint for PC main component

The breakdown of carbon footprints of PC manufacturing in term components has been presented in Figure 1.The manufacturing of monitor, CPU and keyboard produce 60%, 38% and 2% of the total GHC emissions from the manufacturing stage. Therefore, the production of monitor/display has been regarded as "hotspot" during the life cycle of PC.

4 CLEANER PRODUCTION OPTION

In order to reduce the carbon footprint and embodied energy of PC, following cleaner production strategies have been applied to treat the "hotspot"

a) Product modification: modification size of CPU and monitor could reduce both of energy consumption and GHG by 50 %. [5]
b) Input substitution: replacement of CRT monitor with LCD can reduce the GHG emission by 14 % and energy use by 86 % [15]
c) Recycle on site: replacing steel with plastic for producing CPU housing can reduce GHG emission and energy demand by 30 %. [5]



By implementing these CP options, energy demand and carbon footprint can be reduced by 42 % (e.g. from 20,742 MJ to be 12,059 MJ) and carbon footprint can be reduced by 40 % (i.e. From 3017.75 $KgCO_2$ to be 1752 $KgCO_2$) (fig.2)

5 SUMMARY

An LCA has been carried out to assess the environmental impacts of PC. The inputs causing the major global warming impact are raw materials production (e.g. steel and glass) and excessive use of electricity during the life cycle of PC. The use and manufacturing stages have the highest embodied energy consumption and GHG emission. Then, the hotspots identified can be reduced by implementing CP strategies which are product modification, input substitution, and recycled. About 40 % of GHG and 42 % embodied energy can be reduced by applying the CP strategies.

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