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ENVIRONMENTAL ISSUES AND ECOLOGICAL PROFILE IN ELECTRICAL AND ELECTRONICS PRODUCTS DESIGN

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Abstract

Market related requirements and proposed legislative approaches have put more pressure to integrate design for environment principles into the product design process especially in the electrical and electronics industry. In manufacturing companies there is a need for information about environmental aspects of the whole product chain. Life cycle assessment (LCA) is a method to evaluate potential environmental impacts of a product system during its life cycle and LCA has been applied in this study to two product cases, a frequency converter and a welding machine.

Keywords: life cycle assessment (LCA), electrical and electronic equipment, design for environment (DfE)

1. Introduction

Discussion on reducing the life cycle environmental impacts of products and the adoption of the EC directives WEEE and RoHS (WEEE - European Parliament and Council Directive on waste electrical and electronic equipment and RoHS - Restriction on the marketing and use of certain hazardous substances in electrical and electronic equipment) have put more pressure on the need for the design for environment (DfE) approach especially in the electrical and electronics industry. The Commission has published also a draft proposal for an EuE directive (Establishing a framework for Eco-design of End Use Equipment) which objective is to create a framework for the "integration of environmental aspects in the design and development and setting eco-design requirements" for end use equipment.

There are companies, which have already made efforts and considered environmental aspects during the product design. The results have usually been reduced material usage and energy consumption or simplification of disassembly. However there is need for better understanding of the whole life cycles of the products and the management of the environmental information.

Helsinki University of Technology Department of Machine Design has launched the research project "ANSELMI" to study applications and prepare actions in electrical and electronic equipment manufacturing companies concerning legislative and market driven requirements for DfE. The main objective of the project is to promote and support DfE efforts and to facilitate environmental management and goal setting of environmental strategies in the companies. The project is conducted in close co-operation with Tampere University of Technology Institute of Electronics and the participating companies from electrical and electronics industry. The project duration is 2/2002 - 1/2004.

The research project consists of four modules. In the first module the project team has evaluated the objectives of the WEEE- and RoHS-directives and the proposed basic objectives of EuE. A frequency converter as a case product has been evaluated regarding the requirements for life cycle approach (ecological profile). The aim of the second research module was to study the opportunities and limitations of the implementation of life cycle assessment (LCA) for electrical and electronic products. The main tasks were studying the inventory analysis and evaluation of the possibilities to use LCA software tools considering limitations and benefits of those tools.

The paper concentrates on the life cycle assessment principles and applications in electronics and electrical manufacturing industry using two case products.

2. Eco-design - environmental policy approach

Product-oriented approaches in the environmental policy have become more common in the European Union (EU). According to the European Union Sixth Community Environment Action Programme sustainable production and consumption patterns are among the principles and aims of the EU policy. Integrated product policy (IPP) is mentioned as one of the strategic approaches to meet environmental objectives. The IPP initiative, developed by the Directorate General on the Environment, aims at reducing environmental burden of products and services taking into account their whole life cycle from raw material acquisition to end-of-life stage and waste management [1]. Stakeholders in every stage of the life cycle are making decisions, which may influence the environmental impacts of the product. The environmental impacts of processes and products should be clarified covering all stages from the raw materials to the production, distribution, use, recycling and/or recovery and final disposal. The information can be assembled in life cycle inventories (LCIs) and interpreted by life cycle assessment (LCA). The assessment results of environmental aspects of a product may be used internally in companies, e.g. in research and development and design of new product concepts.

2.1 EuE draft proposal

There has been launched discussion on a directive, which may include the principles of the IPP of life cycle thinking and give guidelines for product design. A draft proposal for a directive on establishing a framework for eco-design of end-use equipment (EuE) has been published in 2002. It replaces two earlier draft proposals, the impact on the environment of electrical and electronic equipment (EEE) and the energy efficiency requirements (EER). The proposed directive aims to integrate environmental aspects in the design and to set eco-design requirements for end-use equipment. End-use equipment is defined as equipment which is dependent on energy input (electricity, fossil and renewable fuels) to operate and equipment for the generation, transfer and measurement of such energy including also parts which are intended to be used in the EuE. The main product group included in the directive is electrical and electronics products but it shall not apply to motor vehicles. The proposal is still under consultation and the Commission is collecting feedback from stakeholders. However the general objective is to associate environmental aspects in the design process together with considerations such as technical requirements for functionality, safety and health, quality and economic aspects. The entire life cycle of the product shall be taken into consideration, which means that information on environmental characteristics shall be provided also by manufacturers of components and sub-assemblies. The directive shall give general provisions and the eco-design parameters for EuE which manufacturers of those products should comply with. Before placing an EuE on the market of EU, a product must have the CE marking, by which it is ensured that the product complies with the relevant provisions of the directive.

2.2 WEEE and RoHS directives

Waste electrical and electronic equipment (WEEE) have been included in the Community policy and target areas to be regulated in relation to the environment and sustainable development. Reducing the quantity of waste for disposal and waste recovery in association with producer responsibility have been essential targets during the preparation of the WEEE directive. There has also been concern about the content of hazardous substances in components and parts in electrical and electronic equipment and the potential risks during the waste management phase and recycling. To reduce those problems the directive on the restriction of the use of certain hazardous substances (RoHS) has been prepared. These new directives which were published in the official Journal of EU in February 2003 give manufacturers of electrical and electronic products objectives for DfE. The WEEE legislation has an objective of prevention of waste electrical and electronic equipment and promotion re-use, recycling and recovery of such wastes.

According to the WEEE directive producers of electrical and electronic equipment will be responsible for financing the waste treatment of their own products and the costs of "historical waste" will be shared between producers on the market. The directive has also an aim to improve environmental performance in the life cycle of electrical and electronic equipment and particularly the treatment of electrical and electronics waste, re-use and recycling of their components and materials. Article four of the directive gives objectives to product design and especially encourages to take into account dismantling and recovery in the design of electrical and electronic equipment. Producers are obliged to provide re-use and treatment information of new products put on the market in the Community. The information shall identify especially the location of dangerous substances in electrical and electronic products. The manufacturers shall be prepared to collect materials information from their suppliers and subcontractors and on the other hand distribute the information to the recovery and recycling companies. The data management and product history data of the whole product chain will play a more important role.

The directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) will give a ban on lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) in new electrical and electronic equipment from 1 July 2006. On the basis of scientific and technical reasons, some applications of lead, mercury, cadmium, and hexavalent chromium are exempted from this requirement. The directive shall give new challenges to materials, components, and process equipment development and design.

3. LCA - use in DfE in electronics

One proposed basic requirement of the EuE draft proposal is the establishment of the ecological profile of a product. Ecological profile describes the magnitude and significance of the environmentally relevant inputs and outputs (including, as appropriate, raw materials, intermediate products, emissions and waste) associated with a product throughout its life cycle. In practice this means the LCA of a product system. Producers need to take into account energy consumption, resources used, emissions and wastes during raw material acquisition, manufacturing, packaging, transport, and distribution, installation and maintenance, use and end-of-life phases.

Life cycle assessment is based on international standards ISO 14040-14043. Four main stages can be distinguished in a life cycle assessment study: goal and scope definition, inventory analysis, impact assessment and the interpretation of results. LCA has been used in making comparisons between alternative systems for a product or service. The focus can be on comparison between alternative products or between alternative methods to be used in the production of a single product. The results of an analysis without an existing reference (an alternative product) are clearly more difficult to interpret and use as basis for decision making.

In addition to fulfil the possible forthcoming legislative requirements in electrical and electronics industry, LCA can be used in compilation of the environmental product declarations and as a source in establishing environmental strategy for a company. It can be utilised in any phase of product development from the creation of a new concept to a detailed development or production phase. It is a useful tool in companies as a guidance of DfE and also used in pilot projects to gain experience of the LCA method itself and its applications.

One application of LCA is the use in communication with suppliers and other operators in the product chain. The knowledge and information procured during the whole LCA process helps to respond to an ever-increasing amount of information requests concerning product's environmental aspect. The gained knowledge can be used when marketing a product, informing the subcontracting chain and in business-to-business co-ordination.

However the LCAs of electronic products are still relatively unestablished practices. The LCA of complex products is demanding because of several components, sub-assemblies and global supply chains and the global markets of the manufactured products. The number of published case studies is relatively low, e.g. [2], [3], [4] and the definitions, methods and impact assessments are unestablished and evaluation of the cases is difficult. Additionally the environmental impacts of many substances used in products and in the manufacturing processes are not well-known and there is no reliable information available on the impacts of emissions.

4. Case studies

4.1 Frequency converter

In the first "ANSELMI"-project research module the ecological profile of a product was examined from the viewpoint of a frequency converter (ACS 400 from ABB company, Figure 1) [5]. The life cycle assessment (made earlier by ABB Oy BAU Drives, Helsinki, Finland) of the product and the utilization of the results achieved were starting points as the creation of the ecological profile was studied. Issues to consider when creating the profile were examined: the compilation of environmental information from a supply chain, the transmission and quality aspects of the information, methods to assess environmental impacts and possibilities to utilize the ecological profile in product development.

The frequency converter together with an alternating-current motor constitutes a variable speed drive, which starts softly with a small starting current and has a continuous speed control over a wide range. Application areas for the ACS 400 are typically low-duty variable speed drives in conveyor, packing, mixing and ventilation machinery.

The life cycle assessment made by ABB had been used as a basic information for an environmental product declaration guided by the instructions [6] of the Swedish Environmental Management Council. Those instructions defined specifications for the LCA, for example the environmental impact indicators. The product system boundaries of the LCA covered material and energy consumption as well as emission and waste generation during the following life cycle phases: the extraction and production of raw materials, the manufacturing of main parts, the use of the product and disposal. The production information of the components of the main parts was not demanded but it was voluntary for producers. On the basis of a typical electric motor load selected, energy consumption during the product usage was calculated. The consumption was defined to be the amount of electricity production needed to compensate power dissipation. In addition, it was assumed that the product had been manufactured in Helsinki (Finland), stored in Menden (Germany) and used in Central Europe.

ABB compilated the information of the product main parts from the supply chain with a life cycle inventory questionnaire. Questions related to the material contents of components, chemicals and energy consumption in manufacturing processes, production waste, recycling as well as the transportation of components and main parts. The life cycle inventory input/output data from energy, material and component production processes and from transportation had been gathered from existing life cycle inventory databases, which substantially cut down the data collection work needed. On the other hand, an information chain from a raw material acquisition to the finished product would be unbroken, if the manufacturers of frequency converter main parts transmitted information from their own subcontractors to ABB. Then the amount of processes from which information is required would be very broad. Solely, the life cycle and the production of product cover parts includes many processes, which can be seen from the hypothetical flowchart in Figure 2.

The results of the life cycle impact assessment included estimated potential environmental impacts in five impact categories and the estimation of main natural resources and hydroelectric power used. The environmental impacts of the product usage, particularly those of electricity consumption, were dominant compared to the other phases. Because of that, the choice of electricity production mix for inventory analysis had an important influence in terms of the reliability and sensitivity of the LCA. According to the sensitivity analysis made by ABB, the impacts of e.g. average OECD electricity production were about 60 – 100 times greater than the impacts of Norwegian hydro power depending on the impact category.

Figure 1. Variations of the ABB´s ACS frequency converters.

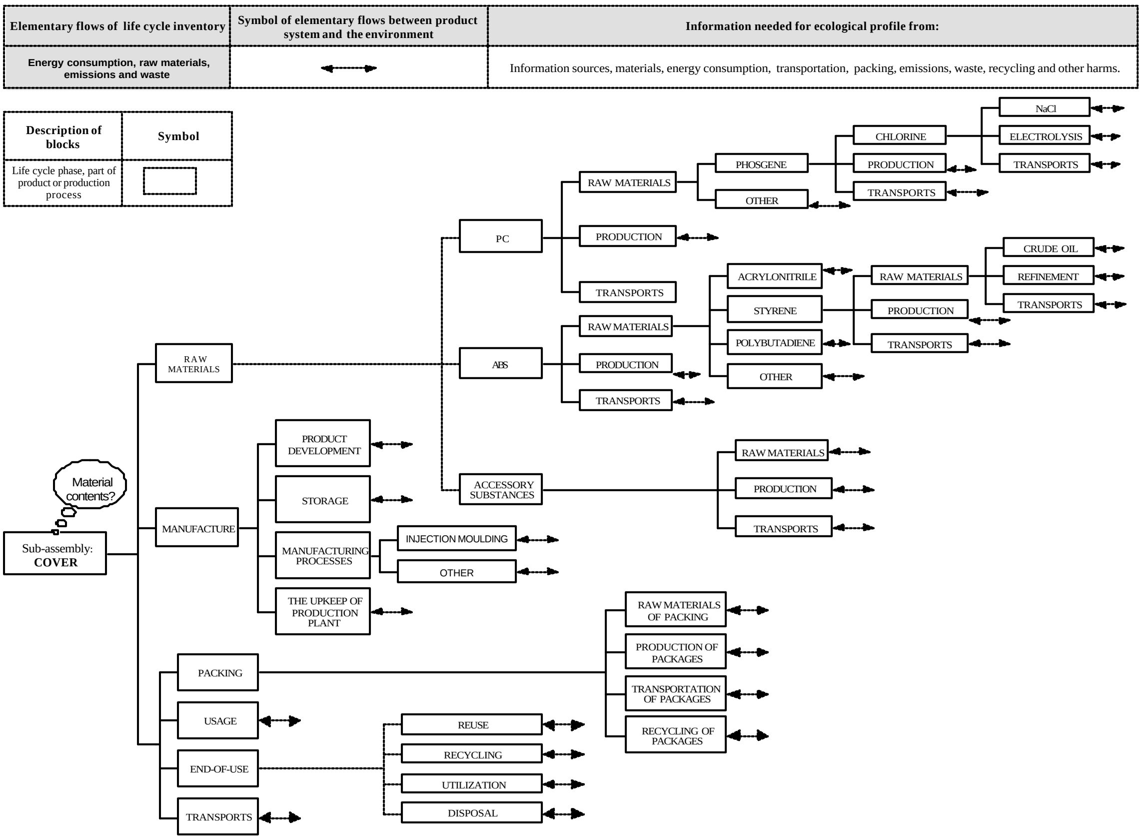

Figure 2. The flowchart of the hypothetical life cycle of the frequency converter cover parts.

According to the case study results the quality aspects of the environmental information are essential. The availability and on the other hand the amount of data to be handled is a problem. There is also a need of common environmental impact assessment methods for electrical and electronics industry.

Integration of environmental aspects into the design process has been a strategic choice at ABB. An environmental plan for the product has been prepared in the beginning of every new product development project, in which earlier LCAs and forthcoming environmental legislation are considered. Especially the most significant elements of a product system affecting the environment have been inspected carefully. So far, environmental impacts have been reduced by developing the efficiency, recyclability and serviceability of products. For example, the replaceability of fans and electrolytic capacitors has been improved. The usage of ecological profile of prospective products could improve the DfE efforts further.

The assessment of other environmental aspects, like noise and the impacts of electromagnetic fields, is one part of the ecological profile of a product also. The electromagnetic compatibility of the frequency converter has been studied by ABB because of the EMC – directive. The measurement of product noise has own standards also.

4.2 Welding machine

The life cycle assessment of a welding machine was carried out in the second "ANSELMI"-project research module. The LCA methodology was evaluated concentrating on the implementation phase of the LCA. The product studied was a light and compact MMA/TIG welding machine (Minarc 140 from Kemppi Oy, Lahti, Finland, Figure 4) typically used for repair and maintenance welding. Potential environmental impacts in 11 categories at the manufacturing, delivery and usage phases of the product were estimated using EIME™ ver. 1.5 (Environmental Information and Management Explorer) DfE/LCA software. The database of the software includes life cycle inventory data units from the production of materials and electr(on)ic components as well as from industry specific manufacturing processes [7]. The inventory data model for the product manufacturing phase was created by parametrizing the inventory data units of the database. The manufacturing phase included the beginning of the life cycle up to the finished product. The energy consumption of the usage phase was modelled with average usage profiles including estimated working years as well as arcing and force-off time with their energy consumption. The usage profiles considered were:

1. Service, Central Europe, 10 years, 25 days/year: arc time 0,5 h/day, force-off time 2 h/day
2. Farm, Finland, 15 years, 10 days/year: arc time 1 h/day, force-off time 7 h/day
3. Shipbuilding dock, France, 6 years, 200 days/year: arc time 0,75 h/day, force-off time 4 h/day

Only the power dissipation of the welding machine was included in the energy consumption of the usage phase. The impacts of the welding process itself were excluded from the LCA. The disposal of the product was excluded because of the lack of available inventory data. The evaluated product system is described in Figure 3.

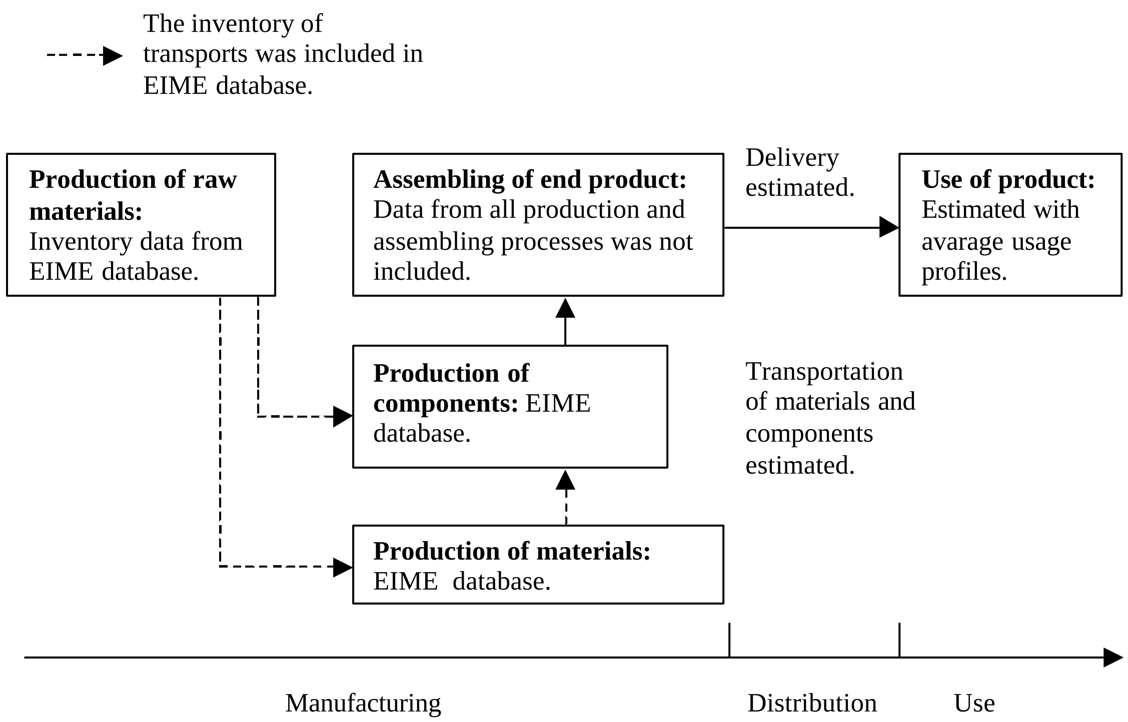

Figure 3. The evaluated product system of the welding machine in the LCA.

The modelling of the product life cycle inventory, particularly the evaluation of inventory data units' applicability as well as the parametrizing and editing of units, was time consuming. The distribution of environmental impacts, the elementary flows of manufacturing phase and materials between subassemblies and components was calculated by the software. By analyzing the distribution information the main elements including environmental loads were identified. The recording of the calculated distribution was the most labor-consuming phase of impact assessment data handling due to features of the EIME software.

The comparison of life cycle phases was not entirely unambiguous, since the proportion of impacts between manufacturing and usage phases varied depending on the impact category. The share of transports was almost negligible. Some influences of choices made during inventory analysis on impact assessment results were tracked by sensitivity analysis. For example the usage profiles and the electricity production mix used and the assumptions made when modelling the inventory of the manufacturing phase were studied. It was observed that the composition of the electricity production mix and e.g. the size of silicon chip in integrated circuits had a great influence on results. In addition, the life cycle interpretation was simplified with subjective key figures, calculated by the sum of equally weighted impact indicators, to facilitate the use of LCA results for DfE.

The quality of initial data for the LCA varied and the EIME inventory model was partly inaccurate. Therefore, reliable conclusions were not able to be drawn on the grounds of small impact differences between the details of the product. On the other hand, the knowledge of both DfE and specifications for the product would have been needed to draft actual proposals for DfE. Inventory data gathering from the real product system instead of using avarage data from databases could improve the reliability of the LCA. However, this would be difficult under present circumstances because there is not enough inventory data available. Again, according to the EuE draft, information from subcontractors will be required in all cases.

To achieve transparency, all essential LCA data and the sources of additional information were documented. On the contrary, to reproduce the LCA, the documentation was not adequate enough. One reason for this was the absence of a suitable data export file format for the EIME inventory model. The LCA can be repeated with EIME software but the documentation of the EIME model is not usable with other LCA softwares. The available quality information of the initial data used was constricted and qualitative, which made data quality assessment too uncertain to be useful.

Figure 4. Kemppi´s Minarc welding machines.

5. Conclusions

According to the case studies there will still be several open questions in creating an ecological profile of the electrical equipment. The key questions are inventory data collection and distribution, environmental impact assessment methods, and applying the results to the DfE process. There is a need to improve inventory: information about many of the chemicals used in electrical and electronics industry is not available in existing LCA databases or the information is outdated. Also the development of more specific, publicly available environmental databases and tools to perform impact assessment is needed. Because the work is difficult and time consuming a common effort by the suppliers in the same sector of activity would be needed. Standardisation could be very helpful in this respect.

The commercial life cycle of a typical electrical and electronic equipment is often short, the new product versions replace the old ones. There is a need for compromise between the wideness and rate of performing LCA process. If LCA is to be used to provide real time information (e.g. as a tool to predict environmental impact of existing and future processes), it might require development of more process based inventory data. Wider quantitative life cycle assessments are possible for instance to a new product family for the reference data of single product design. It is often difficult to obtain exact information from suppliers for LCAs. There is not much published inventory data of the LCA studies performed on the branch and the data available is quite superficial. To facilitate the usage of LCA, dated information about methods, instructions, software tools and databases and performed assessments is needed.

One possibility to shorten and simplify the LCA process is to confine studies only to a limited part of the product life cycle, for instance the production stage or the production and usage stages combined. There may however be a risk of oversimplification and exclusion of some important factors.

Environmental properties should be integrated as an optimisation parameter during the product development together with more traditional values such as function, production cost, and ergonomics. To integrate the LCA into a part of product development process, there is a need for linked LCA and design softwares. LCA softwares on the market are not as such suitable for designer’s everyday tools, because their use requires time, conversance and expertise. The results are never unambiguous, which makes their interpretation difficult. LCA is at its best a company level tool to define the environmental policies and goals of product design, which can be used as basis for compiling individual recommendations for DfE.

The "ANSELMI"-project will be continuing with environmental information and communication aspects. Relevant information about the environmental loads of the product is essential to every operator in the product chain. There will be need for instructions relating to the manufacturing process, information for consumers of the significant environmental attributes and user instructions. Operators of electronics waste treatment are interested in information of substances and components, which may have influence on disassembly and recycling processes. The fourth module will produce a summary report of the DfE principles and application possibilities in electrical and electronics product design and manufacturing.

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