

An Investigation into Evaluating Laptop Computers using The Triple Bottom Line (Environmental)

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APSC 262

May 09, 2014

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April 10th, 2014

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ABSTRACT

Laptop computer is essential in the university among students and staff members; however, there is little information provided on the economic, environmental, and social assessments when it comes to purchasing laptop computers. This report investigates the analysis of environmental impacts on the laptop computers in order to select the environmentally friendly technology. The environmental impacts are analyzed by looking into the manufacturing process, energy consumption of laptop, and the disposal of the laptop computers. This report makes an thorough examination of laptop's energy consumption in use, the manufacturing phases, and the necessity and benefit of recycling laptops. In addition, a survey is completed to investigate the reason of purchasing a new laptop and the average lifespan of a laptop. Advantages and disadvantages of the individual brands are illustrated, and will follow with a recommendation into the selection of laptops in terms of its environmental aspect.

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LIST OF ABBREVIATIONS

BFR: Brominated Flame Retardant

HP: Hewlett Packard

IO: Input-Output

LCD: Liquid Crystal Display

PCB: Prototype Circuit Board

PVC: Polyvinyl Chloride

SWICO: Swiss Economic Association for the Suppliers of Information, Communication and Organizational Technology

WEEE Directive: Waste Electrical and Electronic Equipment Directive

1.0 INTRODUCTION

A laptop computer that is also known as notebook is a portable computer that is widely used by UBC faculty, staffs, and students for several of purposes. UBC staffs are interested in upgrading their laptops to a greener and more environmentally friendly technology. The method to analyze the laptop computers is using the triple bottom line. The triple bottom line is an analysis that consists of economic, social, and environmental aspects. The triple bottom line analysis will help the stakeholders or UBC staffs to have better purchase information about laptop. As other teams analyze economic and social aspect, this report specifically evaluates laptop focusing based on the environment aspect.

In detail, the report evaluates environment aspect of laptop by understanding recyclable components, energy consumption and emissions, environmental impacts of laptop disposal, and the renewability of the laptop. To achieve these objectives, the report only focuses on four brands that are most popular: Apple, Dell, HP, and Lenovo.

2.0 BACKGROUND

The idea of creating sustainable electronics is currently promoted worldwide; industries compete in producing greener technologies in order to gain users' interests. The initiative to evaluate computers based on its energy consumption and recycling magnitude began in the 1990s, where Europe established SWICO as an electronic equipment and informatics recycling organization. Then, the European Union also implemented its' own system known as the WEEE Directive. These organizations serve to collect office, communications, and graphics industry technology. In the United States, the National Computer Recycling Act was introduced by the Congressman Mike Thompson, and laws regarding battery disposal was also presented. On top of these federal legislations, there are also state regulated systems that relate to electronic recycling, such as the Arkansas Computer and Electronic Solid Waste Management Act. However, even under the supervision of these legislatures, businesses and households often neglect the proper disposal instructions and directly rid of their electronic wastes by melting and crushing the components.

As sustainable projects continue to progress, renewability was then introduced into the theory of green laptops. Battery consumption plays a key role in this aspect. Although the common lithium ion battery is being experimented and renewed to provide even longer battery life, there are new theories about capacitor batteries, which require a shorter charge period, and provide a much longer usage time. These types of experiments are the hope to reduce battery disposal and carbon dioxide emissions in the future.

The University of British Columbia continues to research on the methods of choosing laptops based on student's needs and the environmental standards. Its effort to promote aspects of sustainability through assigning research tasks for students is effective.

Engineers, who focus upon developing technology and augmented reality, have the voice to influence others through detailed research regarding laptop studies. In doing so, a stronger awareness for choosing laptops is raised.

3.0 RECYCLABLE COMPONENTS

3.1 Comparing Recyclable Materials

With 20 to 50 million tons of electronic landfill contributed per year, laptop recycling is essential in order to continue the production of mobilized computers. In the four types of laptops evaluated in this report, Apple has shown the most sustainable nature in creating toxic-free components and offering deals to encourage recycling. For example, apples products do not contain lead, BFR, PVC, or mercury, whereas Hewlett Packard continues to use mercury to create most of their LCD monitors. Lenovo laptops use the traditional methods to produce most of their components, while making less emphasis on the environmental aspect. To provide a detailed analysis of the material assessment, a table was made to summarize the result of findings. The components of evaluated laptops at the University of British Columbia mainly consist of the following materials:

	Apple	Hewlett Packard (HP)	Dell	Lenovo
Motherboard	<ul style="list-style-type: none"> - Copper - Barium - Aluminum Oxide resistors - Polymer capacitors 	<ul style="list-style-type: none"> - Copper - Ceramic capacitors - Tin - silver 	<ul style="list-style-type: none"> - Copper - Lead - silver 	<ul style="list-style-type: none"> - Copper - Lead - silver
Battery	<ul style="list-style-type: none"> - Nickel 	<ul style="list-style-type: none"> - Nickel 	<ul style="list-style-type: none"> - Nickel 	<ul style="list-style-type: none"> - Nickel
LCD Monitor	<ul style="list-style-type: none"> - 	<ul style="list-style-type: none"> - Mercury 	<ul style="list-style-type: none"> - Mercury 	<ul style="list-style-type: none"> - Mercury
Chassis	<ul style="list-style-type: none"> - Re-polymerized plastic bottles - Aluminum 	<ul style="list-style-type: none"> - Aluminum - 	<ul style="list-style-type: none"> - Aluminum - Lead 	

Figure 1. Contrasts between Materials in Evaluated Laptops

3.2 Methods of Recycling

There are a variety of ways to recycle laptops, here are the most commonly practiced methods:

Consumer Recycling

This method of recycling is fairly straight forward; it usually involves sending the components or computers directly to the manufactures, or providing the laptops to organizations in demand.

Business Recycling

Since businesses need to be extremely careful to avoid data leakage, the recycling process is much more sophisticated. Often, corporates may contact the origin of their manufacture to discuss recycling options. A favored option is to have the database wiped clean, and then making an estimate of the remaining values of the leftover components. These remaining components may include hardware, which can be refurbished and sold to those who do not seek to purchase new laptops.

Exchange and Replacement

Many of the laptop producers are very willing to receive recycled products. For instance, Apple achieves a 90 percent recovery rate by the weight of the original products sold. Hewlett Packard also owns the largest computer recycler in America, who will accept laptops of any brand and provides benefits to those who recycle.

Individual Recycling

Recycling based on one's own sorting may require some technical knowledge on the components of the laptop. However, this can contribute to the user's knowledge on selecting laptops. Materials such as copper, aluminum, and lead are fully recyclable and welcomed at scrap recycling plants.

4.0 ENERGY CONSUMPTION AND EMISSIONS

4.1 Energy Consumption in Manufacturing Phase

The energy consumption associated with laptop manufacturing is tremendous. A related research shows that a two gram memory chip consumes at least 630 times its weight fossil fuels during manufacturing. The ratio of fossil fuel consumed in manufacturing to the weight of laptop is about eleven which could be five to ten times greater than other manufactured products. In addition, the lifespan of laptop is usually three to five year. The rapid turnover exaggerates its energy consumption in manufacturing phase.

Several measuring methods are used to evaluate the energy consumption in manufacturing phase. Process-sum, economic input-output and hybrid assessment are three mainstream methods. Our study will discuss these methods below.

Method 1: Process-sum

The idea of process-sum method is straight forward. It is to sum up the values in each step of manufacturing. For example, to measure the energy consumption associated with laptop manufacturing, energy consumption in production of semiconductor devices, fabrication of printed circuit boards, fabrication of silicon wafers, monitor manufacturing and assembly of the computer from components are evaluated independently. By summing them up, the total energy consumption could be achieved.

To apply the method, we have to divide the manufacturing process to several steps.

However, data collection in certain step could be infeasible. Furthermore, it is also difficult to measure the energy consumption associated with capital goods and input of services.

Method 2: Economic input-output (IO)

The IO method is based on further study on energy density. The economy could be divided into 400-500 different sectors. Many studies are undergoing to estimate the energy density in each sector. (Green Design Institute at Carnegie Mellon University have done many research on it) Using Mathematical techniques developed by Leontief, energy consumption in specific sector could be evaluated by multiplying the money spent in the sector and energy density of the sector. The IO method makes it easy to estimate energy consumption in the supply chain. But it is not necessarily accurate, especially when people try to aggregate several processes into one sector.

Method 3: Hybrid Assessment

The hybrid method is based on IO method by first attempting to find the parts of the IO analysis that are inaccurate. Then, it will replace those data by the accurate process data. Therefore, the method is able to achieve an accurate result and also includes the power consumption of the whole supply chain. The method could be represented by the following formula:

$$\text{Total energy} = \text{Process-sum result} + \text{IO correction factor}$$

4.2 Energy consumption in use phase

As our investigation shown above, the energy consumption in the manufacturing phase is tremendous. But the energy consumption in the use phase is much higher. A related research in Europe shows that a laptop at the office consumes 1266 MJ (about 18%) in manufacturing and 5832 MJ (about 82%) in daily use. Therefore, much more energy consumption is associated with daily usage, and the rated power of a laptop shows significant impact on its life cycle energy consumption.

People usually use their laptop in three modes: off, sleep and active (idle). The time spent and the rated power in those modes will determine the energy consumption in use phase. IVF Industrial Research and Development Corporation have done many measurements on it. As the data shown by their measurement, a laptop in the office takes 3285 hours/ year (37%) in off mode, 3196 hours/ year (36%) in sleep mode and 2279 hours/ year (33%) in active mode. These value could help our investigation to determine how to weigh laptop's performance.

Many prevailing labeling criteria provide various standard powers for laptop. The details of those criteria are shown in the table above. Our study compares these criteria and uses the averages in different modes as base values to evaluate laptops' performance in energy consumption.

Energy Criteria for Laptops	Energy Star	The Swan	EU-flower	TCO'05	GEEA	Blue Angel
Sleep (W)	1.7	3	3	4	5	3.5
Off (W)	1	2	2	2	2	2
Idle(W)	14-22	-	-	-	-	-

Figure 2. Comparison of Criteria for Laptops

The index to evaluate laptops' performance in energy consumption is shown below. F is the factor to weigh the impacts of laptops' performance in different modes and phase. The value of F is based on the time used in different modes and the proportion of energy consumption. M is the measurements for specific laptops. B is base value which can be determined by labeling criteria and laptops' average performance. In addition, the squared value is to exaggerate the violation. The factors and base values are shown in the appendix.

$$\text{Index of energy consumption} = \sum F \times \left(\frac{M}{B}\right)^2$$

5.0 ENVIRONMENTAL IMPACTS OF DISPOSABILITY

The major environmental issues regarding laptop computers are determined by the highly toxic nature of its component or materials. Unfortunately, the laptop computers have approximately life cycles of three to four years. After laptop computer reach the end of their life cycle, the laptop computers are likely to be disposed in the landfills. This causes a potential impact to the environment due to the hazardous chemicals inside of laptop components. In this section, two major aspects of environmental impacts are discussed: the impact of non-recycling and benefits of recycling laptop computers.

5.1 Environmental Impacts of Disposing Wastes

The Greenpeace organization conducted studies of laptop computers to indicate the hazardous chemicals of laptop components. They have concluded heavy metal chemicals such as lead, mercury, and bromine or certain brominated flame retardants (BFRs) are the toxins found in laptops. Also, those chemical substances indicate that it has potential impacts on environmental and human health.

Lead

The exposure of the lead in the environment causes significant impact to environment. Disposing lead in the environment affects humans, animals, and fish by intoxicating food, soil, and water. Wild and domestic animals ingest lead during grazing. And as for humans,

the lead will damage kidneys, liver, brain and nerves, and other organs. In addition, the low concentration of lead can slow the growth of the vegetation.

In laptop components, the lead is commonly used as electronic solder that connects electronic components into the Prototype Circuit Board (PCB) or motherboard in the laptop. Lead is widely used due to good conductivity.

Mercury

Mercury also known as quick silver is a chemical element that has high acidity level. Not recycling laptop computer may lead to exposing mercury into a nature which can cause significant effect on human health. If mercury exposed in the water surface or soil, it can convert into methyl mercury. The methyl mercury accumulates in fish and animals that can cause in kidney damage, reproductive failure, and DNA alteration.

Mercury is significantly found in the LCD monitor in the laptop component. The mercury is contained in LCD screen light bulbs which has very energy and cost effective. Many companies continue to reduce the mercury contain light bulb in the monitor but there are lack of alternative for this change. The mercury level can contain from 0.12mg to 5mg per lamp.

Bromine and Brominated Flame Retardant (BFR)

Bromine is a chemical compound that can be formulated into Brominated Flame Retardant. Bromine is well known for disinfecting and protecting agent that destroys micro organism.

This chemical compound can cause negative health effects. The symptoms are shown as liver damage, decrease of immunity and milk production, and possible development of cancer.

Bromine is found in most of the materials in laptop computers: circuit board, chips, insulation sheet, wires, fans, keyboard, and mouse pad. Also, these components consist of significant amount of bromine. Insulation sheet, for example, contain 2.6 to 9.4 percent of bromine content by weight.

5.2 Benefit of Recycling Laptop Computers

Recycling is a process to convert a waste into new product or to reuse the materials to relief the consumption of new materials and pollution. Laptops consist of multiple electronic devices that can be reused such as LCD screen, Keyboard, and hard disk drives. Recycling laptop computer can stop polluting soils and water due to toxics in the chemical substances. In addition, companies that produce laptop supports the recycling their product by giving benefits to the consumers as they return their unwanted laptop computers.

Apple

Apple indicates that most of their products have closely 90% of recovery rate. Apple shows that key components are reused; glasses and metals are reprocessing to make new products; plastics can be reproduced as a secondary material.

Apple also provides some benefits to consumers if they recycle apple's product. As consumer ship their product to Apple, they return consumer with apple store gift cards. However, not all their products can be traded with gift cards but apple encourage their consumers to recycle their unwanted products for the environment.

HP

HP also provides a global recycling program that is initiated in 70 different countries. HP provides their best solution for returning their product. If their product has still resale value, they will refurbish the return and gives cash back to the consumer. If not, HP will extract the components as much as possible to reuse their product.

HP currently provides many benefits to the consumers. They provide the following options for returning their product for recycles: recycle, trade-in, return for cash, donate, and destroy. If the product still has resale value, HP attempts to give credit back to consumer as much as possible.

6.0 THE RENEWABILITY OF LAPTOPS

The market is often initiated by demands for services and/or goods. In order to fully understand the sustainability of laptops, it is necessary for us to probe into the root of the supply chain of laptop industry—the lifespan of those laptops, which is the key factors in determine the sales.

6.1 Common Reasons of Purchasing New Laptops

Since we have already introduced the influence of the laptop industry, it is crucial to understand why people keep purchasing new laptops. Any kind of market or producing industry would require continuous demand from customers to profit. Similar to how butchers would lose their jobs if a BSE crisis erupted globally, causing less demand in the beef market. Likewise, in order to evaluate the environmental impact of laptop industry as a whole, we have to go into the factors that influence people to purchasing the new laptop.

We conducted a short survey among friends and relatives. People choose to purchase laptop out of following reasons:

1. Lost/stolen of old device
2. Hardware/software breakdown of old device
3. Update
4. First time buyer

We excluded the first reason despite it is the most popular reason of purchasing new device. This is belongs to unnatural causes and fall out of the limit of our report, therefore, we would not look into this matter. However, the hardware or software breakdown is the second most popular reason that drives people to buy new laptops. This issue encounters the lifespan of laptops, which determines how often do people change their laptop. Sinec more customers change their devices, the demand for laptop or ultra-books would increase, and therefore leading to more potential environmental damages of laptops. We put our focus on what causes hardware and software breakdown in this report.

6.2 General Lifespan

Because of the rapid development of integrated circuits and microcontroller, the failure rates of electric device, like laptops, have been reduced significantly. This innovative development of electronic also brings us some new issues. Portable electronic devices like super thin laptops and ultra-books contain highly integrated systems. Once failure occurs, the devices cannot be repaired without special apparatuses. Therefore, the only option customers have is to purchase or exchange for a new one. This phenomenon promotes laptop industry to manufacture more products by using more resources, which include multiple chemicals that are not environmental friendly. According to our survey, hardware or software breakdown is the major reason that lead consumer to purchase new laptops.

Hardware Breakdown

Hardware breakdown is the most common issue that happens to electric device, which would result maintenance or replacement. In order to assess the environmental impacts of laptop industry, our team looked into the causes of majority hardware breakdown that result in exchanging device. As a result, we categorize those causes into two genres: internal and external. Internal causes of breakdown include severe battery runtime decrease, non-functional radiator, monitor failure, and etc. The damages are resulted from external force. For example, gravity and accidental impact, we place those factors into external causes of breakdown.

Internal breakdown is influenced by the quality of the laptop and using habits. Based on the survey we conducted, the decrease of battery runtime is the most common type, and then it is the radiator failure. According to the study that atbatt.com conducted, common laptop battery would show a sign of decrease in runtime after 18 months (). Despite almost all laptop companies offer replacement service for batteries, most of the consumers would consider it is more convenient to purchase new laptops. On the other hand, radiator problems usually happen to intermediate and high performance laptop users. Two of candidates from our survey pointed out that their Lenovo laptops always experience CPU overheated and shut down automatically. Theirs laptops are both used for over two years. This is a typical problem of radiator breakdown. Although those laptops are still functional, users have to purchase a better laptop to fulfill their needs.

External breakdown is often caused by accidents. Comparing to the internal breakdown, external breakdown occurs less often and not depends on laptop brands. However, the survival rate of the device would depend on material use and overall sign of laptops. Based on survey we conducted, candidates voted the Apple and Dell products as toughest laptops. One indicates his dropped his MacBook Air four times, and it still operates perfectly.

Software Breakdown

Many things, like computer virus, could trigger software breakdown. However, it is largely influenced by operating system of laptops. Windows and OS (Apple) are two most popular operating systems in the market. They all have their own flaws and benefits.

Windows, as one of most popular operating system owned by Microsoft, is able to run most of the software developing programs and coding languages. It is also capable of many other tasks that user assigns. However, from Windows XP to Windows 7, the common drawback of this operating system is the endless patches. Microsoft used to release 5-10 patches every month and that resulted Windows users have to install those patches every month. If one neglects those installations, his or her personal computer would be exposed in danger of virus invasion. This would also slowly fill up the hard drive memory, and after three to five years, there is no memory left for any operations. Windows also has a special characteristic that the operating system generates useless files over time. In result, Windows user would experience lagging operations and slow computing speed. Meanwhile, Windows keeps releasing new operating system as a marketing strategy, which promotes its customers to purchase new laptops that have new Windows installed and to abandon the old device.

On the other hand, Apple operating system is known for its simplicity and personal design. OS system does not require much updates and has faster speed on initializing the system. Security breaches that exist in Apple operating system are less than Windows. Therefore, more and more people switch to Apple operating system due to its efficiency. However, OS system is not software friendly under many circumstances. Software developers and video game players are still in favor of using Windows laptops.

6.3 Conclusion

Above all, after summarizing the causes of both hardware and software breakdown, we concluded that laptops that are used among our survey candidates (UBC students) have a lifespan of 3 – 5 years. This indicates that students would change their laptops every three to five years.

7.0 CONCLUSION AND RECOMMENDATIONS

Laptops have an influential impact on the environment through energy consumption and component disposal. Also, the rapid turnover could exaggerate those impacts. Hybrid assessment is more advanced to evaluate the energy consumption associated with laptop manufacturing because it is accurate and also considering energy consumption in the whole supply chain. Various prevailing labeling criteria provide standards for assessing laptops' energy consumption in use phase. If laptops' components are not disposed appropriately, it can harm people's health, especially lead, mercurial and BFR. Compared to other laptop manufacturers, HP and Apple offer recycling benefit to their consumer. Cash or credit could be repaid for recycling used laptops. In addition, a survey shows that Apple has longer lifespan than Lenovo, HP and Dell. Through the comprehensive examining and weighing, Apple's laptops have less negative influence on environment. Therefore, Apple is the recommended brand for purchasing.

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APPENDIX A: DETERMINING FACTORS AND BASE VALUES

Factor of manufacturing $f_{\text{manu}} = 0.18$

Factor of sleep $f_{\text{sleep}} = 0.88 * 0.34 = 0.3$

Factor of idle $f_{\text{idle}} = 0.88 * 0.30 = 0.264$

Factor of off $f_{\text{off}} = 0.88 * 0.36 = 0.317$

Base of Sleep $B_{\text{sleep}} = 4W$

Base of idle $B_{\text{idel}} = 20W$

Base of off $B_{\text{off}} = 2W$

Base of manufacturing energy consumption = 1266MJ

APPENDIX B: A SMALL GROUP SURVEY AMONG UBC STUDENTS

In order to investigate the general lifespan of different laptop brands, we conducted a small group survey among UBC student. The candidates size is 50 people, and there are only 36 candidates' data are used in this report. Within those 36 candidates, 13 candidates are in Electrical engineering, 7 candidates are from computer engineering, 5 candidates from Sauder Business School, 5 candidates from Arts, and 6 candidates from Science. The survey includes questions about the brand, performance, and technical difficulty of their pervious laptops. We also asked why they changed their old laptops and what is the common reason they think people change laptops. In addition, we questioned our candidates what do they use their laptops for.

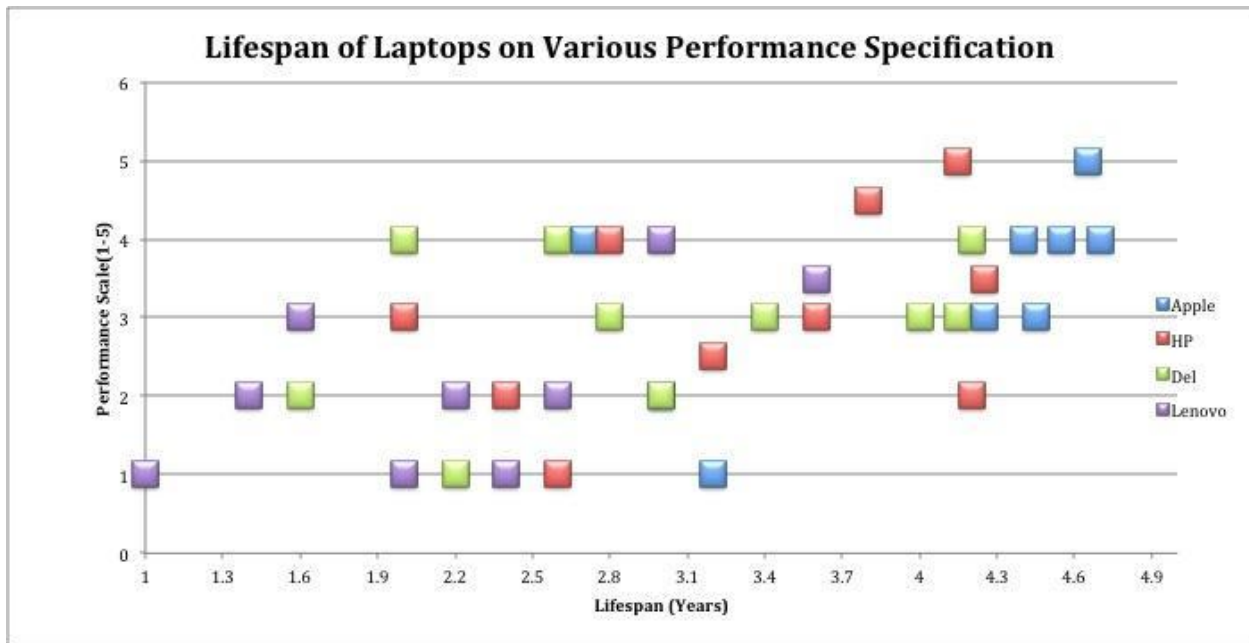


Figure 3: Scatter graph of different laptop brands' lifespan versus its performance scale

This is a lifespan graph of laptops from the survey. We used the scale 1-5 to measure the performance specification of different laptops. Clearly, Apple and Dell have longer lifespan comparing to Lenovo and HP.

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