LCA Case Studies

Life Cycle Assessment Study of Color Computer Monitor

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Abstract. The environmental performance of a color computer monitor is investigated by implementing a Life Cycle Assessment. The goal of this study is to collect LCI data of foreground systems, to identify hot spots, and to introduce life cycle thinking at the product design stage. Secondary data are used in the background system, and site-specific data are collected in the foreground system.

Results show that the use phase is the most contributing phase. The operating mode and the energy saving mode during the overall use phase contribute to the total by 59% and by 9.9%, respectively. In the production phase, the cathode ray tube assembly process and the printed circuit board assembly process are the most contributing processes. The sensitivity analysis on the use pattern scenario shows that the contribution ratio of the use phase ranges from 32% to 84%. Even in the home use case, which is the best case scenario, the use phase is one of the most contributing processes to the environmental performance of the color computer monitor. There is no significant difference in the choice of the impact assessment methodologies for identifying the improvement opportunities.

For the external use of Life Cycle Assessment in a short-run product for the market, it is recommended that Life Cycle Assessment should be carried out in parallel with the product design stage. It is also necessary to have a pre-existing, in-house database for a product group in order to accelerate life cycle procedures.

Keywords: Cathode ray tube; color computer monitor; consumer electronic product; data collection; identification of hot spots; LCA; Life Cycle Assessment; sensitivity analysis

Introduction

Manufacturing has usually focused on the quality of a product and the cost. The environmental issues in a company have been regarded only as an 'End-of-Pipe' treatment to comply with the environmental regulation. However, environmental concern about a product gradually becomes another driving force in business activity, i.e. as extended producer responsibility and environmental labeling. Though the effect of this concern on the market is still invisible, the potential is continuously growing so that an environmentally friendly product takes a higher position on the market. Furthermore, the International Organization for Standardization (ISO) has been working on standardizing environmental management systems since 1993. The activities at ISO have driven industries in Korea to pay more attention to the environmental performance of a product.

For these reasons, Samsung Electronics has explored ways to develop an environmentally friendly product. As a first step for this, a Life Cycle Assessment project on a microwave oven was launched in 1995. The goal of that project was to learn how to implement Life Cycle Assessment, and to identify environmental hot spots in a microwave oven [1].

There was a little confusion between the implementation of Life Cycle Assessment and the improvement in the environmental performance of product at the beginning. People at the manufacturing division considered Life Cycle Assessment as an improvement tool so that the implementation of Life Cycle Assessment itself could improve the environmental performance of a product. However, they realized later that Life Cycle Assessment was an evaluation tool, which provided information on the environmental aspects of the product system - from the raw material extraction through manufacturing, use, and to the waste management, and that this holistic information was also very important in a future product design.

After that project, Life Cycle Assessment was recognized as one of the most valuable tools to guide improvement in the environmental performance of products. The Life Cycle Assessment has been expanded to other product groups from semiconductors to electronic products. One of the main goals in Life Cycle Assessment studies at Samsung is to collect life cycle inventory data for foreground systems in order to introduce life cycle thinking at the product design stage with a computer-based environmental scoring system. Another goal is to identify hot spots in the product life cycle system for improvement in the environmental performance of products.

The implementation of Life Cycle Assessment is a first step to developing an environmentally friendly product. The outputs of a Life Cycle Assessment 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.

This paper, as a summary of the Life Cycle Assessment project on a color computer monitor [2], discusses the environmental performance of the color computer monitor, and the procedures of Life Cycle Assessment for electronic goods.

1 Life Cycle Assessment

1.1 Goal of the study

The initial goal of this study is to identify hot spots in relation to a color computer monitor for improving environmental performance. During the Life Cycle Assessment, the goals for study were expanded – to collect life cycle inventory data of foreground systems in color computer monitor systems, to identify hot spots for use in developing a new model, and furthermore to introduce life cycle thinking at the product design stage. The outcomes from this study are obviously a pre-step toward activities for improving the environmental performance of color computer monitors.

1.2 Product and functional unit

A color computer monitor, with a screen size of 17-inch, was chosen as a product in the Life Cycle Assessment study because the 17-inch monitor is the most popular in the market. The functional unit was defined as a 17-inch color computer monitor with six years of lifetime. Though the technical lifetime of a color computer monitor may be longer than six years, the company usually keeps components for service in stock for six years. Along with the goal of the study, a six-year period for the lifetime is taken in the functional unit.

Table 1: Components and materials used in the computer color monitor in this study

Component	Weight [kg]	Material
Cathode ray tube Assay	10.679	Glass/ Steel/ Cu/ PVC/ Sn/ Rubber/ Paper
PCB Assay	3.503	Al/ Rubber/ Steel/ Paper/ PP/ Cu/ PVC/ Sn/ Ag/ Pb/ Phenol/ Ba/ Ti/ Polyester/ Epoxy/ PP/ Polyamide/ Bronze/ Nylon 66/ Crystal/ Silver/ Mo/ Mn/ Ni/ Si2O3/ Brass/ Ceramic/ PBT
Cabinet Assay	3.156	ABS/Steel/Rubber/PC-ABS/PVC
Packaging Box	2.663	Corrugated box
Packaging Material	1.627	LDPE/HDPE/EPS/Sponge
Shield Assay	0.943	Steel/PBS/Cu/Sn/Bronze/Nylon 66/Rubber
Others[a]	0.638	Cu/PVC/PBT/PB/Paper/PET/Acryl/PE/Paper/Stainless steel
Total	23.209	

[a] : e.g. power cord, label, screw, and etc

1.3 System boundary and data collection

All processes in the color computer monitor system, from the cradle to the grave, are included in the inventory calculation. However, there are some data gaps due to confidentiality or uncertainty. These data gaps were either left as a data gap or other process data, similar to an original process, were used.

As the data collection is a time and cost intensive step, the life cycle system is divided into two systems – background system and foreground system – to facilitate the data collection. For a process in the background system, secondary data are used instead of collecting site-specific data. For example, commercial databases are used in raw material production process and energy systems. In the foreground system, the site-specific data are collected for every process by using questionnaires. **Table 2** shows the background and the foreground systems as classified in this study.

The raw material extraction, the material production, and the energy production systems are defined as the background system because the markets for those processes are assumed to be homogeneous. Processes of the primary suppliers that usually produce a component or an assembly and processes within the company are defined as the foreground system. The waste management system is also defined as the foreground system. However, it is difficult to obtain site-specific data for the waste management system because the number of color computer monitors disposed of is now too small to get the site-specific data. Therefore, the site-specific data from the waste management system for a color television set, which were collected in another Life Cycle Assessment study [3], were used in this study.

Table 2: Background/foreground system and data characteristics

Life cycle phase	System	Data Characteristics
Raw material extraction	Background	Secondary data
Energy production	Background	Secondary data
Material production	Background	Secondary data
Component/Assembly production	Foreground	Site-specific data
Color Computer Monitor Assembling process	Foreground	Site-specific data
Use	Foreground	Assumption
Waste Management	Foreground	Secondary data

1.4 Allocation and scenario

Most of the electronic component manufacturing processes are multi-output processes, where more than one component is produced. The amount of raw materials or subcomponents used in an electronic component can be obtained from the bill of material (BOM). In this case, no allocation for the raw material use is required. However, other environmental burdens, like energy consumed, emission released, and waste generated, still need to be allocated to a given product. Physical property or quantity of product produced is chosen as an allocation factor for those burdens depending on the process characteristics. For example, a multi-output process where the quantity of product is used as an allocation factor is a process that the product evenly generates environmental burdens, like a simple assembling process. For a multi-input process, such as waste management processes, the allocation is done based on the cause-effect analysis.

In the use phase of an electronic product, there are two important factors considered; use pattern and power consumption. Use pattern of a monitor is too varied to derive a general use pattern scenario. For instance, monitors in a software company consume much more electricity than monitors at home. Furthermore, a monitor has two modes in the operation. One is an operating mode and another is an energy saving mode.

In this study, the use phase is assumed in such a way that a monitor is operated for 8 hours a day: four hours for the operating mode and four hours for the energy saving mode. The power consumption rate for both modes is collected from company testing records.

As mentioned previously, the waste management for a color television is used instead of the site-specific data because of the data gap. In the waste management of a color television set, the large assemblies such as cathode ray tube (CRT), printed circuit board (PCB), cabinet, and power cord are assumed to be manually separated at the end of the product life stage, and then to be recycled. The expanded polystyrene (EPS) and the corrugated box in the packaging material are usually recycled as well. Other components such as electrical cable, cable clamp, etc. are incinerated or landfilled.

The cathode ray tube is broken by a hammer, and sorted into several types of glass because the lead contents of glass are varied between panel and funnel. The broken glass is then rinsed by hydrofluoric acid and water to remove fluorescent substances. After rinsing, the broken glass is recycled to a cathode ray tube manufacturing company and used as a raw material.

The print circuit board at the end of product life is reportedly exported to China for reuse. The reused components are regarded as an outflow, which crosses the system boundary, since no information on the reuse process is available. The cabinet, which is a compound of polycarbonate/acrylonitrile-butadiene-styrene (PC/ABS), is recycled to another product system like a toy or a low-grade plastic product. Copper is extracted from the power cord.

The packaging materials are usually taken back by retailers after delivering a product, or disposed of by a consumer. For packaging materials, expanded polystyrene (EPS) and the corrugated box are usually recycled, but small packaging materials such as polyethylene (PE) bags and steel wire are incinerated and landfilled, respectively.

1.5 Inventory analysis and impact assessment

Once data from suppliers are collected , the energy consumption, the emissions released, and the mass balance in a process are checked by both LCA practitioner and internal expert. When there are missing data or abnormal data in a process, the data questionnaire is sent back to a supplier to check the data again and to collect missing data. If the supplier does not have enough data, the missing data are treated by the LCA practitioner based on the composition of materials, the expert's opinion, or the data from other suppliers. The emissions related to the electricity are calculated based on Korean power grid. The emission factors for each power plant is adopted from the literature data [4-5]. The inventory calculations are done by using commercial LCA software (LCAiT, CIT Ekologik, Sweden).

The impact categories and the characterization factors in the CML guide [6] are used in this study; i.e. depletion of abiotic resource, global warming, depletion of stratospheric ozone layer, acidification, photochemical oxidant formation, eutrophication, human toxicity, and ecological toxicity. Furthermore, normalization and weighting across the impact categories are done to facilitate communication with product designers and other people at the company. The normalization is done based on the Korean situation [1]. The weighting factors for each impact category are estimated from a survey of expert panels, who are selected from both internal and external parties.

2 Results and Discussion

2.1 Results from inventory analysis

Over 200 environmental parameters are included in the inventory analysis. Since it is impossible to show all of the environmental parameters here, some environmental parameters are selected to present. This is shown in **Fig. 1** and **2**, where the contribution ratio of each life cycle stage is portrayed.

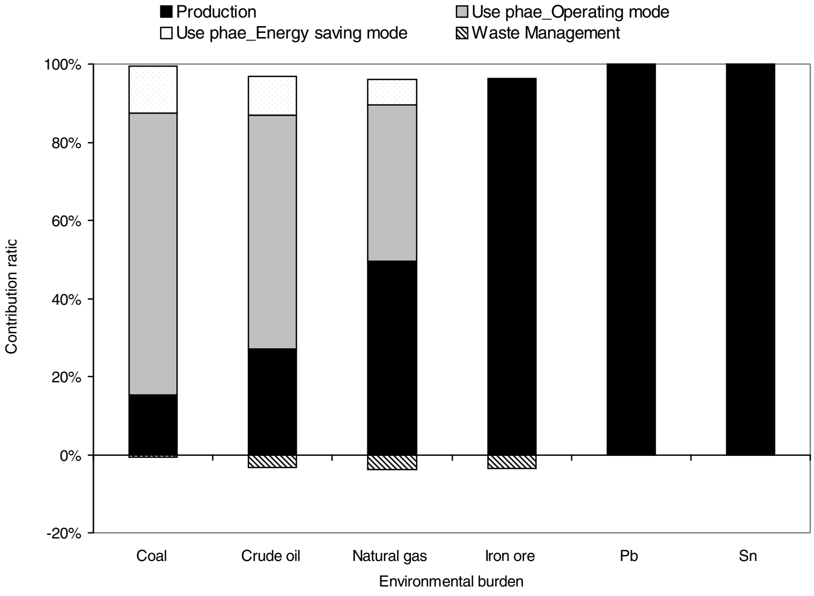

Fig. 1: Consumption of abiotic resources in life cycle of the computer color monitor

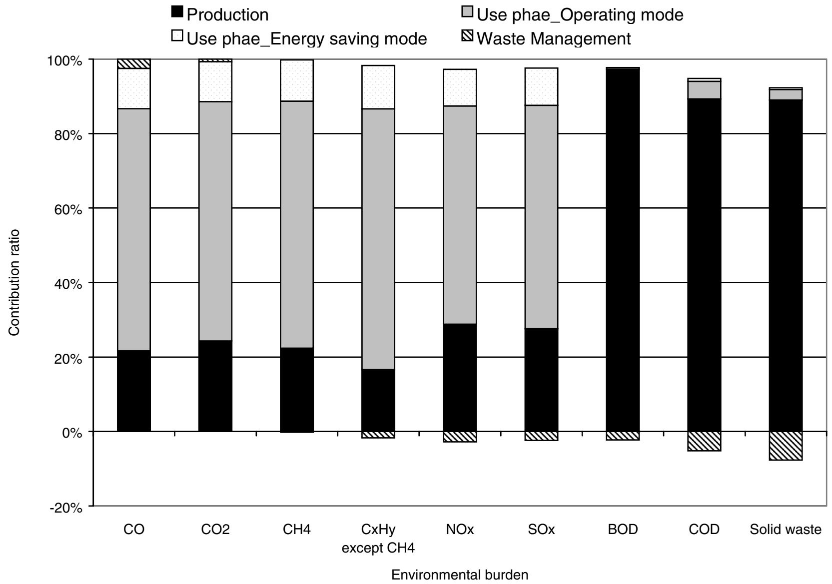

Fig. 2: Environmental emissions in life cycle of the computer color monitor

The most important contributor for the energy-related resources, like coal, crude oil, and natural gas, is the operating mode in the monitor use phase. Note that in Fig. 1 crude oil and natural gas for the feedstock is included. The production phase contributes largely to the use of iron ore, lead, and tin because these are the main materials used in the color computer monitor. The negative contribution is due to environmental credit from the recycling at the waste management phase.

As seen in Fig. 2, the use phase releases the energy-related emissions much more than other phases because of the consumption of the electricity. BOD, COD, and solid waste, which are process-related emissions, are released primarily in the production phase.

It is very difficult to identify the hot spots in the life cycle of the color computer monitor from the inventory results. Even more, the product designers have difficulty in understanding the results of the inventory analysis. However, the outcomes of the inventory analysis are very valuable information for establishing an in-house database.

2.2 Results from impact assessment

Eight impact categories for each process are shown in **Fig. 3**, giving a cradle to gate picture. The depletion of biotic resource and water resource are not considered in the impact assessment because biotic resources are regarded not as a deposit but as a fund, and water resource is a flow. The depletion of abiotic resources is calculated from the reserve-base method that is based on the concentration in the earth crust. The main contributor to the depletion of abiotic resource is the production phase. Lead is the most important environmental burden in the depletion of abiotic resources.

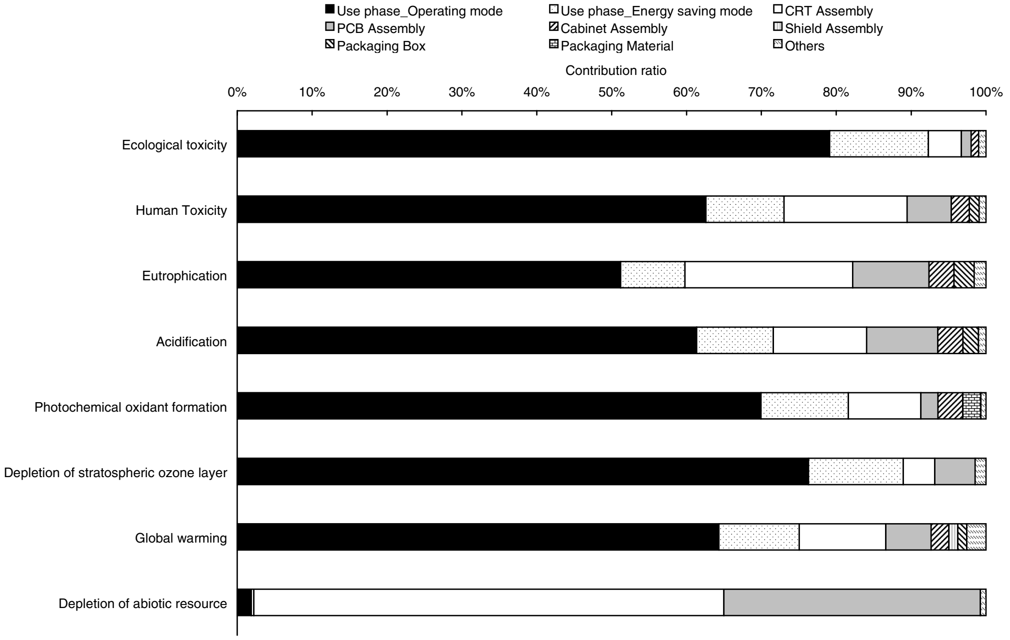

Fig. 3: Characterization results of the environmental performance of the computer color monitor

The most important contributing process is the cathode ray tube assembly process because lead is used as a raw material in the glass tube.

The potential impact of global warming includes only direct effect gases with a time frame of 100 years. The most important contributing environmental burden is carbon dioxide, which is released from energy consumption. The operating mode in the use phase contributes to the global warming by over 60%. The next important phase in the global warming category is the cathode ray tube assembly process, where most of the greenhouse gases are released from furnaces.

The main contributor to the depletion of the stratospheric ozone layer is Halon 1301. All of the ozone layer depletion gases are released from electricity production, which is taken from commercial databases [4, 5]. Therefore, the operating mode and the energy saving mode in the use phase are the most important phases in the depletion of the stratospheric ozone layer.

In the photochemical oxidant formation category, hydrocarbon is the most contributing environmental burden, and the most contributing phase is the operating mode in the use phase. The energy-saving mode in the use phase contributes to the photochemical oxidant formation more than other processes in the production phase. In the production phase, the cathode ray tube assembly is the most important contributor to the photochemical oxidant formation.

SOx was the most common environmental burden contributing to acidification, while the most important environmental burden in eutrophication is NOx. Both environmental burdens are energy-related burdens. The operating mode in the use phase is the largest contributor to acidification and eutrophication. The CRT assembly process is the next contributor in these two impact categories because of high energy consumption. The operating mode in the use phase is a dominant contributor to both human toxicity and ecological toxicity. SOx contributes most to the total of the human toxicity, and oil emissions to water is the most important environmental burden in the ecotoxicity category.

It is easily noticed that the operating mode in the use phase is the most important portion to most of the potential impacts except the depletion of abiotic resources. There are still trade-offs between the potential impact categories. Instead of results for each impact category, product designers want a total solution to the environmental performance in setting a priority between the hot spots for improvement activities. Therefore, the weight across the potential impacts is undertaken, and shown in the next section.

2.3 Results of weighting

The contribution ratio for each phase or process is presented in **Fig. 4**. The ratio is based on the results from the weighting step. Like other consumer electronic products, the results show that the use phase is the most contributing phase because of the power consumption. As mentioned previously, the use phase is divided into two modes: operating mode and energy saving mode. The operating mode contributes 59% to the total value, while the energy saving mode is 9.9%.

Since the energy requirements of two modes are different, and also depend on the time duration, it is worthwhile to estimate the effects for various use pattern scenarios on the consistency of results. The scenarios considered in the sensitivity analysis are as following:

- Scenario 1: operating mode: 1 hr/day, energy saving mode: 0 hr/day
- Scenario 2: operating mode: 2 hrs/day, energy saving mode: 0.5 hr/day
- Scenario 3: operating mode: 3 hrs/day, energy saving mode: 1 hr/day
- Scenario 4: operating mode: 4 hrs/day, energy saving mode: 4 hrs/day
- Scenario 5: operating mode: 6 hrs/day, energy saving mode: 2 hrs/day
- Scenario 6: operating mode: 8 hrs/day, energy saving mode: 16 hrs/day

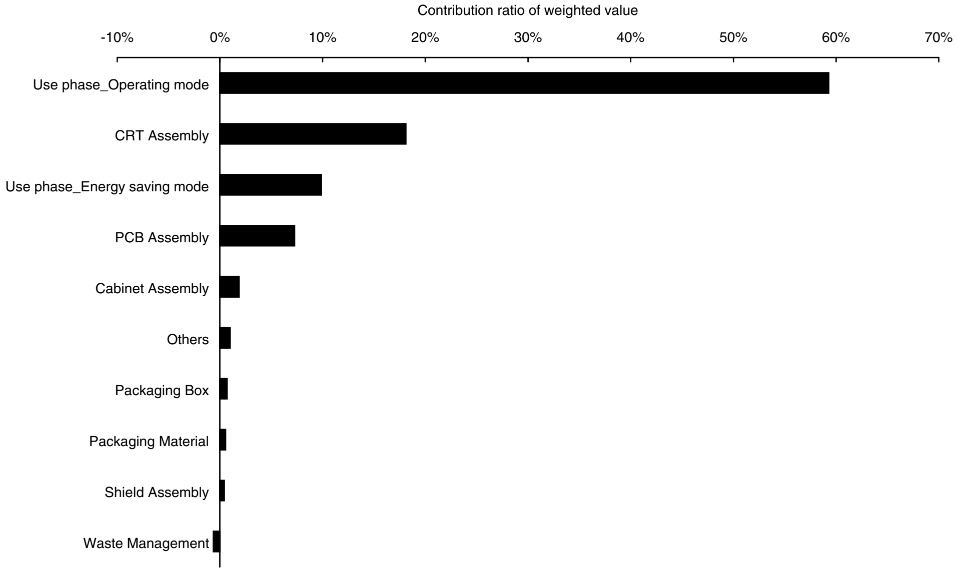

Fig. 4: Contribution ratio of each phase or assembly in the weighted results

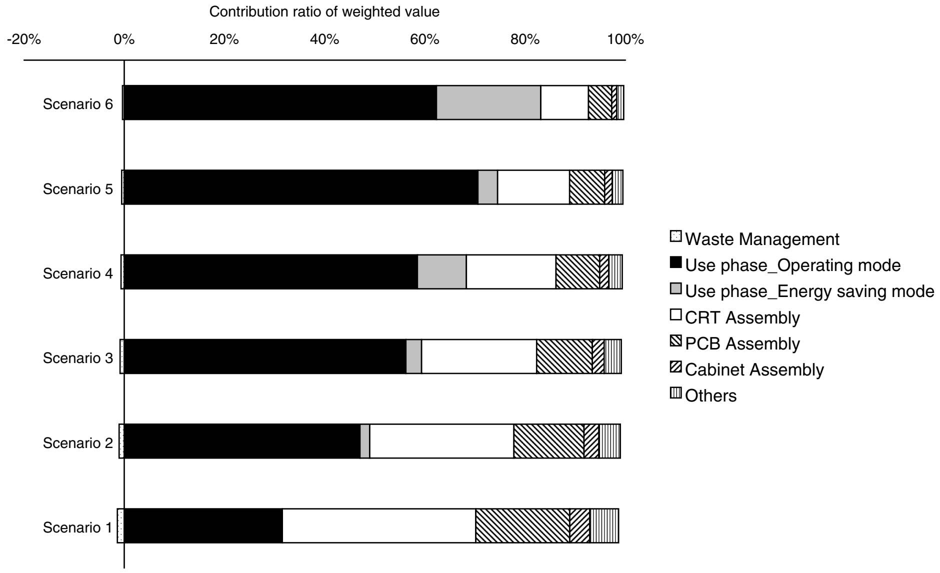

Fig. 5: Results of the sensitivity analysis on the use pattern scenario

Results are presented in **Fig.** 5. In scenario 1, the cathode ray tube becomes the most contributing process (40%) in the whole life cycle of the color computer monitor. The use phase is about 32% of the total environmental performance. This scenario can reflect home use. In all other scenarios, the use phase is the most contributing phase. As can be seen, the contributing ratio of the use phase increases with the time duration of use. The contribution ratio of the use phase ranges from 32% to 84%. Results show that the use phase is one of the most contributing phases even in the best-case scenario, home use case. Comparing scenario 5 with scenario 6, the contributing ratio of the operating mode in scenario 5 is larger than in scenario 6 because of the time duration of the energy saving mode in scenario 6. It should be noted that the total for scenario 6 is the largest, even though in Figure 5 all are expressed on a basis of 100%.

The large contribution of the use phase is implicitly realized from the beginning of the study. Most of monitor companies have recognized clearly that the power consumption during the use phase is one of the greatest improvement opportunities. They have been working very hard to reduce the power consumption of the computer monitor.

In the production phase, the cathode ray tube assembly is the most contributing process. The cathode ray tube assembly, 10.7 kg, is the heaviest assembly in the color computer monitor. The manufacturing process of the cathode ray tube is energy-intensive. The major materials in the cathode ray tube assembly are glass, steel, phenol resin, copper, coating materials and electronic devices. To improve the environmental performance of the cathode display tube, the energy requirement in the manufacturing process can be optimized.

The printed circuit board assembly is also one of the most contributing components in the production phase. It contributes about 7.3% to the total environmental impact associated with the color computer monitor. In the assembly process of the printed circuit board, where electronic devices are inserted onto the phenol resin board, some of the electronic devices are rearranged and attached to a paper roll and cut automatically to the proper size for an inserting machine. Therefore, the inserting process generates a large amount of paper and steel wire waste. After inserting electronic devices, the board moves to the soldering process followed by the cleaning process, where steam is used as a cleaning agent. The printed circuit board assembly process is energy intensive, too.

The cabinet assembly contributes to the total environmental performance of the color computer monitor by about 1.9%. The composition is PC and ABS. The processes in the cabinet assembly production are plastic resin manufacturing and molding. Most of the contribution results from the plastic resin manufacturing process. Therefore, reducing the amount of resin used in the cabinet assembly by a gas injection molding technology or a better design in the geometry of the cabinet can improve the environmental performance of the cabinet assembly.

It is of interest that packaging material and the packaging box contribute to some extent in the total environmental performance of the color computer monitor. A better design to reduce the amount of material is recommended to improve environmental performance.

The main function of the shield assembly, which is a steel plate, is to prevent the emission of electromagnetic radiation during the operation. The shield assembly can be eliminated by using a conductivity polymer resin for the cabinet assembly or coating magnesium inside the cabinet assembly. It is necessary to implement another Life Cycle Assessment to estimate the environmental performances of both alternatives.

As can be seen in Fig. 5, some environmental benefits are gained from the waste management processes because most components and material are recycled or reused at the end of the product life. This is an optimistic scenario. However, more work is required to collect the sit-specific data so as to clarify the environmental performance of a color computer monitor at the waste management stage.

The sensitivity in Life Cycle Assessment studies results from data sources, allocation methods, system boundary, impact assessment methodology, etc. For the data source, secondary data are used for the background system, while the site specific data are collected for the foreground system. The sensitivity from the choice of data arises more in the background system than in the foreground system because of the variations of emission factors between commercial databases. The choice of the commercial databases is a very difficult task without any detailed information. Moreover, the commercial databases do not generally provide detailed information. To verify the credibility of the results, the cradle to gate data for metals from other commercial data sources [7] are used in calculating the sensitivity in the environmental performance of the color computer monitor. Results show that there are no significant differences in the total environmental performance because the components or assemblies, where metals are used as a raw material, contribute to the environmental performance less than the use phase, and the environmental parameters are aggregated into the characterization indicator in the impact assessment. Furthermore, each characterization indicator is normalized and then weighted.

The sensitivity of the choice of emission factors for the power system was not investigated because the goal of this study was an identification of hot spots. The sensitivity of the open loop recycling allocation method is not considered in this study because only a small portion of the material is recycled to the other product systems.

To identify the sensitivity of the impact assessment methodology to the results, other impact assessment methodologies are applied – Ecoindicator [8], Ecoscarcity [9], Environmental priority strategy (EPS) [10]. Results are presented in **Fig. 6**, where Environmental theme [6] is used as a basic methodology in the impact assessment. Except for the environmental priority strategy, other methodologies show a consistency in the contribution ratio. In the environmental priority strategy, the cathode ray tube process is the most contributing process, while the use phase is the most contributing process in other methodologies. This results from the fact that resource use is emphasized more than released emission in the environmental priority strategy.

In the Ecoindicator, the contribution ratio of the printed circuit board is relatively small compared to the other impact assessment methodologies because there are no characterization factors for the resource use.

3 Procedure of Life Cycle Assessment in Electronic Product

This study was focused on a product that had been already introduced to the market. It took nine months to complete the Life Cycle Assessment on this product by four persons. Two or three months after this study, a new model was introduced to the market. Usually electronic companies in Korea develop a new competitive model every year. The time interval between an old model and a new model on the market is about one year.

One of the important applications of Life Cycle Assessment is an external use. For instance, many companies might be interested in the external use of Life Cycle Assessment, such as a type III environmental labeling program [11]. To maximize the effect of type III environmental labeling on the market, a product should be introduced to the market with a type III labeling at the beginning. However, there are some difficulties in the external use of the LCA results for such short-run products in the market due to the time frame. Typical time frames of electronic products in Korea are shown in **Fig. 7**. The solid line in Fig. 7 represents information flow, while the dotted line represents product flow. The arrow is denoted by the direction of flow.

The design process for an electronic product usually takes 6-12 months, and the time frame of the manufacturing stage

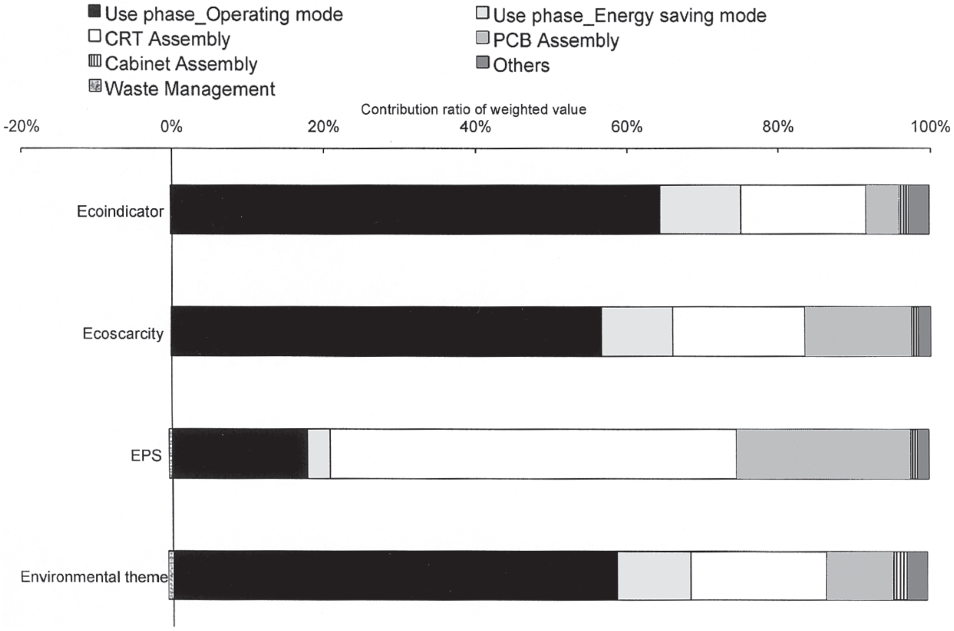

Fig. 6: Environmental performance of the color computer monitor from several impact assessment methodologies

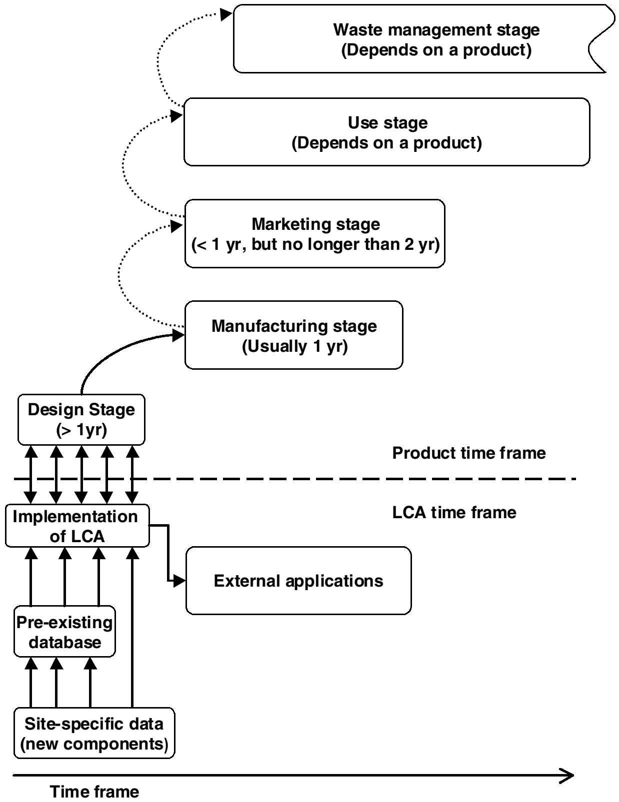

Fig. 7: Product time frame of electronic product in Korea with the starting point of LCA

until a new model is ready is about one year. The marketing stage may be a little longer than the manufacturing stage, but considering a major market, it is almost the same as the manufacturing stage. The time frame of the use stage definitely depends on the characteristic of product. Therefore, the time period for the most efficient way to use LCA results for the public becomes about one year. Since a Life Cycle Assessment study on an electronic product may take at least 6-9 months, there is less than six months available to communicate LCA outcomes to the public if the study starts at the point of the appearance of a product on the market.

To maximize the time period for the communication of LCA outcomes to third parties, Life Cycle Assessment for such a short run product in the market should be implemented at the design stage. Otherwise there is no room for using the external application of LCA because Life Cycle Assessment is a time intensive process. Even though the Life Cycle Assessment is started at the beginning of the design stage, a pre-existing methodology and in-house database are required.

Generally, the specification of a new product is fixed at the beginning of the design stage. If LCI data for a component are in a pre-existing, in-house database, those data are ready to use in a new Life Cycle Assessment. If not, the site-specific data are collected for a new component. But in most cases the number of new components appears to be smaller than the components used before. Therefore, this can reduce the time frame of Life Cycle Assessment. The new site-specific data collected are added on the pre-existing database. This procedure therefore can save time and cost. A possible approach of LCA for this application is as following:

(1) Develop Life Cycle Assessment tool for a product group
(2) Collect the process data for components and assemblies, and raw materials used in a product group to develop a pre-existing database.
(3) Identify the changes in the design specification of a new product during the product design stage and collect the process data for those changes if not available.
(4) Implement Life Cycle Assessment on a new product using a pre-exiting database set during the manufacturing stage.

Step 1 and 2 are a pre-procedure before implementing LCA for an external application. Those two steps are general steps for a given product group. In step 1, the methodologies of LCA on a given product group such as allocation rule, use pattern scenario, waste management, etc., are decided. The site-specific data for a product group are collected as much as possible in step 2. Once Step 1 and 2 are completed, the time consumption in collecting LCI data and deciding LCA methodologies can be reduced, and it is ready to implement LCA in parallel with product design process for the external application. The methodology and database that is already established in step 1 and 2 can be used over and over until there are changes in the methodology and the in-house database.

Step 3 and 4 are specific steps for a given product. In step 3, the differences between a new model and an old model are identified. LCA practitioner and process designer decide which components are needed to collect the site-specific data. After screening the data availability, the site-specific data for new components are collected from suppliers. Components that are previously available from suppliers are easily collected as compared with components that are totally new. Regarding components that are not available before, the collection of the site-specific data is done after completing the design of this component.

To follow the above procedure, a huge in-house database and a computer-based LCA calculating program specialized in a given product group are necessary. Furthermore, the LCA practitioner and the product designer must cooperate closely together. This procedure is also very useful in selecting material/component and improving the environmental performance of the product. Since Life Cycle Assessment is carried out at the product design stage, a designer can easily estimate the environmental performance of an alternative option, and figure out the trade-offs between the options.

4 Conclusions

One of the goals of this study is to identify hot spots throughout computer color monitor life cycle for future improvement. This study shows that the use phase is the most contributing phase throughout the life cycle. Even the energy saving mode in the use phase contributes to some extent to the total environmental performance of the computer color monitor. The cathode ray tube assembly and the printed circuit board assembly are the most important in the production phase. Other hot spots identified in this study are cabinet assembly, packaging stuffs, and shield assembly. These hot spots have been reviewed by the product designers to find out the improvement options.

The hot spots can be classified into a controllable option and an uncontrollable option. In the controllable option, a company can improve it by itself or directly influence suppliers to improve. For instance, the power consumption in the use phase can be controllable, but the use patterns of the consumers are not. The company can ask suppliers to reduce environmental impacts or a specific environmental burden or define an upper limit of the environmental burden in order to encourage suppliers to improve the environmental performance of their products. Therefore, the controllable options are based on a strong economic relationship between company and suppliers. Even the controllable options can not always be improved due to technical gaps or investment.

Companies can do nothing in directly changing an uncontrollable option. For instance, environmental impact associated with power grid and raw material extraction/processing, and use pattern of the consumers are uncontrollable. The economic relationship between company and raw material extraction/processing manufacturers in the upstream is too weak for the company to directly ask to improve the environmental performance of those processes or products. The company may drive the suppliers, which are directly related to the company, to ask the raw material processing manufacturer to improve the environmental performance. However, this is hardly achievable because the direct suppliers are usually much smaller than the raw material processing companies and have very few chances of selecting their raw material suppliers.

Furthermore, the improvement strategies for the controllable options can be divided into two categories depending on the time period of development, investment cost, and technical feasibility – a long-term improvement strategy and a short-term improvement strategy. The long-term improvement strategies can be the reduction of power consumption of the use phase, the optimization of energy consumption in the cathode ray tube manufacturing process and the improvement of the printed circuit board process.

The short-term improvement strategy is a relatively low investment cost and easily applicable. It can be the replacement of raw material, the selection of suppliers, the reduction of raw material requirement, and the better design for packaging. The short-term improvement options are practiced within the product design stage. The decisions on the short-term improvement strategies are based on the process data for current technologies for which data are ready to use. Hence, a large data set is required for the short-term strategies. A computer-based environmental scoring system for product designers is also suggested because a product designer, who is usually unfamiliar with Life Cycle Assessment, must make a decision. Therefore, the Life Cycle Assessment in the short-term improvement strategy follows the procedure described in the previous section.

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