LCA and Ecodesign Framework and Applications in the Electronics Sector

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Abstract

Life Cycle Assessment (LCA) is an indispensable tool in estimating the environmental impact of products and services. Generating estimates according to international standards is a crucial precondition towards optimizing the environmental performance of those products and services. In Europe, the Ecodesign Directive (2009/125/EC) provides a method on how to determine impacts associated with energy-using and energy-related products, including electric and electronic equipment (EEE). One the one hand, efforts are being made to further harmonize LCA methods to allow for comparative assertions between different products and to eventually integrate LCA into further parts of the European environmental legislation. On the other hand, LCA studies of electronics components, products, and product-service-systems can be very complex as they need to reflect the global supply chains, advanced production methods, and fast technological development in the field of EEE. This paper provides and overview of both the LCA and Ecodesign framework, current developments in the field, and illustrates the intricacies of LCA studies in the field of EEE with a focus on consumer ICT and IT devices.

Keywords: *Life Cycle Assessment; Ecodesign; Electronics; Circular Economy*

Abstrak

Life Cycle Assessment (LCA) merupakan sebuah alat yang sangat dibutuhkan untuk memperhitungkan dampak lingkungan dari produk dan jasa. Menentukan estimasi berdasarkan standard Internasional merupakan prasyarat utama dalam optimasi kinerja lingkungan baik produk maupun jasa. *Ecodesign Directive* (2009/125 / EC) merupakan sebuah metoda standard di Eropa untuk menentukan dampak yang terkait baik dengan penggunaan energi maupun produk energi, termasuk peralatan listrik dan elektronik. Di lain sisi, harmonisasi metode LCA untuk perbandingan produk yang berbeda dan mengintegrasikan LCA ke dalam bagian undang-undang Eropa masih terus diusahakan. Sementara itu, studi tentang LCA terkait komponen elektronik, produk, dan system layanan produk dapat sangat kompleks karena harus mewakili rantai pasokan global, moetpda produksi, dan pengembangan teknologi yang cepat di bidang peralatan listrik dan elektronik. Makalah ini memberikan gambaran umum tentang kerangka kerja dan ecodesign LCA, perkembangan terkini di lapangan, dan menggambarkan selik-beluk studi LCA di bidang peralatan listrik dan elektronik dengan fokus pada konsumen dan peralatan IT.

Kata kunci: *Kajian Daur Hidup, Ekodesain, Elektronik, Ekonomi Sirkuler*

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1. INTRODUCTION

Life Cycle Assessment (LCA) is an indispensable tool in estimating the environmental impacts of products and services, and is nowadays utilized in many applications and economic sectors. Electrical and electronic equipment (EEE) is a challenging field for LCA, due to devices consisting of hundreds or thousands of individual components, the complex global supply chains, the manifold materials utilized, advanced production methods, continuous fast technological developments, and, from a European perspective, the concentration of production mostly in Asia as a challenge in data acquisition. Nevertheless, the steady increase in global sales figures and the associated rising amounts of e-waste are major global challenges, with considerable implications for the environment and human health. Therefore, appropriate LCA methods need to be employed in order to quantify and mitigate the environmental issues caused by the increasing consumption of EEE. Having such quantifications on the environmental performance of products or entire product groups allows relevant actors to target hotspots in the life cycle and to minimize overall impacts in an efficient manner.

This paper reviews the relation between LCA and ecodesign of EEE with a focus on consumer electronics. Examples of the complexity of LCA of electronics are presented on component, product, company, and system level. Additionally, the paper discusses recent and current developments in LCA methods and their legislative environment in Europe.

2. LCA AND ECODESIGN FRAMEWORK

The European Ecodesign Directive (2009/125/EC) was implemented with the goal to reduce the energy and material consumption of energy-using and energy-related products [1]. While the Directive has succeeded in its goal to increase the energy efficiency of EEE since its inception [2] through implementing mandatory requirements on a product-group basis, material efficiency aspects have only recently started to gain increased attention [3]. The first such requirements were set for vacuum cleaners in 2013, for which manufacturers need to provide test results on the durability of the motor and the hose of the device [4] in order to be granted access to the European Union market.

To enable the Ecodesign Directive to target product groups of the highest relevance, preparatory studies are carried out using a standardized method known as the Methodology for Ecodesign of Energy-related Products (MEErP) [1]. MEErP comprises techno-economic analysis, information on markets, technologies and users, streamlined LCA, design options and scenario analysis. For the LCA aspects, MEErP includes a spreadsheet-based LCA tool known as EcoReport that produces a simplified environ-mental assessment in a comparatively manageable timeframe. While this approach has been sufficient for screening LCA purposes to identify hotspots in the life cycle of studied product groups, full-scale LCAs of electronics need to dig deeper into the technological intricacies of current electronics hardware to generate appropriate life cycle inventories and assessments. The following section presents concrete examples of LCA work to illustrate complexities of specific study cases.

3. LCA STUDIES AND ECODESIGN OF EEE

The following subsections present examples of simplified or full LCA studies on electronic components, products, product-service-systems, and carbon footprinting on company level, to illustrate the challenges and opportunities of each case study.

3.1. Component Level LCA

3.1.1. Lithium-Ion Batteries

Mobile ICT and IT devices require batteries with a high energy density. Since its introduction to the market in 1991, the lithium-ion battery has become the de-facto standard for mobile ICT and IT equipment such as notebooks, tablets, smartphones, wearables, and many other applications. The relevance of batteries in a device from a life cycle perspective are two-fold: The inevitable degradation of the battery may shorten the lifespan of the entire device, particularly if it cannot easily and cost-effectively be replaced, and the battery contains valuable resources, including critical raw materials (CRM) such as Cobalt.

Fig. 1. Typical Li-ion-polymer notebook/tablet battery pack (top) and look inside the pack (bottom) [5]

A comprehensive LCA study of a notebook/ tablet-PC lithium-ion-polymer battery pack used primary data on material composition and energy use of the production from one of the global players in battery

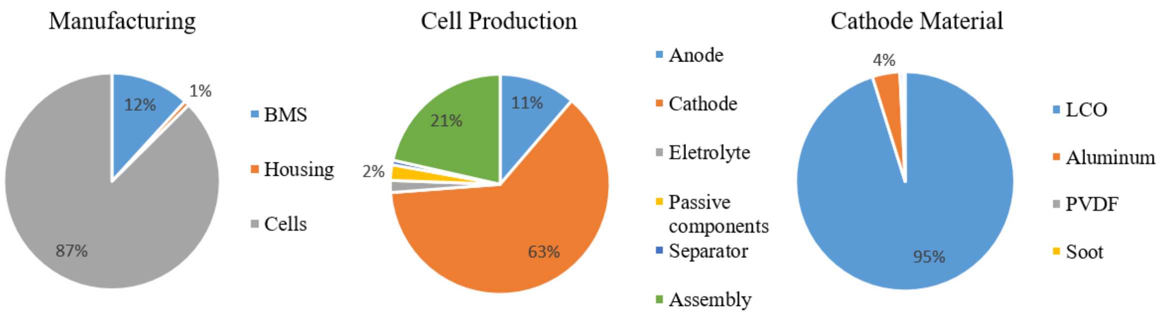

Fig. 2. Hotspot analysis of the manufacturing phase of the studied Li-ion-polymer notebook/tablet battery pack [5]

cell manufacturing. The additional components, being the battery management system (BMS), wiring and housing, was modelled via a tear-down analysis and mapping against relevant generic datasets. The study found that the hotspot of environmental impacts over the life cycle of the battery is associated with the production of the active material used to produce the cathode, lithium cobalt oxide (cp. Fig. 2) [5]. This is due to considerable energy consumption associated with the electrically powered kiln required to produce high temperatures for relevant chemical reactions to take place. The study excluded the use phase from its scope, as energy use needs to be allocated to the life cycle of a device using the battery, such as a notebook or tablet-PC, rather than the battery itself.

Optimizing the environmental performance of batteries, too, is closely related to the device it powers. For instance, devices can increase the lifespan of Li-ion batteries by reducing the charge/discharge rate, limiting the maximum voltage the battery charged to, or optimizing thermal management to avoid excess heat [5]. Additionally, other cathode materials may result in lower impacts, however, costs and specific energy of cathode materials are currently the decisive factors for the choice of Li-ion electrode materials.

3.1.2. Wireless Charging Equipment

Wireless charging by induction is a known method that has been implemented into devices such as electric toothbrushes for years. More recently, however, smartphone manufacturers have increasingly added this feature into their products. The primary questions from an environmental point of view pertain to the additional hardware required to enable wireless charging and the energy efficiency compared to wired chargers during the charging process.

A study investigated these questions using empirical measurement of the energy efficiency of a set of tested smartphone chargers, as well as analysis of the required hardware [6]. Primary data for the LCA was obtained from disassembly of charging devices: an AC adapter, a USB cable and a wireless charging pad. In terms of hardware, both wired and wireless chargers are identical, with the exception that the wireless charger requires a charging pad in addition. The charging pad is composed of three main elements: the mainboard, the copper induction coil and the plastic housing (Fig. 3).

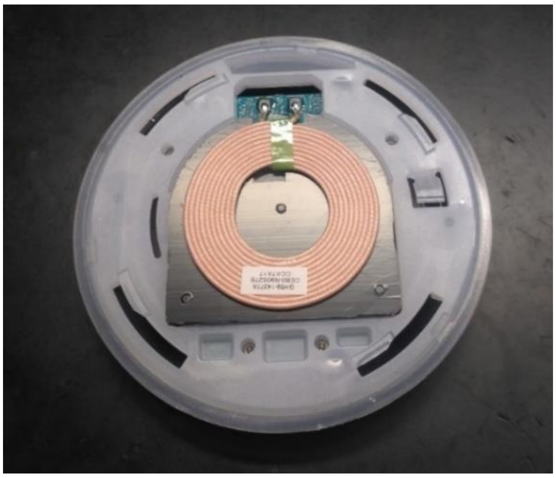

Fig. 3. Partially disassembled wireless charging pad, showing the copper induction coil and underlying PCB [6]

Two different smartphones were tested with four different wired and three wireless chargers to establish differences in energy efficiency during charging. The input energy was measured and the battery information of tested phones was used to estimate the charging efficiency. It was found that the wireless chargers were on average 24 % less energy efficient compared to the wired solution. However, the different models tested resulted in a notable variation of the individual results of the tests (Fig. 4).

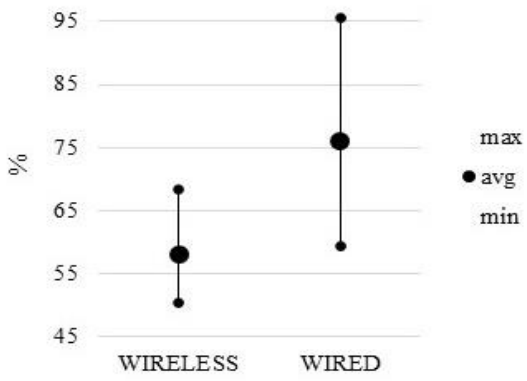

Fig. 4. Comparison of the charging efficiency of both solutions, illustrating the wide variety of efficiency of different models used for testing [6]

In terms of the LCA results, Fig. 5 shows that the wireless charger incurs considerably more CO_2 equivalents compared to the wired charger over the entire life cycle. This is due to increased manufacturing and distribution efforts as well as the discussed decreased energy efficiency (only losses were included in the calculation, not the actual energy to charge phones). The mainboard, including ICs and passive components, was found to contribute 84 % of the GWP of the manufacturing of the charging pad.

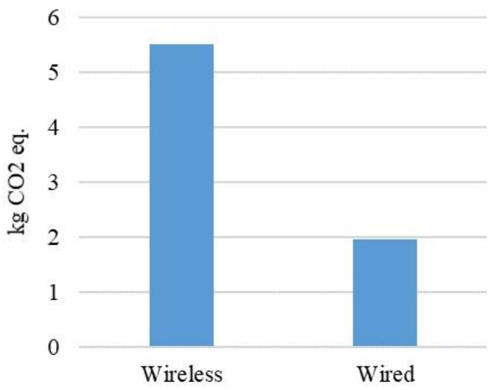

Fig. 5: Comparative GWP results for the entire life cycle of a wireless and a wired charger [6]

The study results imply that wireless chargers for mobile ICT devices may only be environmentally beneficial, in case the total number of chargers in use is reduced notably. However, it seems unlikely that such a reduction of the numbers of chargers would occur, even in case of a widespread (public) implementation and high interoperability between different brands and devices.

3.1.3. Integrated Circuits

Semiconductors commonly contribute a significant share of the total environmental impacts incurred by the manufacturing of electronic equipment, however, they are frequently challenging to model in LCA studies. The main reason for this is the lack of data availability, as manufacturers of such equipment do not commonly publish detailed data on the latest fabrication processes. Additionally, integrated circuits (ICs) are frequently packaged into polymeric housings, which complicates the process of gathering information on the semiconductor itself. To appropriately model semiconductors in LCA studies, the area of silicon contained within the IC package needs to be known, as the area of processed semiconductor material is the most appropriate parameter to estimate environmental impacts of the complex clean room production processes including lithography, etching, and metallization steps. Various techniques can be applied to obtain such information to differing degrees of certainty.

Fig. 6 shows the photo of a packaged IC from a smartphone mainboard as well as an X-ray image of the same IC, revealing the internal structures that can be used to estimate the semiconductor area contained in the package. In this particular case, the X-ray image shows that an estimation made from only judging the package itself would easily lead to an overestimation of the actual area. Destructive methods, such as decapping, can reveal the actual die size, however, the X-ray image is a good starting point to reduce uncertainty of assumptions regarding semiconductor area in an IC.

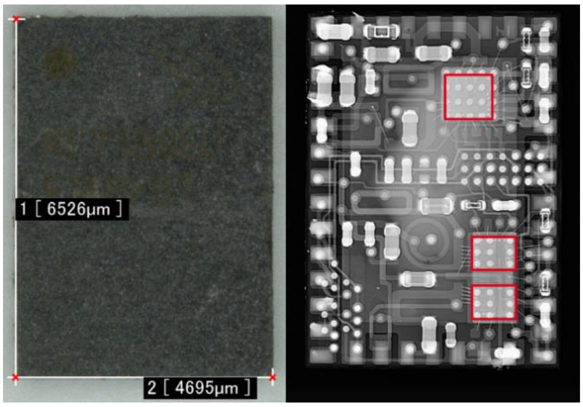

Fig. 6. Photo of a packaged 3G/4G power amplifier IC from a smartphone mainboard (left) and X-ray image of the same component indicating it is a module with three smaller dies (highlighted in red boxes) and various passive components [7]

3.2. Product-Level LCA

Generally speaking, EEE fall into two major groups regarding their life cycle phase environmental impact contribution. For some EEE, the manufacturing phase is the largest contributor to overall impacts. This is frequently the case for consumer electronics that are comparatively energy efficient during use, for instance mobile equipment such as notebooks, tablets, or wearables. For other EEE, the use phase is the largest contributor. This is frequently the case for consumer electronics that are comparatively energy efficient during use, for instance mobile equipment such as notebooks, tablets, or wearables. For other EEE, the use phase is the largest contributor. This frequently applies to large household goods such as washing machines, refrigerators, or dish washers. The following study case falls into the first group.

3.2.1. Smartphone

An LCA study of the Fairphone 2 smartphone [8] found that the majority of environmental impacts over its entire life cycle are associated with the production of the device (Fig. 8). A contribution analysis revealed that the mainboard, consisting of a PCB, ICs, hundreds of passive components such as capacitors and resistors, and other components, such as connectors, contributes the largest share of environmental burden associated with the manufacturing of the phone (63 % of the GWP). The production of the multilayer PCB as well as the larger ICs, particularly the CPU, RAM, and flash memory, cause the largest environmental impact. The display module and the battery, on the other hand, only contribute minor shares to the overall manufacturing GPW (8 % and 3 %, respectively). Consequently, for an ecodesign approach, the study concluded that a replacement of components such as the display and battery is justified in order to extend the use phase of the device, including the mainboard. Therefore, the device should be designed in a way that allows easy swapping of those parts so that a user can carry out the repair themselves and keep using the part with the highest environmental impact for as long as possible.

One of the distinguishing features of the Fairphone 2 is its modular design. Different functions are embedded in separate modules that can easily be accessed and replaced. Individual modules are connected to the mainboard via pogo pin connectors (Fig. 7). The study found that the design aspects of the device that enable modularity, i.e. the gold-plated copper pins and the PCB area required for the connectors, contributes 4.6 % of the manufacturing GWP. Being aware of this impact may have been one factor for the company to decide for a new design for their recently announced follow-up device, the Fairphone 3, which replaces most of the pogo-pin connectors more traditional, smaller connectors. Only a full LCA study of the Fairphone 3 will show the effect changes to its design have in terms of environmental impacts.

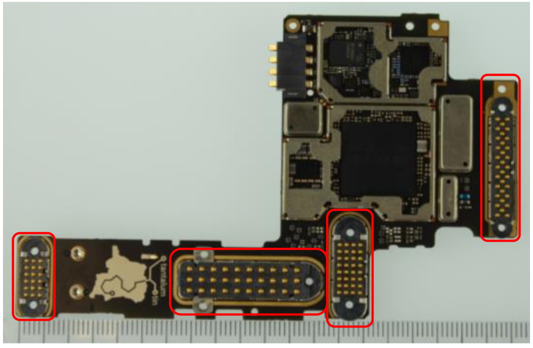

Fig. 7. Mainboard of the Fairphone 2 smartphone with gold-plated pogo pin connectors highlighted with red boxes [8]

3.3. Product-Service-System LCA

In some cases, solely assessing the manufacturing of hardware, its distribution, energy consumption during the use phase, and EOL treatment and recycling does not appear appropriate when capturing the full impact of a product on the environment. For instance, an increasing number of services is being developed for smart city solutions, based on internet of things (IoT) devices, which aim to have net positive environmental impact. One such example is a smart city service that relies on the use of a sensor network, server and network infrastructure, and a software application to direct drivers of automobiles to a parking spot in the vicinity of their destination. On the one hand, the provided functionality requires the implementation and use of hard- and software, with associated environmental burdens, on the other hand,

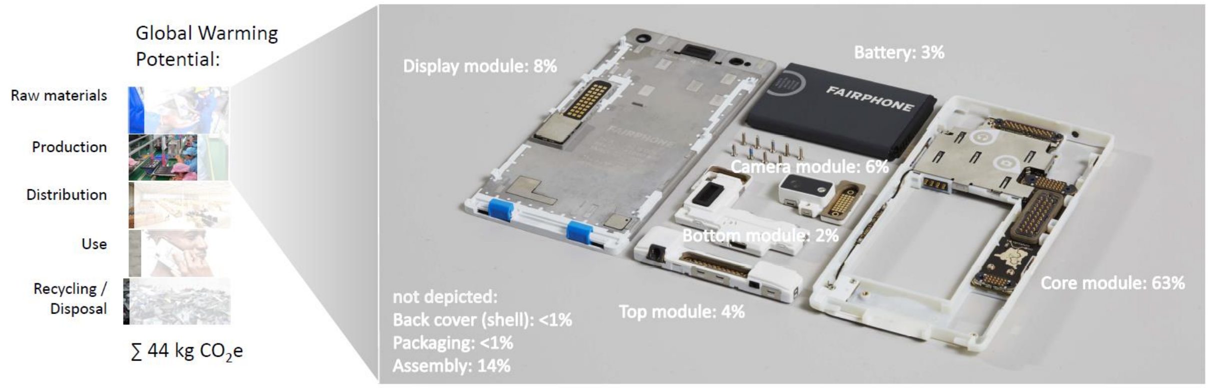

Fig. 8. Fairphone 2 LCA results (global warming potential, GWP) over full life cycle and per module [9]

it aims to reduce traffic and emissions in cities by shortening the driving distance in search for parking.

The scope of the study investigating the net environmental impacts of such a smart parking system [10] included the manufacturing of sensors (Fig. 9), their roll-out in the city (distribution, drilling into asphalt underneath parking spots, installation), and the required server infrastructure. EOL treatment and recycling of sensors is not foreseen by the manufacturer and are thus not part of the LCA.

Fig. 9. Parking sensor closed (left) and open (right) [10]

Table 1. Results for the sensor LCA over its lifetime [10]

Component	Kg CO2 eq.	GWP Share
PCB	3.1	26 %
ICs	3.3	38 %
Passives	1.2	10 %
Battery	0.6	5 %
Roll-out (installation)	3	25 %
Rest	0.5	4 %
Total	**11.8**	**100 %**

While the LCA of the sensor and servers conforms to standard LCA work of electronics, the core questions arise with respect to the savings potential offered by the service. How many users will make use of the system? How many kilometres of driving in the city and thus which amount of emissions can be avoided? How actively does the system need to be used in order to achieve net benefits, i.e. where is the break-even point?

As a first study case, the German city of Hamburg was used. The infrastructure required to implement the smart parking service in Hamburg was calculated to cost around 17 tons of CO_2-equivalent annually. Using statistical data on parking traffic with and without the smart parking service, it was determined that more than 800 meters of driving distance are avoided on average per parking process via the smart parking service. Taking into account CO_2 and NO_x emissions on a per-kilometer basis and accounting for the average emissions from the German fleet of automobiles, it was found that the entire system incurs net environmental starting at a very low market penetration rate. The break-even point is reached in case 0.28 % of all parking processes are carried out using the service, beyond which the overall benefits increase considerably in terms of GWP. However, this applies to a large city like Hamburg, while for smaller cities the break-even point is situated in the range close to 3-4 % use rate. It is, however, critically discussed that the system does not foresee a recovery and recycling of the sensor at their end of life (i.e. before the battery has used up all of its capacity). It is therefore pointed out that the negative impacts with respect to resource consumption cannot directly be offset by the avoided vehicle emissions.

3.4. Company Level

Some companies have been reporting their overall annual carbon footprints, such as Apple Inc. [11]. Detailed LCA studies are carried out per product, the results of which are multiplied with the number of product sold globally in a respective year, in addition to an estimation of other company-related activities such as building and network infrastructure. Table 2 summarizes the company carbon footprint reported by Apple in their annual environmental responsibility report [11].

Table 2. Company carbon footprint reported by Apple Inc. [11]

Aspect	GWP contribution
Manufacturing	74 %
Product use	19 %
Product transport	5 %
Corporate facilities	2 %
End of life	< 1 %
Total GWP	**25.2 mio. tons CO_2-eq.**

This approach provides insights into hotspots that may be targeted to put in place efficient mitigation measures, and to track whether a company is able to reduce their environmental impacts on the global environment while continuing to grow their business.

4. DEVELOPMENTS IN THE FIELD

A lot of progress has been made with LCA and Ecodesign of EEE in recent years, and more progress is expected in the near future. To illustrate, two current developments are summarized in this section.

Firstly, there have been efforts within the European Union to further harmonize the LCA methods to allow for greater comparability between the results of different studies. In 2013, the European Commission launched the “product environmental footprint” (PEF) method [12], the main goal of which is to increase comparability between products of the same product category and therefore also allow for comparisons and comparative assertions. Such comparisons could be used by industry to promote their own progress or products against competitors, or for policymakers to include into EU environmental legislation. Between 2013 and 2016, 17 pilot studies were carried out to test the process and to develop product- and sector-specific rules. The pilot studies included product groups from the EEE sector, such as batteries, IT equipment, and photovoltaic electricity generation, but also from other sectors, such as T-shirts, detergents, and beer. However, as is pointed out in the PEF pilot phase review report [13], views on the Environmental Footprint have been strongly polarized. While industry generally saw the approach as a good opportunity to use LCA in the promotion of a green market in the EU, consumer, environmental NGOs and have cast doubt on the approach, leading to lively debates [14].

Secondly, it is expected that the MEErP will be updated in the near future to better account of Circular Economy aspects, particularly material efficiency, durability, and reparability, among other aspects [15]. This implies that the Ecodesign Directive will continue to tackle environmental impacts of energy-using and energy-related products with respect to not only energy efficiency, but with increasing emphasis on material efficiency.

5. CONCLUSIONS

The significance of life cycle assessment methods in the field of electronics, as well as in other sectors, is likely to increase further in the near future, as members of the civil society, manufacturers, and policy makers strive towards harmonization and implementation of LCA results into public and legislative processes. Challenges remain, not at least in methodology and the degree of detail with which complex products such as electronics need to be assessed in order to appropriately account for the fast development taking place in the field.

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