Global Warming Potential of a Smartphone

Using Life Cycle Assessment Methodology

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ROYAL INSTITUTE OF TECHNOLOGY

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Abstract

The global development and usage of smartphones are rapidly increasing. Further, the high capacity and functionality of these devices indicate high technological manufacturing processes and complex supply chains. Thus it is of interest to investigate the potential environmental impacts of a smartphone, from a life cycle perspective.

This study uses a Life Cycle Assessment (LCA) methodology in order to evaluate the potential environmental impacts of a smartphone, in particularly the smartphone Sony Xperia™ T. Environmental in- and outflows, including resources, emissions to air, water and soil as well as waste treatment and electric energy consumption are quantified for the entire life cycle of the smartphone. The system boundary for the LCA includes raw material acquisition, production, in- and outbound transportation, utilization and end-of-life treatment for a smartphone with an estimated lifetime of 3 years. All phone components and processes as well as the charger, USB-Cable, headset, delivery box, instruction manuals and the use of network infrastructure have been included within this boundary. The data collection process involved dismantling and analyzing a Sony Xperia™ T smartphone to gain knowledge on the hardware and collecting information from Sony Mobile and Ericsson Research and partially from external sources for major smartphone processes. GaBi 6.0 Software was used for the modeling and analysis. Sensitivity analysis was performed on different parameters of the model to evaluate the effects of the assumptions and methodological choices adopted for the study. The chosen characterization model for this study is established by the Institute of Environmental Sciences (CML). The analysis of the LCA results focus on the CML global warming potential (GWP) impact category and present figures representing the carbon dioxide equivalents (kg CO_2e) for each life cycle stage of the smartphone.

According to this LCA study, the Sony Xperia™ T smartphone, excluding accessories and network usage, produces a total of 45 kg CO_2e to the atmosphere during its entire lifetime, when considering medium usage and a Swedish electricity mix for the use stage. This corresponds to the amount released when driving an average European car for approximately 300 km. The life cycle stage that is calculated to have the most significant environmental impact on the results is the production stage, accounting for just above 30 kg CO_2e. Activities with main contributions to the total GWP impact include integrated circuit (IC) production, phone shell raw material acquisition and production followed by smartphone assembly and distribution. If accessories and mobile network are included, the total life cycle impact is 68 kg CO_2e for the assessed scenario. As no results are available for other impact categories, no conclusions can be made related to impacts such as eutrophication and acidification.

If a global electricity mix is applied, the total results for the smartphone including accessories and network usage increase to 117 kg CO_2e for the moderate user scenario for the 3 year life cycle period. This corresponds to approximately 40 kg CO_2e per year which is equivalent to the amount released when driving an average European car for 270 km. Excluding accessories and network usage, the life cycle impact for the smartphone for this alternative is 51 kg CO_2e.

A parameter model in Microsoft Excel, based on multiple parameters, has also been constructed as an integrated part of this study. This parameter model is aimed to provide results for smartphone models that differ in look and performance and also aimed to be applied for tablets.

Abstrakt

Den globala utvecklingen och användningen av 'smartphones' ökar allt snabbare i dagens samhälle. Högre krav på både prestanda och kapacitet resulterar i hög-teknologiska tillverkningsprocesser och komplexa leverantörskedjor. Det är därför viktigt att, ur ett livscykelperspektiv, utforska potentiell miljöpåverkan som en 'smartphone' kan ha.

Detta examensarbete genomfördes på Ericsson Research i nära samarbete med Sony Mobile. Syftet med denna studie är att genomföra en Livscyckelanalys (LCA) på en 'smartphone', i detta fall en Sony Xperia™ T, och uppdatera en tidigare LCA studie utförd på Ericsson och Sony Ericsson 2008. Miljömässiga in och ut flöden till och från systemet inklusive resurser, utsläpp till vatten, luft och mark samt avfallshantering och energi användning har kartlagts där dessa flöden är kvantifierade för den totala livslängden av produkten.

Den definierade systemgränsen för LCA:n inkluderar framställning av råmaterial, produktion, interna/externa transporter, användning och avfallshantering för en 'smartphone' med en uppskattad livslängd på 3 år. Alla väsentliga 'smartphone' komponenter och processer samt laddare, hörlurar och nätverksinfrastruktur har inkluderats inom denna gräns. Mjukvaran GaBi 6.0 har används för modelleringen och analysen. Kvalitets- och känslighets –analys av data har utförts på olika parametrar av modellen för att kunna utvärdera effekterna av metod val som har gjorts för denna studie. Den utvalda karakteriseringsmodellen för denna studie är fastställd av Institute of Environmental Science (CML). Analysen av LCA resultaten fokuserar på CMLs miljöpåverkanskategori för global uppvärmning där värdena är presenterade i koldioxidekvivalenter för varje livscykelfas för en 'smartphone'. Data-insamlingsprocessen omfattade isär plockning av en Sony Xperia™ T 'smartphone' med syftet att öka kunskapen om hårdvaran samt insamling av information från Sony Mobile, Ericsson samt från externa källor för de större 'smartphone'-processerna.

Enligt denna LCA studie producerar, med undantag för tillbehör och nätverksanvändning, Sony Xperia™ T 'smartphone' totalt 45 kg koldioxidekvivalenter under produktens hela livslängd med genomsnittlig svensk el-mix under användarfasen. När ett globalt el-mix genomsnitt tillämpas i livscykelanalysen blir resultat 51 kg koldioxidekvivalenter. Detta motsvarar mängden av koldioxidutsläpp när man kör en genomsnittlig bil 300 km respektive 350 km. Livscykelfasen som har störst miljöpåverkning på resultatet är produktionsfasen som står för 30 kg koldioxidekvivalenter.

En parametermodell i Microsoft Excel har konstruerats som en del av examensarbetet. Denna modell är skapad för att kunna användas då resultat önskas för en mobiltelefonmodell med annat utseende och kapacitet än Sony Xperia™ T 'smartphone'.

Summary

The world's population today is over 7 billion and is expected to reach 9 billion by the year 2043.This increase is expected to go hand in hand with the demand and need for information and communication technology (ICT) as it can be considered as a strong tool in providing humans with necessities as well as improving life standards. Mobile phones are a type of popular ICT device; the worldwide mobile cellular subscription has reached 6 billion and is expected to expand in the coming years. ICT is considered as a solution for more sustainable development but requires additional attention to the potential environmental effects its products and services may have.

This study applies a Life Cycle Assessment (LCA) methodology in order to analyze the potential environmental impacts of a smartphone. To evaluate these impacts the smartphone model Sony Xperia™ T has been investigated. Smartphone accessories including charger, USB-Cable, headset, delivery box, instruction manuals and mobile network required for the use have been included in the study. Additionally, a parameter model for smartphones and tablets is created for future use based on the LCA results. A cradle-to-gate approach has been adopted where the entire life cycle of the product has been examined including the stages; raw material acquisition, production, use and end-of-life treatment and related transportations. Environmental in- and outflows, including resources, emissions to air, water and soil as well as waste treatment and electric energy consumption are quantified for all activities in the life cycle. The software program used for modeling and analyzing the life cycle models was GaBi version 6.0.

The main goal of this study is to conduct an LCA of a smartphone in order to determine the potential environmental impacts the device has during its life cycle. The functional unit for which results are presented have been set to the use of one smartphone during the lifetime of 3 years.

In this study the chosen characterization model is established by the Institute of Environmental Sciences (CML) at the University of Leiden in the Netherlands. The methodology adopted for this study is in accordance with the ISO guidelines and considers the LCA recommendations for ICT equipment provided by ETSI and ITU as far as possible. The analysis of the results focus on the global warming potential (GWP) and are presented representing the carbon dioxide equivalents (CO_2e) for each stage of the mobile device.

For a better understanding and a technical overview of the smartphone, a Sony Xperia™ T phone was dismantled and weighed to determine the components in the device. The phone materials were provided by Sony Mobile. A wide range of production data was collected with focus on processes that were considered to have a significant effect on the results. The determined key processes are the production of main phone components, the smartphone assembly, network usage and smartphone electricity use. The main phone components include integrated circuits (IC), printed wiring board (PWB), printed board assembly (PBA), liquid crystal display (LCD), battery, camera and phone shell.

The main data sources include a previous LCA study performed in 2008 of a Sony Ericsson feature phone, Sony Mobile materials, Ericsson Research documents and supplier questionnaires.

In this LCA the use stage includes alternative user scenarios i.e. scenarios for how the smartphone is utilized during its lifespan. Three scenarios specifying the electricity consumption of the smartphone; heavy, moderate and light users are created to represent the different types of smartphone users. The mobile network is divided into operational units as follows: user equipment, base station sites (RBS), control and core nodes, operator activities, transmission and IP core network, and data centers. Network allocation has been done to one smartphone based on gigabytes and number of mobile subscription.

According to this LCA study, the Sony Xperia™ T smartphone, excluding accessories and network usage, produces a total of 45 kg CO_2e to the atmosphere during its entire lifetime, when considering medium usage and a Swedish electricity mix for the use stage. The life cycle stage that is calculated to have the most significant environmental impact on the results is the production stage, accounting for just above 30 kg CO_2e corresponding to 68 percent. Use stage accounts for 8 percent, raw material acquisition stage for 11 percent, transportation stage for 11 percent and end-of-life treatment for 2 percent. Activities with main contribution to the total GWP impact include integrated circuit (IC) production, phone shell raw material acquisition and production followed by smartphone assembly and distribution.

If accessories and mobile network are included for the moderate user scenario in Sweden, the total life cycle impact is 68 kg CO_2e where the network usage accounts for 30 percent of the total life cycle impact. If heavy and light scenarios are considered, the results range between 67 and 71 kg CO_2e.

If a global electricity mix is applied the total results for the smartphone including accessories and network usage increase to 117 kg CO_2e over the 3 year life cycle period for the moderate user scenario, or approximately 40 kg CO_2e per year which is equivalent to the amount released when driving an average European car for 270 km. Excluding accessories and network usage, the life cycle impact for the smartphone for this alternative is 51 kg CO_2e.

From the sensitivity analysis it is assessed that the model is considered to be relatively stable with respect to the parameter values that have been altered as there is no drastic change in the total results.

Similar LCA studies, conducted by Apple and Nokia for their own line of smartphones, have been used for benchmarking results. As these studies provide only an overlooking portrayal of the results, the methodological procedures of the studies are unknown and thus the result comparison cannot be considered to be completely reliable. The present study is the only study that includes the mobile network usage.

Finally, an LCA study is based on representative data and models to symbolize real life circumstances. The resulting environmental impacts of an LCA study can only provide information on potential impacts and present representative and estimated figures. GWP has been selected for the result analysis of this LCA study and this study does not further analyze the remaining impact categories such as eutrophication and acidification. Thus general conclusions cannot be drawn regarding the total impact a smartphone may have on the environment.

A parameter model was created in Microsoft excel as part of the master thesis project. This model is intended to be used when assessing other smartphones and tablets.

Acknowledgements

This thesis is the finalizing study for a Master of Science at The Royal Institute of Technology (KTH) in Stockholm, Sweden. The study has been conducted at Ericsson Research in collaboration with Sony Mobile and has been completed in the summer of 2013.

As the study has involved data collection from multiple sources, a number of people have contributed to this work. On a higher level I would like to thank Ericsson Research and Sony Mobile for making it possible for me to undertake this thesis project. I would like to thank my supervisor at Ericsson Research, Anna Bondesson, for her guidance, support and knowledge as well as her cheerful attitude which has been valuable and greatly appreciated during the thesis work. I would like to thank my supervisor at Sony Mobile, Emma Kimfalk, for actively providing me information and data without which this thesis would not have been possible to complete.

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1 Introduction

Today's world faces challenges that are directly related to climate change and its resulting effects. Extreme weather conditions and the economic, social and environmental pressure it exerts on governments are considered to be related to climate change and thus there is a major driving force to develop technologies that will promote greener alternatives (UNEP, 2012).

According to United Nations Environment Programme (UNEP) the world's population today is over 7 billion and is expected to reach 9 billion by the year 2043. This growth in population lays great demand on the Earth's natural resources. The resource scarcity creates vulnerability for governments in managing these reserves that are closely coupled to the growing production and consumption rates of the modern world (UNEP 2012).

The modern society of today is industry oriented and thus this industrialization is an essential driving force for growth. Industrial production plays the role of providing humans with desired needs and better life standards but in doing so it also has the power to both improve and degrade the environment (UNEP, 2011).

ICTs are playing an increasingly important role in today's world. The changes that have taken place over the years have rapidly increased and can be reflected on simply by looking at the pace of development over the past hundred years. The transition from landline telephones to mobile phones and especially the internet has been at a greater pace than any other technological innovations of the past era, anywhere around the world. Sectors are taking more and more advantage of the potential of technological innovation in order to progress in sustainability (Souter, D., 2012).

Information and communication technology (ICT) is considered as one solution to the increasing environmental impacts in other sectors but requires additional attention to the environmental effects its products, solutions and services may potentially have is required (Gesi, 2013). International standards and tools should serve as a common basis for determining environmental impacts of services or products. This will allow objective comparison; and adoption of mitigation measures consequently keeping consciously in mind the uncertainties linked to the calculation processes. By integrating environmental consideration in the development process of a product, significant amount of environmental impacts may be effectively reduced. Examining the entire life cycle of a product including; raw material acquisition, production, use, end-of-life treatment and transportation, all product associated impacts can be considered and included in an assessment and measures can be taken accordingly (UNEP, 2011).

In order to increase awareness and environmental conscious decision making, life cycle assessment (LCA), amongst many tools, has been developed as a method for analyzing the possible environmental impacts of various products and services (Baumann and Tillman 2004).

The following report describes an LCA study on ICT equipment, in particular the smartphone Sony Xperia™ T, in order to better understand the product's environmental performance and find processes and components that are the major contributors to the environmental impact.

1.1 Background

As the world's population increases, ICT extend and grow all around the world. While Figure 1 illustrates the accelerating growth and use of ICT, it also identifies the various technological areas where such growth is taking place in. Although there has been a net growth in ICT during the past ten years, it is possible to see a decline in fixed telephone lines which can be explained by the introduction of mobile internet and its extensive growth. According to ITU in 2012, mobile cellular subscriptions worldwide have reached 6 billion and a continued expansion is to be expected in the coming years (ITU, 2012).

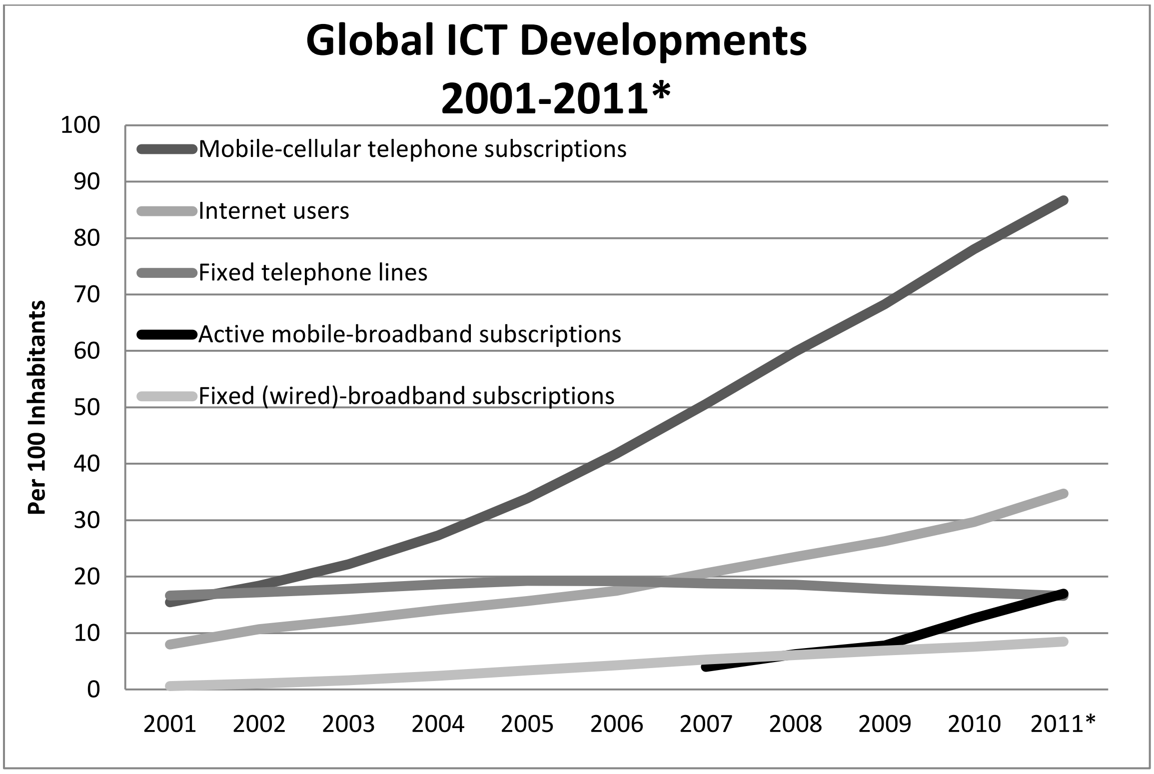


Figure 1 Global ICT development patterns during 2001 to 2011 (ITU Statistics, 2013). * Estimate.

The continuous demand for cellular phones throughout the years, along with the demand for other electronics, has created an enormous market in the ICT world. Production of electronic products requires a significant amount of raw material and energy input. The production is considered to involve high technological and energy demanding processes and require a significant amount of valuable metals and complex materials.

From an environmental perspective, an LCA may contribute to the documentation of the sustainability activities of the industry which increase transparency. It is important to integrate and develop an environmental performance perspective of a product into the core business operations as it considers multiple aspects of a product. General other sustainability issues include sustainable product and packaging design, concentrating on minimizing harmful chemicals, amount and weight of materials used as well as improving the energy efficiency of the produced product. Other aspects include sustainable facilities, sustainable transport and delivery, energy efficiency and electronics recycling (CEA, 2010). To tackle these issues, in respect to the telecom industry, an LCA study for a mobile device can be seen as a useful tool in identifying the life cycle processes of the device that cause the most significant environmental impacts. Thus, LCA results can be informative for decision-makers in order for them to take cautionary measures and develop alternatives to improve the environmental performance of the electronic device.

1.2 The Previous 2008 LCA Study

During 2008, a master thesis was conducted, in collaboration between Sony Ericsson (now Sony Mobile) and Ericsson Research covering an LCA study on the Sony Ericsson feature phone W890 (Bergelin, F., 2008), displayed in Figure 2. Bergelin's results included a parameter model that was applicable to other mobile phones. While using GaBi, the life cycle impact assessment (LCIA) was conducted using an evaluation method created at Ericsson (Bergelin, F., 2008). The characterization model used was based on the LCSEA Manual: Life Cycle Stressor-Effects Assessment, A Practitioner's Manual and the Danish Guideline method.

According to that study, a W890 releases 20 kg carbon dioxide equivalent (CO_2e) to the environment during the product's entire lifespan, 3.5 years, using a global electricity mix for the use stage.

This study hereinafter is referred to as the previous 2008 LCA study.

The parameter model developed in that study has been used by Sony Mobile until present time. However, since the year 2008, the technological progress in the phone industry has changed considerably in regards to design, construction and the components of the device. Smartphones are equipped with larger displays with a higher resolution and a touch-screen and have more powerful processors. The operating system is considered to be more advanced and the device is fit with multiple functions in contrast to a feature phone. Consequently, these technical advancements in the device require additional updates of the current model.

Figure 2 also illustrates the smartphone Sony Xperia^{TM} T assessed in the present study. Table 1 compares some of the basic specifications of both devices.

Figure 2 Image of feature phone, Sony Ericsson W890, used in the previous, 2008 LCA study and the Sony Xperia^{TM} T used in this study.

Table 1 Mobile phone specifications for both devices (Sonymobile, 200-).

	Sony Xperia^{TM} T	Sony Ericsson W890
Dimensions	129.4 x 67.3 x 9.4 mm	104 x 46.5 x 9.9 mm
Weight	139 g	78 g
Display size	720 x 1280 pixels, 4.55 inches	240 x 320 pixels, 2.0 inches

1.3 Goal and Study Objective of the Thesis

The main purpose of this study is to update the previous 2008 LCA data and corresponding parameter model to better suit mobile phones of today; the smartphones and present the results in accordance with international standards. To update and reevaluate the model will ensure up-to date figures and will allow future studies to be based on these new numbers. Incorporated into the goal was also the task of constructing a parameter model and see whether or not it would be applicable for other mobile phone models and tablets. In order to accomplish these tasks, an LCA study was conducted as an integrated part of this thesis and the results are presented in the following chapters.

The previous LCA study considered the standardized method for conducting an LCA developed by the International Standardization Organization, ISO (ISO, 2006a, 2006b).This master thesis, along with the ISO additionally considers the framework of the European Telecommunications Standards Institute ETSI, (ETSI, 2011) and the International Telecommunication Union ITU, (ITU, 2012).

The objectives of this study including the LCA study were to:

- Re-assess the 2008 LCA study and determine the required updates for the life cycle inventory, (LCI)

1. Updating and developing the current Ericsson/Sony Mobile LCA model of a mobile phone and its equivalent data developed in 2008 in order to make the model applicable for smartphones.

2. Aligning the improved LCA model with recognized LCA methodologies and in accordance with International Standards.

3. Present life cycle impact assessment results (LCIA) for the carbon dioxide equivalents (CO_2e) each stage yields.

4. Determine the processes and activities included in the product life cycle that have the most significant environmental impact considering CO_2e.

5. Extend the scope by including the surrounding system aspects of mobile device usage i.e. mobile network required for the usage and smartphone accessories.

- Based on the LCA results update and improve the parameter model created in the previous 2008 LCA study.

- Identifying the limitations and constraints of the model and proposing strategies for maintenance and future improvement as well as investigating the possibility of using the parameter model on other end-user electronic devices such as other smartphones and tablets.

- Benchmark the obtained results with other applicable mobile phone LCA studies and results including the previous 2008LCA results.

1.4 Report Structure

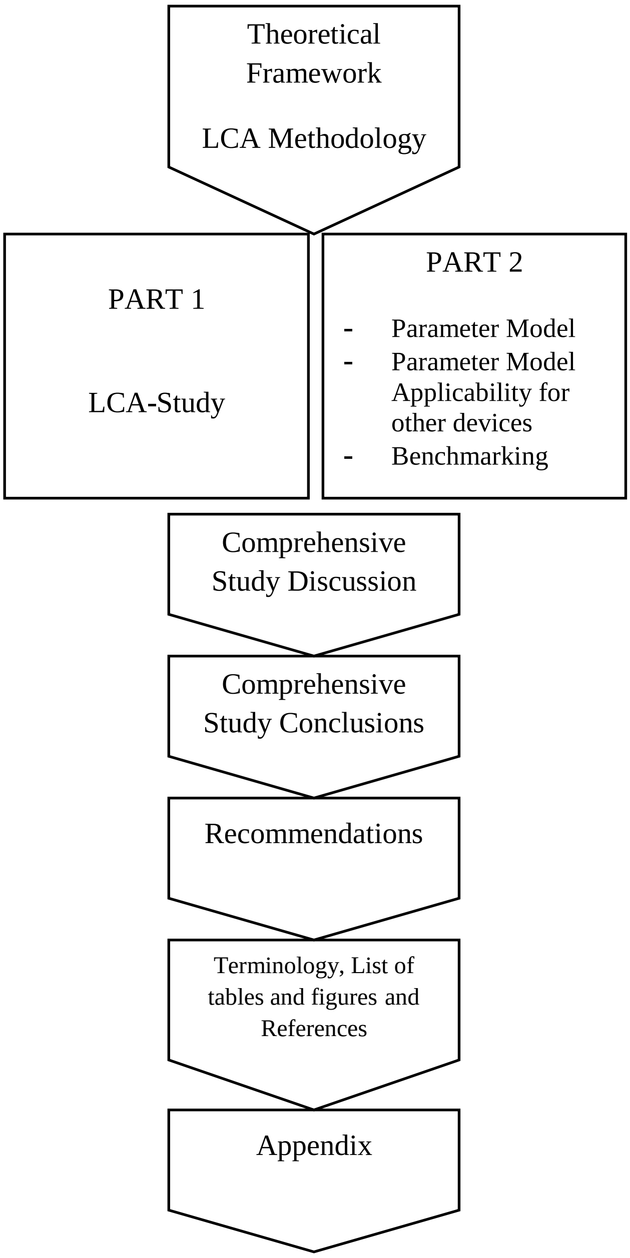


Figure 3 Report Structure

This report has been structured as illustrated in Figure 3. There are two parts included in the comprehensive study where the first part consists of the LCA study. This LCA part follows the format recommendations set out by the ISO Standards. The second part includes the parameter model, created based on the conducted LCA study for the smartphone. Also included in this part is the benchmarking of the results with other smartphone LCA studies conducted by competitors as well as comments on the applicability of the parameter model on other mobile devices. Finally it proposes a maintenance strategy and future improvements for the model.

The following chapters covering discussion and conclusion are based on the results of the two parts; the LCA study and the Parameter Model. The report is finalized by listing the terminology, list of tables and figures used in the complete study. Concluding, additional supportive materials are attached as appendix at the end of the report.

2 LCA Methodology

The growing concern regarding the environmental issues we are facing today has over the past years encouraged experts to create assessment tools which may be used to determine the environmental performances of various products and services. LCA, being one of such tools, is designed to assist companies in identifying and thus improving the life cycle stages from an environmental perspective (Baumann and Tillman, 2004).

The adopted life cycle perspective in an LCA study should be considered as a strength of the tool; as it considers the entire life cycle of a product, most product related environmental impacts are included and not overlooked. This might especially be important for ICT equipment; as the raw material acquisition and production stages can account for a significant amount of the total environmental impact. Thus, if these stages were to be left out of an LCA study more that 50 percent of the products life cycle impacts would be overlooked (Nokia, 2011).

As the inventory analysis of an LCA covers different environmental impact categories, it allows us to see how the distribution of the impacts for the life cycle stages varies for the different environmental impact categories. This multidimensional aspect provides valuable information for decision-makers at it allows them to adopt changes in respect to the different impact categories (Baumann and Tillman,2004).

The following section aims to give the reader a better understanding of LCA methodology in general and the standardized procedures involved in the execution of the technique according to ISO, ETSI and ITU. The LCA that has been performed in this specific case considers the international standards and for further information regarding LCA methodology please see ISO (2006a, 2006b), ETSI (2011), ITU (2012) and Baumann and Tillman (2004).

In accordance with ISO Standards, an LCA is divided into four phases as can also be seen in Figure 4 (ISO, 2006b).

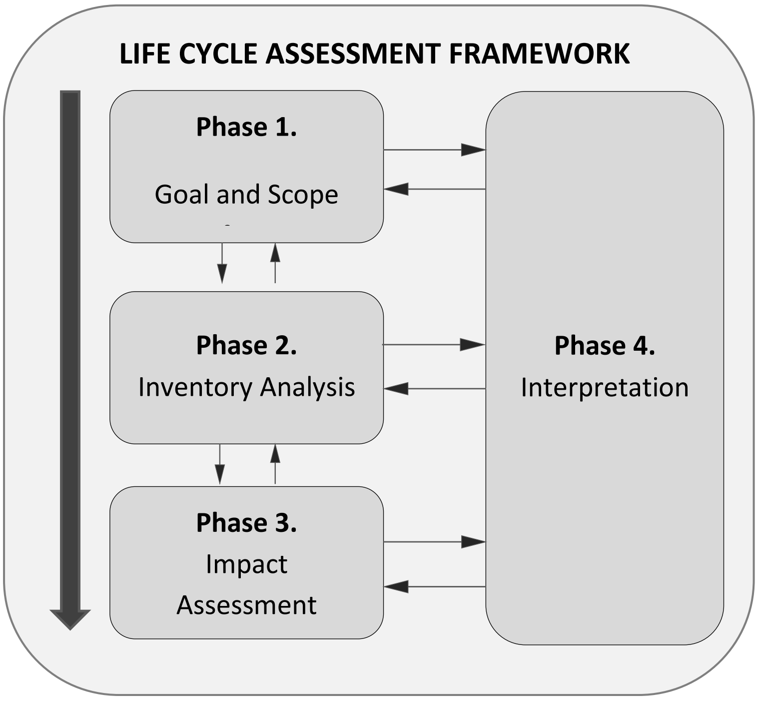


Figure 4 Life Cycle Assessment Framework and the different stages (ISO, 2006b).

As the ISO 14040 and 14044 provide a standardization of the LCA methodology, there are supportive documents that provide specific ICT additions in order to give a more in depth guidance on each LCA step. The European Telecommunications Standards Institute (ETSI, 2011) and the International Telecommunication Union (ITU, 2012) have brought forth such documents where supervision in regards to ICT *Equipment, Networks* and *Services* are taken into special consideration and additional ICT specific requirements are implemented in ETSI TS 103 199 and ITU-T L.1410 respectively. As stated in ETSI, full compliance with the document is not possible at all times, especially for network and services and this is justifiable if an explanation is provided in the results (ETSI, 2011) (ITU, 2012).

The following chapters will present more in-depth description of the different assessment phases in an LCA.

2.1 Goal and Scope Definition

2.1.1 Goal Definition

In order for the LCA study to provide relevant and expected results, the correct questions need to be formulated. Defining of the goal affects the choices to be made when formulating the methodological framework of the study (Baumann and Tillman, 2004). According to the ISO Standard (ISO, 2006b) the goal should state the intended application, reason for the study, intended audience and whether the results are to be disclosed or concealed to the public.

2.1.2 Scope Definition

The scope definition involves making choices which in terms determines the methodology that will be adopted during the study. ICT *Network* involves infrastructure with multiple elements; fixed and wireless network, terminals, base stations etc. The LCA may study the total network or include and focus on a specific part of the network and in that case the focus shall be defined in the goal and scope of the study. Similarly, the ICT *Services* that are included in the study, need to be defined and quantified (ETSI, 2011) (ITU, 2012).

Basic aspects that should be defined in the scope include the function and functional unit, system boundary, choice of impact categories and method of impact assessment, allocation principles and data quality requirements (ISO, 2006b). In addition, according to ETSI, the operating life time of the Equipment shall always be reported with the results since it has critical effects for the LCA results and this life time should also be set during the scope definition. For Networks and Services, the lifespan cannot be defined on these levels due to the continuous built on and upgrades associated with these two features (ETSI, 2011).

Determination of the function of the studied system implies setting the performance characteristics of the system and must be in consistency with the defined goal and scope. In order to provide a common basis for comparison, a reference flow i.e. functional unit must be determined and must be a quantitative measure that all the other modeled flows in the study can be compared to (Baumann and Tillman, 2004).

The scope of the LCA study also includes setting system boundaries in order to clarify which processes are to be included in the model (ISO, 2006b). This step allows the executer to determine and clearly state the accuracy and detail level of the model. Determination of system boundaries need to be specific in regards to several aspects including geography, nature, time and technology. This is necessary since different choices set for the boundary will give different results. Thus, it is crucial to define such factors prior to the modeling in order to assure the reliability of the report (Baumann and Tillman, 2004).

ETSI lists the life cycle activities to include in ICT LCAs. Exclusion of processes is allowed only when they oppose no substantial change on the overall result. According to ETSI, Figure 5 comprises the mandatory flows that should be included in an LCA for ICT. ETSI regards some flows and emissions such as noise, odor, biodiversity and eco-system depletion to be optional to include. Explanations and in depth description regarding which activities are considered mandatory and which are not, is provided in ETSI (ETSI, 2011).

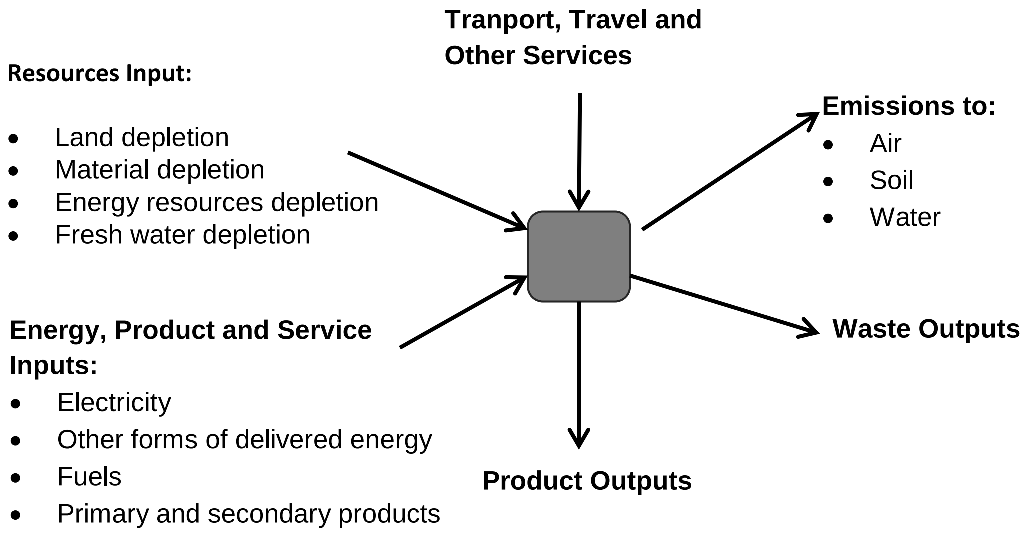


Figure 5 Mandatory features included in an ICT LCA according to ETSI (ETSI, 2011).

During the scope definition the cut-off criteria needs to be defined, as it is stated in the International Standards Office (2006b, p.8):

'The cut-off criteria for initial inclusion of inputs and outputs and the assumptions on which the cut-off criteria are established shall be clearly described.'

Cut-offs require careful consideration and thus it is preferred to avoid them when possible (ETSI, 2011).

In an LCA, transparency in types and sources of data, as well as quality of data, need to be specified and assessed for its level of accuracy and always described in the final report (ISO, 2006b). Due to the nature of an LCA, the process involves making assumptions and this brings limitations to the results. These assumptions, limitations and simplifications of the study are required to be taken into consideration and described in the goal and scope definition. Calculation procedures and assumptions need to be documented so that calculation procedures are consistent throughout the study (ETSI, 2011).

2.2 Life Cycle Impact Assessment (LCIA)

The impact assessment stage of an LCA translates the data collected in the inventory analysis into the form of environmental consequences allowing the study results to be more environmentally relevant and comprehensive (Baumann and Tillman, 2004). According to ISO Standards and as can be seen in Figure 6, the impact assessment stage includes mandatory and optional components.

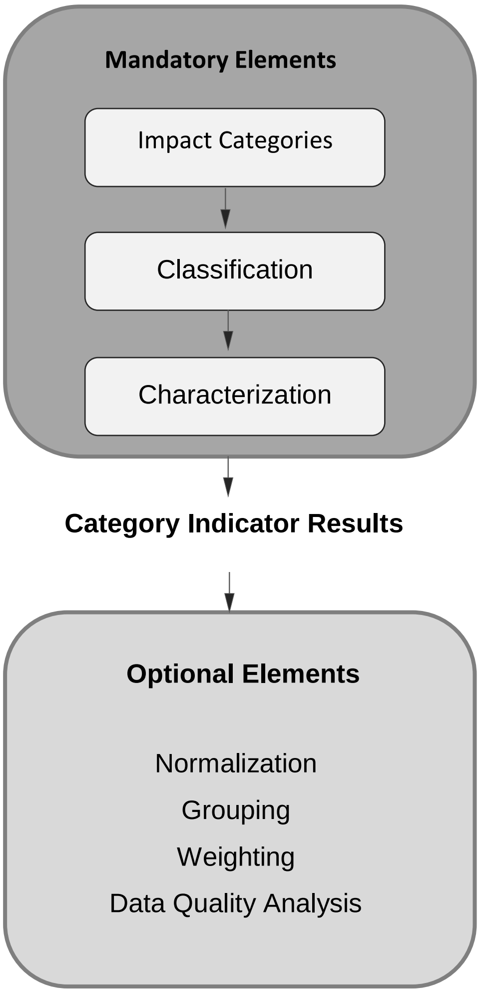


Figure 6 Mandatory and optional elements of the LCA impact assessment stage (Baumann and Tillman, 2004).

The mandatory components consist of selecting impact categories, indicators and characterization models as well as classification and characterization of the inventory results. The evaluation method determines the impact categories and should be clearly stated in the report. Classification is the process of dividing the inventory results into categories where the results are converted by a multiplication factor to a suitable indicator. Converting with the multiplication factor, named characterization, allows the results to be compared to one and another, in regards to environmental effects, on a common basis (ISO, 2006b). According to ETSI, climate change is a mandatory category and the characterization factors for global warming from the Intergovernmental Panel on Climate Change (IPCC) are required to be used (ETSI, 2011). For determining other impact categories, there is no consent and thus the selection is tailored for each individual LCA study.

The optional elements include normalization, grouping of the categories, weighting of indicators and data quality analysis. Normalization involves relating the characterization results to a reference value while grouping involves the sorting and ranking of the indicators. The weighting process converts the indicator results of different categories based on value-choices. Due to the fact that preferences differ from one individual to the other; different weighting results may be obtained. In order to check the reliability and to gain better understanding of the significance and uncertainties of the results, a data quality analysis can be executed where, for example, a sensitivity analysis should be conducted (ISO, 2006b).

2.3 Life Cycle Inventory Analysis (LCI)

Inventory analysis begins with structuring a flow model where only the environmentally relevant flows are represented and taken into consideration. The activities included in this stage consist of constructing a flowchart that is in accordance with the defined system boundary, data collection for all activities included in the system and documentation of these data followed by calculation of the environmental load in relation to the functional unit (Baumann and Tillman, 2004).

The flowchart is an elaborated mapping of all the modeled activities and the flows in between these activities. The inventory stage is an iterative stage and thus as further progression is made in the data collection and more is learned, the flowchart is reviewed and further extended.

The data collection procedure is considered to be one of the most time consuming activity in an LCA study. In order to maintain transparency of the study, it is important to record the details relevant to the data collection process, the time period for the collected data and information regarding the data quality. As stated in the ISO Standards, data classification categories may include energy input, raw material input, emissions to water, soil and air and other environmental aspects (ISO, 2006b).

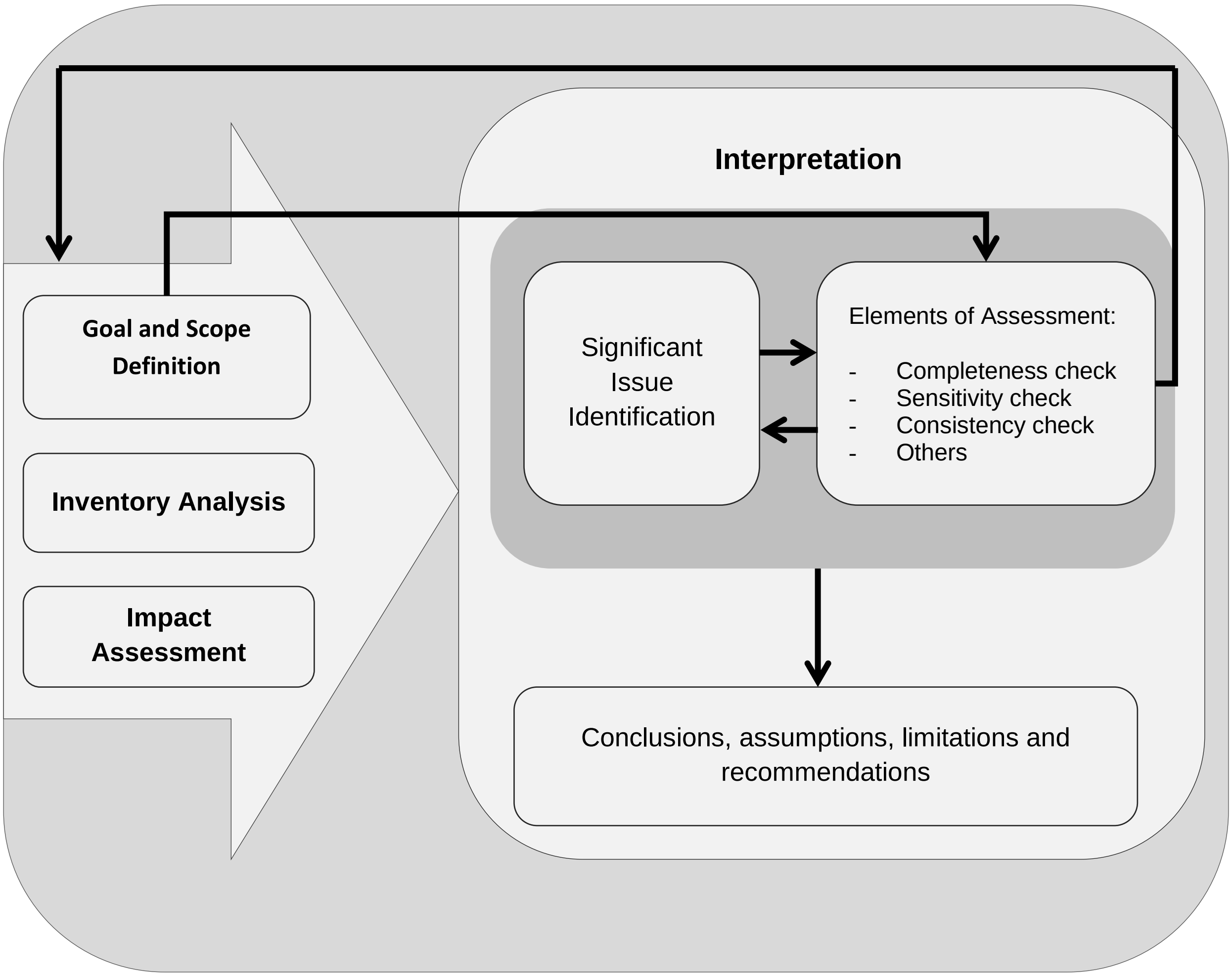
The calculation process involves determining an applicable flow for each unit process and calculating the input and output data of the unit process in comparison to this flow. Here, the unit process refers to the smallest element in the inventory analysis where both input and output data are quantified. The generated data should be quantitative in order for the flows in between the unit processes to be related to the reference flow. Calculations should result in linking the inventory data to the selected functional unit (ISO, 2006b).

In situations where more than one product shares the same process for which data is collected, allocation problem must be taken into consideration (Baumann and Tillman, 2004). Allocation should always be avoided if possible by dividing the unit process into multiple sub-processes or expanding and increasing the level of detail of the product system (ISO, 2006b). In situations where allocation cannot be avoided, the order of operation should be as follows; identify shared activities before allocation, the total allocated loads should be equal to the unallocated loads, and when there are numerous allocation alternatives a sensitivity analysis must be conducted (Baumann and Tillman,2004).

2.4 Life Cycle Interpretation and Results

The interpretation stage of an LCA involves assessment of the obtained results and drawing conclusions from these in order to provide straightforward and refined final results. The ISO Standard accentuates that the findings of the study must be in alignment with the defined goal and scope in order to maintain consistency throughout the study (ISO, 2006b). An LCA study may result in unanticipated results, hence may be detached from the study goal and scope.

As mentioned earlier, an LCA is an iterative process and thus allows reformulation of the goal and scope (Baumann and Tillman, 2004). Figure 7 illustrates the schematic relationship between the different stages of an LCA and the elements within the interpretation stage. The interpretation stage involves identifying the issues resulting from the LCI and LCIA stage, evaluating these issues with respect to completeness, sensitivity and consistency check and, based on this procedure, drawing transparent conclusions where the limitations and



recommendations are clearly stated (ISO, 2006b).

Figure 7 Schematic illustration of the different LCA stages in relation to each other (ISO, 2006b).

Part 1

The LCA Study

3 The LCA Study

The following section describes the LCA performed on a Sony Xperia™ T smartphone.

3.1 LCA Goal

The goals of the LCA study:

1. Updating and developing the current Ericsson/Sony Mobile LCA model of a mobile phone and its equivalent data developed in 2008 in order to make the model applicable for smartphones.

2. Aligning the improved LCA model with recognized LCA methodologies and in accordance with International Standards including ISO [14040 and 14044], European Telecommunications Standards Institute (ETSI) and the International Telecommunication Union (ITU).

3. Examine the four stages and collect inventory data for the raw material acquisition, production, use and end-of-life treatment of a smartphone in respect to all activities and environmental impacts. Perform the environmental assessment where data are collected for all CML impact categories, but only evaluated and analyze GWP each stage yields.

4. Identify the main processes and activities included in the product life cycle that have the most significant GWP impact.

5. Extend the scope by including the surrounding system aspects of mobile device usage i.e. mobile network required for the usage and smartphone accessories.

3.1.1 Target Audience

The LCA results are intended for the field of environmental studies where it will primarily be used internally by Sony Mobile and Ericsson Research. Additionally, the results will be of interest externally to other researchers in the field and the ICT sector.

3.1.2 Applicability of the Study

As the development in the mobile industry has shifted its focus to smartphones, this report will reflect the changes and enhancements required for the current mobile phone LCA model and further align the application of it to today's technological progress. The resulting study will also concentrate on aligning the model in accordance with international standards for LCA within the ICT sector and collect up-to-date data. The results will provide knowledge in regards to the subsequent environmental effects, considering CO_2 emissions, and thus allow future improvements and advancements in the system. Furthermore, the results will be used as input to a parameter model that will be created based on the LCA study and will serve as an environmental impact calculator for smartphones. As only GWP has been analyzed in this study, no conclusions on the full environmental impacts related to a smartphone can be drawn.

3.2 Scope

3.2.1 System Description

In this LCA, the studied system is modeled from a cradle-to-grave perspective and encompasses raw material acquisition, production, use and end-of life treatment as well as the associated transportation activities of a Sony Xperia™ T mobile phone, see Figure 2. Thus, in order to have a fully functioning mobile device, external components; consisting of the charger, USB-cable and headset; are included into this system as well as the phone-kit including the packaging cardboard box, plastic wrappings and phone manual. In the use stage the related life cycle impact of the required mobile network has been included.

See Figure 2 and Table 1 for understanding differences between the previous 2008 LCA study feature phone and the smartphone in this study.

The smartphone is assumed to be used in a Swedish context.

3.2.2 Functional Unit

The functional unit will serve as a reference flow and will represent quantitative data in order for all other modeled flows in the system to be related and linked to one and another.

The functional unit, (FU) for the study is: use of one smartphone during the lifetime of 3 years.

3.2.3 System Boundaries

Defining the system boundary requires attention and concern in several aspects; geographical, temporal and technological aspects. All of the significant life cycle stages have been included in the system boundary and have been schematically illustrated in Figure 8. The substantial inputs and outputs into and out of the system are encompassed in the model. The selected system boundaries for this study are based on the framework of the previous 2008 LCA study and supervisor experience and support.

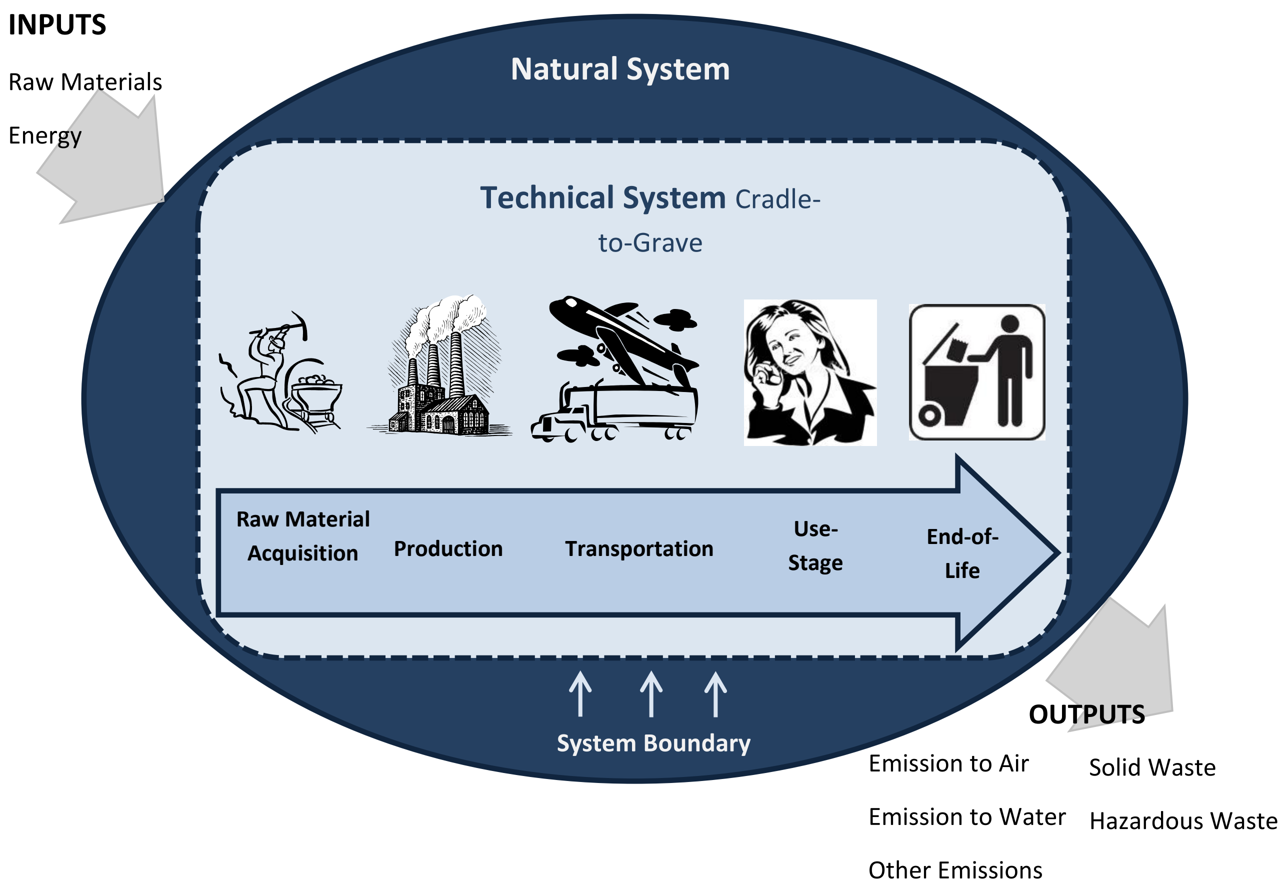


Figure 8 Life Cycle Stages and the defined System boundary for the smartphone LCA study (PE International, 2011)

3.2.3.1 Geographical Boundary

Different parts of the life cycle are located in different part of the world. The origin of raw materials is unknown, hence not determined by further research but instead set by the predefined GaBi processes. The product is considered to be produced at specific locations and thus location specific data is used and location specific GaBi processes on, for example energy has been used. The use stage includes the final product, smartphone, that is transported and utilized in Sweden and thus for the use stage a Swedish scenario is considered and hence a Swedish electricity mix is applied. In order to better understand the relative impact of the use stage, a global average electricity mix is used as well during the analysis stage.

3.2.3.2 Time Boundary

The lifespan of a smartphone as well as the included accessories is set to 3 years based on an assumption by Sony Mobile. Data for raw material acquisition are based on the built-in GaBi databases where the list of all significant data sources and dates can be found in Appendix B. Due to the level of detail of the study and time limitation, the age of raw material acquisition data are not taken into consideration nor addressed in this study.

Data for component production have, where applicable and available, been attained from respective suppliers through a questionnaire available in Appendix E. Data from year 2012 have been requested and in circumstances where this was not possible older data was accessed. For smartphone components for which no new data were available, the previous 2008 LCA data was modified and rescaled along with generic GaBi data.

The use stage represents current data regarding electricity consumption of the phone and network usage where the most updated electricity mixes in GaBi have been used. The network LCA data is based on a study conducted by Ericsson Research and considers data from year 2006 to 2010 (Malmodin, et al., submitted). User scenarios are generated from a study from year 2012 conducted by Delft University of Technology (Flipsen, et al., 2012).

In general, generic data for raw material, transportation, fuels, etc. from GaBi database, with raging age, have been applied without further analysis in regards to the age of the data.

3.2.3.3 Technical Boundary

The studied system includes the smartphone as well as its accessories and network usage. Accessories include the charger, headset, USB-Cable and the phone box and instructions manual. All network equipment required for the use of the smartphone has been accounted for in the system boundary including Base Station Sites, Control and Core Nodes, Operator Activities, Transmission and IP Core Network, Data Centers. The 2nd tier suppliers, meaning part suppliers to the main smartphone component suppliers, have been cut-off. This implies the production stage of these parts have been cut-off only and not the materials, as all materials of the smartphone have been included in the model. Additionally, the infrastructure for facilities etc. has been left out.

3.2.3.4 Methods for Inventory Analysis

This project focuses on updating an existing LCA conducted on a feature phone so that it is applicable for smartphones. Therefore, during the inventory analysis it was required to investigate the technological changes that had occurred since the production of the W890 phone in 2008. As described, for comparative analysis and investigation, the Sony Xperia™ T smartphone model was chosen. The general methodology adopted in this project is further described in section 4 and follows the stages of system modeling, data collection and calculation of the environmental loads.

In the inventory analysis the general flow chart which was set when determining the system boundary was further extended to provide a detailed, schematic plan of the processes included in the system. In order to get a better understanding and a technical overview of the smartphone a Sony Xperia™ T phone, provided by Sony Mobile, was dismantled and weighed to determine the components in the device. Individual components were identified. This method allowed for comparison of the two mobile phones and determination of the changes that have occurred and thus to identify where there is a need for an update. Additional components and processes that needed to be updated for the smartphone assessment require data collection and these suppliers were contacted for information.

As is in the previous 2008 LCA study, the analysis also aims to include materials corresponding to the total weight of the mobile phone materials (Bergelin, F., 2008). Information on the material content of the phone was provided by Sony Mobile. Data for raw material extraction and processing were mainly based on the GaBi databases. A wide range of data was collected with focus on processes that were considered to have a greater effect on the results. In such cases modeling was done in more detail. Data gaps were filled by either information from Sony Mobile or by studies, including commercial databases from GaBi, to the extent possible. For these production processes that are considered significant, production data is collected from suppliers with the aid of a questionnaire which can be found in Appendix E. For processes where data was not available, equivalent or similar processes have been used. User scenarios and network system are adapted from a previous Ericsson and TeliaSonera study (Malmodin, et al., submitted). The end-of-life stage is based on an LCA study conducted by Apple on the smartphone model Iphone 5 (Apple Inc., 2012).

The transportation model is based on primary data received from suppliers where the distance and means of transportation to the Sony Mobile assembly factory have been specifically requested. Due to time limitation, the vehicles types and models have not been specifically addressed but instead average flight and lorry models have been built using the generic GaBi database.

3.2.4 Data Requirements and Data Quality

The established criteria for this study have been to collect as complete and up-to-date data as possible for all processes included within the system boundary. The studied system includes multiple components and hence has a wide scope both in regards to technological as well as geographical coverage. Where possible, data for processes related to component production are provided via the questionnaires. However, data from these suppliers do not continue further down the process chain since this would require time as well as collaboration and extra work for the suppliers. Data for component production are based on single source and subtle information provided via the questionnaire and thus makes verification of the data difficult. Circumstances where no process data was available, data from previous LCA studies were used. Restrained data affects the accessibility of the study i.e. numerical accuracy and uncertainty of data can limit the transparency and reproducibility of the results. For raw material acquisition, transportation modes, electricity and other energy sources commercial databases in GaBi have been used. These assumptions are stated in the life cycle inventory, section 4. A sensitivity analysis is made and presented in section 7.2.

An LCA study is based on representative data and models to symbolize real life circumstances. The resulting environmental impacts of an LCA study can only represent potential impacts and not definite ones due to the uncertainty in the modeling and also due to some impacts represent future conditions. As real life circumstances are multidimensional and complex, collecting primary data will not always result in higher accuracy. Allocation and data gaps can cause misrepresentative figures and thus in some cases, depending on the complexity of the modeled product and especially for ICT products, representative data might be favored (Nokia, 2011).

Most ICT products have multiple components and many suppliers which makes the supply chain very large and complex. Each component itself has also several suppliers in regards to the extraction of raw materials to the point where it is refined to be used in these components. Not to mention, suppliers are objected to change over the lifetime of the product (Nokia, 2011). As this complexity exist in the production of an ICT device, it is clearly not possible to receive a full set of primary data for all the different processes that are included in the life-cycle of the final product. Thus, generally, a combination of representative primary data and generic data is used to model the device.

A balance between generic and specific data sources is often sought for. If the LCA study includes too much generic data the results becomes too generalized and does not represent the specific circumstances. Similarly, if too specific data is used, accuracy and precision for the assessed product is obtained, but the practical relevance on a broader scale is reduced.

3.2.5 Method for Impact Assessment

In this study the chosen characterization model is the model established by the Institute of Environmental Sciences (CML) at the University of Leiden in the Netherlands. The methodology adopted for this study is in accordance with the ISO guidelines as well as the LCA recommendations for ICT equipment provided by ETSI and ITU, but differs from the method used in the previous 2008 LCA study, see section 1.2.

The analysis of the LCA results for this study will focus on the GWP impact category and will present figures representing the kg CO_2e for each stage of the mobile device. For the remaining CML impact categories future studies may be conducted to bring forth these effects as well, as the LCI data for these categories are included in the GaBi model developed for this study.

For further information a detailed description of the CML impact categories and their unit of measurements are available in Appendix A.

3.2.6 LCA Tool

The software program used for constructing the life cycle model was GaBi version 6.0. The GaBi, developed by PE International and the LBP University of Stuttgart, is a modular system meaning plans, processes and flows include their functions form modular units (PE International, 2007). The model allows one to analyze the different life cycle stages, its activities and related environmental flows and interpret the results and is in allegiance with the ISO Standards. The software contains databases that provide the option of using built-in processes and flows to simplify the modeling process and avoid constructing models manually. Appendix B provides the list of premade database models used for the processes included in this LCA.

3.2.7 Study-wide Assumptions, Simplifications and Limitations

Major limitations, simplifications and assumptions of the study are described in the following section below.

3.2.7.1 Limitations

This LCA study includes data from Sony Mobile and from their suppliers but does not cover information from 2nd tier suppliers, meaning part suppliers to the main smartphone component suppliers, and therefore potentially presents a data gap.

In most cases received data from suppliers represents yearly data for the entire production site. As some of the suppliers not only produce the specific component for the assessed smartphone, but components for other devices as well, the calculations for a single smartphone are based on approximation and generalization. No further investigation and check has been made regarding this matter.

For this study, the data collection of ancillary materials, energy input and emissions have mainly been conducted by the suppliers themselves. Due to confidentiality, there is no direct control over this data collection procedure in the given timeframe and scope of this LCA study and thus this creates an uncertainty in the final results.

As single source data has been used for multiple components in spite of a multi-source supply, an inevitable limitation arises. Data for Integrated Circuits (ICs) are based on cradle-to-gate data where only aggregated raw material and production data has been available. The same applies for Standard components. These cradle-to-gate emissions are fully allocated to the production stage of the LCA.

Confidential data used in this LCA also reduces the transparency and reproducibility of the study as it is not presented in the LCI section. Full documentation of supplier data, calculation procedures and material data are available at Ericsson Research.

3.2.7.2 Simplifications

The LCA model includes the total weight of the product but as some materials and compounds do not exist in Gabi, and as some data met difficulties in the collection process, all materials could not be modeled directly but were represented by similar materials. When no representative materials were found, these data gaps were eliminated by scaling the other materials by weight which can be seen in Appendix F where the percentage scaling for each part has been presented.

It is also appropriate to state that the production processes that are included in this model have been simplified when needed due to limitations in the collected data. As a significant amount of the production data is collected from the suppliers, an uncertainty in quality and precision is linked to the received data. The suppliers were asked to provide annual figures for their entire plants together with total production volumes. The data was then allocated to represent the amount of impact relevant to the LCA, by the LCA practitioner.

Uncertainty in data therefore depends on accuracy and method of measurements used at the plant by the suppliers. The received data quality also vary from one supplier to the other where some suppliers have presented incomplete data in terms of emissions and hence their components are presenting data gaps resulting in underestimation of environmental impacts.

Some standard components have not been possible to model in the LCA study due to the limited time frame. Instead, as no corresponding models was available in GaBi, these components were represented by proxy data as described in chapter 4.4.3

For transportation, all unknown transportation distances were modeled by an average transportation model as described in section 4.4.6. Component transportation distances were provided by the suppliers and where the supplier failed to provide transportation data the distance to the Sony Mobile factory was estimated in Google Earth based on the location information provided by the suppliers through the questionnaire (Google Earth, 2013). This results in a simplification of the transportation model. The use scenarios are dependent on theoretical choices made in the study and are subjected to inaccuracy. Similarly, the network model is also based on a study, where measured energy and data traffic for Sweden during 2010 is considered. The obtained results reflect values over Sweden and due to time limitation and the main scope of this thesis study, the network has not been modeled in GaBi but has been included in the parameter model only.

Project time limitation resulted in concentrating on updating raw material, production and use stage and thus less attention was put on the end-of-life stage. The end-of-life stage has therefore been modeled based on a percentage factor from a reference LCA study (Apple Inc., 2012). The reference study model assumed that 100 percent of the smartphones were recycled which is probably not the case as discussed in section 12. The environmental effects of alternative end-of-life treatments are not investigated in this study.

3.2.7.3 Assumptions

As mentioned in section 2.2 and in alliance with the ISO guidelines, allocation should be avoided if possible by dividing the unit process into multiple sub-processes or expanding and increasing the level of detail of the product system (ISO, 2006b). This being said allocation was inevitable as most data was received from various suppliers. The supplier data most often represented data for the production of multiple products at their facilities; as they are most likely to produce other products for other companies. Thus, the data has been allocated. How the allocation was made for each phone part is presented in Table 4. As recommended by ISO a sensitivity analysis has been carried out in section 7.2.

The distribution distance and the means of transportation have been reported by the suppliers for the main components. Transport of waste and recycled materials are expected to be by road and where the distances are not provided by the suppliers, an average of 100 km is set as a value.

For some of the smartphone components, such as the battery, data from the previous 2008 LCA study has been reused and assumed to be representative.

In order to evaluate the impact such assumptions have on the results, a sensitivity analysis has been made. Sensitivity analysis results are presented in section 7.2.

3.2.7.4 Representativeness

The data collection process is based on data from suppliers that have willingly provided this study with environmental performance data and is expected to represent modern and high-technology production. As use of modern technology also implies a consistent and regularly monitored environmental performance of the facility, the low technology production sites are generally expected to be more restrictive and not willing to share such data as they may have poor or non-existing environmental monitoring **(**Biber E., 2010**).** This implies that the data used in this study may be representative only to high-technological production sites and is likely to lead to results that are somewhat better than average production. On the other hand, producers of complex equipment such as smartphones are likely to use only high-technological production sites to guarantee product performance and a reliable supply flow. Thus, for this study the primary data collected is considered representative from this perspective.

3.2.8 Critical Review Procedure

The requirements for the different stages in the LCA study have been met for methodology, data, interpretation, taking into consideration the international standards and reporting as required by ISO (ISO, 2006a and 2006b). Expert support, to ensure the quality of the work has been addressed in this study. Anna Bondesson of Ericsson Research, Emma Kimfalk of Sony Mobile Communications and Göran Finnveden of The Royal Institute of Technology (KTH) have supervised this project and provided valuable review and guidance. No third part review has been done.

4 Life Cycle Inventory

The following section describes construction of the LCA model and the data collection and calculation procedures undertaken in this study. Due to confidentiality, all inventory data has not been included in the external report but is available at Ericsson Research.

4.1 Description of the System and its Life Cycle Stages

The study is undertaken on the smartphone Sony Xperia^{TM} T including the accessories and the network required in the use stage. The system modeled in GaBi is aimed to encompass all significant material and energy inputs and the corresponding emissions to the environment. Parts and processes that were prioritized for primary data collection, either because they were expected to have a substantial impact on the results or an unknown impact are listed in Table 2. This list has been brought forth through discussions with supervisors and results from the previous 2008 LCA study. All remaining components and processes such as transportation, end-of-life and standard component production have been included in the study with less focus on data collection.

Table 2 Phone parts and processes with high data collection priority.

Production of main components;
IC (integrated circuits) PWB (printed wiring board) PBA (printed board assembly) Battery LCD (liquid crystal display) Camera Headsets Charger
Mobile phone assembly
Mobile Network Usage
Smartphone electricity consumption

The constructed model is divided into extraction of raw materials, production of components including the accessories, smartphone assembly and transportation, utilization including network infrastructure and end-of-life treatment. To align with ETSI reporting requirements, the life cycle of the system is divided into six sub LCI models including a separate transportation modeling, as shown in Figure 9.

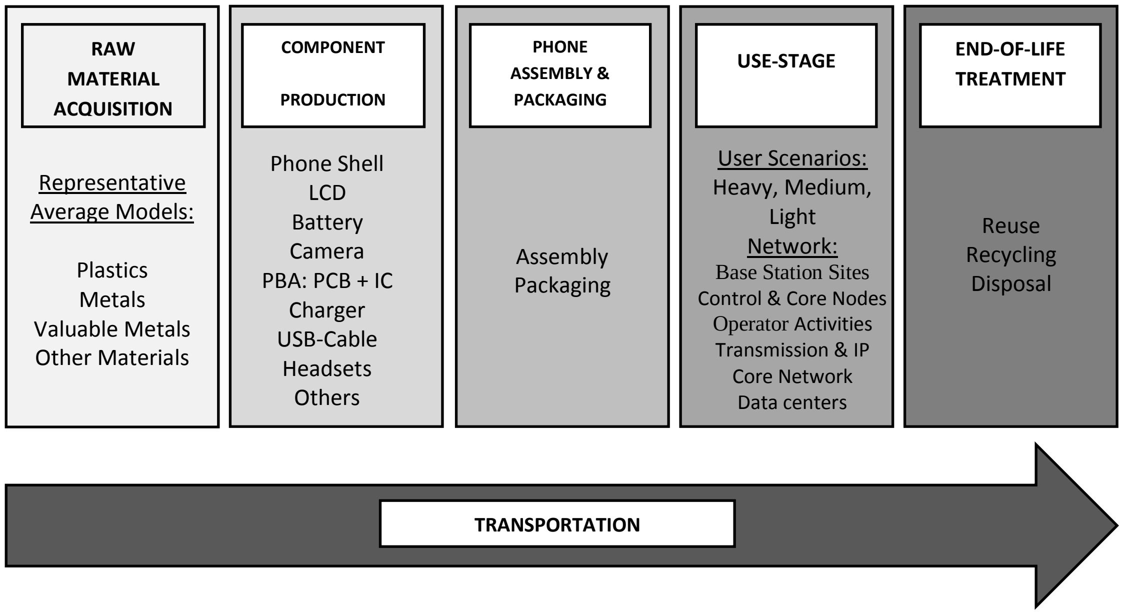


Figure 9 Life cycle stages of the mobile device.

The raw material acquisition stage includes all materials that are present in the system and is divided into four groups; plastics, metals, valuable metals and other materials. Data for raw materials used in the LCA are obtained from material information for Sony Xperia^{TM} T phone, from models built with premade GaBi processes and from the questionnaire answers received from the suppliers.

The production stage involves processing of raw materials in order to obtain the required phone components such as the battery, charger, IC and headset. The activity following component production treats the final assembly stage of the mobile phone i.e. the Sony Xperia^{TM} T mobile phone being mounted and packaged, and made ready to be distributed to resellers from the Sony Mobile factory in China.

The use stage assesses alternative user scenarios determined based on available statistics and studies. The intention is to represent the significant environmental impact this stage represents for a usage time of three years. Heavy, medium and light scenarios were created where the electricity consumption of the device as well as data usage is determined as described in section 4.4.4. The impact of network considers its full life cycle and includes the operations presented in Figure 9.

The end-of-life treatment is established from a smartphone LCA study by Apple (Apple Inc., 2012). In the Apple study this stage is based fully on recycling and counts for 2 percent of the total climate change impact of the smartphone during its life cycle. The same factor has been applied in this study as further described in section 4.4.5.

As for the previous 2008 LCA, the transportation activities of the entire system are modeled separately; this shows the transportation impacts and allows comparison with earlier results. The transportations accounted for in the model include the component transport to the Sony Mobile factory, where the final phone assembly takes place and the shipment of the final phone-kit to Sweden. Transportation is further described in section 4.4.6.

4.2 Data Collection Process

Data has been collected from multiple sources both within the academic and corporate world in order to obtain more accurate and up-to-date inventory data. The data collection process involved studying the previous 2008 LCA report and reviewing Sony Mobile and Ericsson Research documents concerning material information and production processes. The Sony Mobile Xperia^{TM} T smartphone was dismantled, weighed and measured for better understanding of the device and its components. Phone material information was received by Sony Mobile. Component suppliers were contacted and requested to answer a questionnaire. The prepared questionnaire was aimed to provide information from the suppliers with respect to amongst others; emissions, product/process data, energy input, transportation and location of production. For full view of the LCA Supplier Questionnaire see Appendix E.

The methodological framework has been aligned as far as possible with the ISO 14040 series, ETSI and ITU technical specification documents for LCA of ICT equipment. LCA journals and handbooks such as Baumann and Tillman (2004) have also been reviewed. Scientific journals and articles were accessed through the Royal Institute of Technology (KTH) library's search engine as well as through general internet searches using Google and Google Scholar. Source validation was made by origin of data and author credential's check. Further data collection procedures undertaken included collecting information from the database in GaBi and the detailed list can be seen in Appendix B. Due to confidentiality reasons, detailed input and output data are left out of the report but different data types is presented in Table 4.

4.2.1 Established Scenarios

The use and the end-of-life stages required that scenarios were established in order to set values in the GaBi model which in term provides results that allow a comparative analysis of the potential environmental effects related to these scenarios. Three scenarios were established for the use stage; heavy, moderate and light users which are further explained in section 4.4.4, Use Stage. By establishing these three user scenarios, a relative understanding of how consumer behavior affects the resulting impacts becomes more apparent and clear. The end-of-life stage of the mobile device is based on a scenario adopted from the Apple LCA study, described in section 4.4.5. Additionally, a transportation route of the smartphone distribution has been established where the assembled smartphone is transported by air to Copenhagen warehouse from Sony Mobile factory followed by road transport to Malmö hub for further distribution within Sweden.

4.2.2 Data Source Agreement

The data collection procedure involved identifying processes with significant impact and prioritizing in collection of up-to-date data. Once these processes were defined, the means of obtaining such data were discussed and agreed upon during weekly meetings with both Sony Mobile and Ericsson supervisors. Establishing this procedure allowed Sony Mobile and Ericsson to have control over the method of data collection and secured the data quality and use of up-to-date values.

4.3 Data Calculation

All data used as input in the GaBi model has been scaled to a single unit of one smartphone. As supplier data was mainly received for the total plant, simple allocation calculations have been made in order to be able to use figures equivalent to one unit of the device.

4.4 Description of Core Unit Operations and LCI Sub Models

The following section describes, explains and clarifies the life cycle inventory sub-models used in this study and how they have been structured in accordance with the life cycle stages illustrated in Figure 9; Materials, Production, Transportation, Use stage and End-of-Life treatment.

4.4.1 Energy and Fuels

Generic GaBi models have been used for the energy and fuel models and are used throughout the life cycle. These models can be found in Appendix B.

The supply chain for the energy and fuel production has been included, as it may have significant environmental impacts on the total results.

4.4.2 Raw Material Acquisition

All materials covered in the material information for the Xperia™ T smartphone, provided by Sony Mobile have been included for in the different components. For simplicity materials were categorized into four groups in the GaBi model. These four groups include valuable metals, metals, plastics and other materials. Materials that are classified as valuable metals are listed in Table 3. Where the material data as well as the production data were collected is presented in Table 4, where the list of data sources for the previous 2008 LCA study (Bergelin, 2008) is also presented in order to provide a comparative idea of the conducted updates. Primary data refers to data received from Sony Mobile or the suppliers while secondary data includes generic data or figures based on other studies.

Table 3 Valuable metals included in the model.

Valuable Metals
Chromium
Copper
Gold
Nickel
Palladium
Platinum
Silver
Tin

Table 4 Data sources for component specifications, material and production process data, compared to the previous 2008 LCA study.

* The materials content is not transparently available in the GaBi models. See Production Stage 4.4.3.

** The materials content is not transparently available in the LCA which was used as input. See Production Stage 4.4.3.

Process	Allocation of Env. Impacts	Component Specification data/Year	Process/activity Data		Data used in (Bergelin, 2008)
			Material Content/Year	Production	
Battery	Mass	Primary Data/2012	Previous 2008 LCA study/2008	Previous 2008 LCA study	Previous study for Li-Ion Battery
Phone Assembly	per phone	Primary Data/2011	Not Applicable	Primary Data/2012	Data from 2006 as annual figures.
Camera	per unit	Primary Data/2011	Primary Data/2012	Primary Data/2011	Primary Data
Charger	Mass	Primary Data/2012	Primary Data/2012	Primary Data/2012	Primary Data
Headsets	per unit	Primary Data/2012	Primary Data/2012	Primary Data/2012	Not included
LCD	area	Primary Data/2010	*	Generic GaBi Data/2010	Data from an LCA study on a mobile phone
PBA:					
IC	area	Primary Data/2012	**	Secondary IC Data/2012	Wafer production, IC encapsulation from previous study. Chip-on-wafer production: Primary Data
PCB	area	Primary Data/2012	Primary Data/2012	Primary Data/2011	Primary Data and previous study
Standard Components	mass	Primary Data/2005-2012	*	Generic GaBi Data/2002-2011	Generic GaBi Data
USB-Cable	per unit	Primary Data/2008	Primary Data/2012	Previous 2008 LCA study	Primary Data

Due to the limited number of raw material processes in GaBi, processes for some materials included in the phone have been estimated with other processes. Inventory data for the materials included in the GaBi model are presented in Appendix B. Figure 10 illustrates a very rough estimate of the material distribution in the smartphone including the accessories. This figure displays the accessories separately and also does not include the materials for the IC as it is accounted for in the production stage. As not all materials were possible to determine, data gaps have been filled by scaling up the weight according to the actual total phone weight, hence there were no data gap but estimations were made. All material data is based on information received from Sony Mobile.

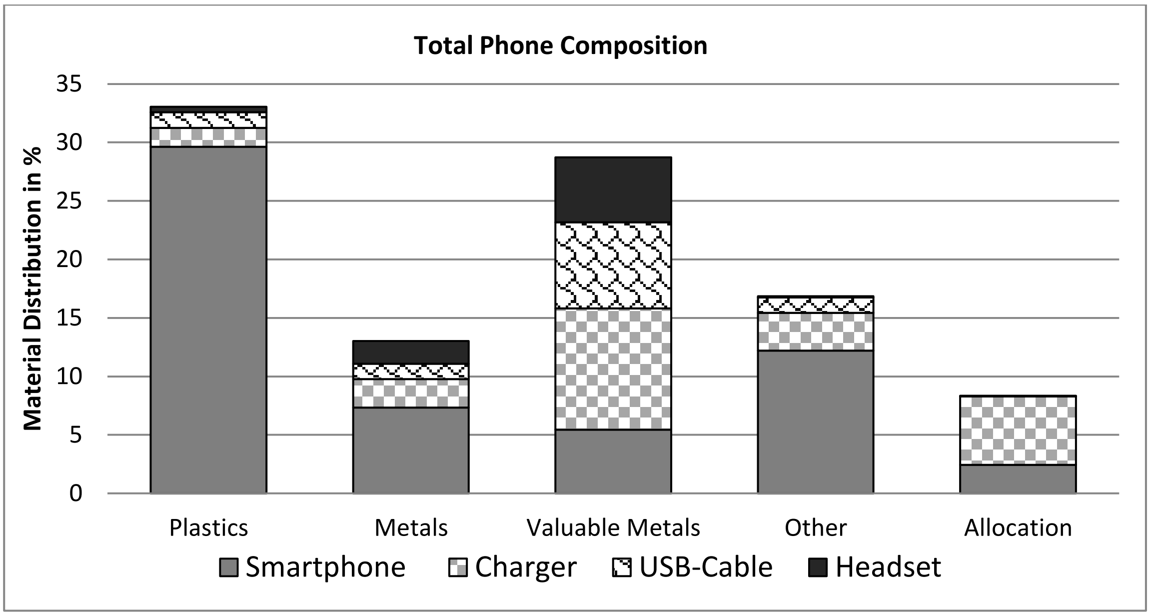


Figure 10 Total phone and acessories composition with respect to the chosen material categories.

A general material model presented in Figure 11 was applied to all smartphone components, including the accessories, in order to enable a separate analysis of the environmental impacts caused by the materials.

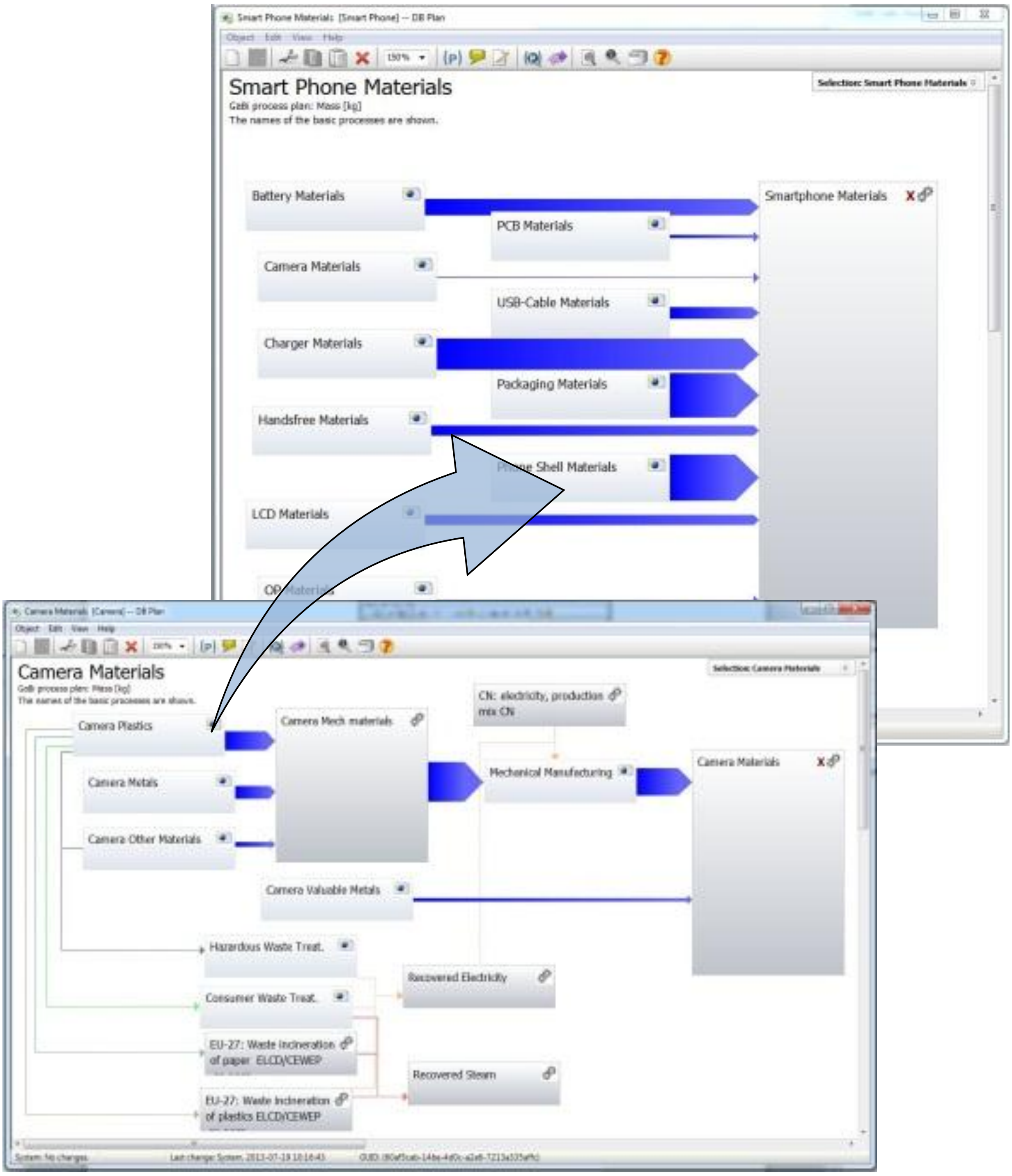


Figure 11 General model structure of the materials in GaBi.

As some of the components contained materials that had no premade model in GaBi these materials were modeled based on GaBi models for similar materials. Material data for the battery was taken from the previous

2008 LCA study (Bergelin, 2008) where data was also simplified. The weight of the battery in the previous 2008 LCA study was 23 grams and as the battery in this study weighs 35 grams, a scaling was made.

The integrated circuit, (IC) data was based on an LCA study provided by an IC manufacturer which was a general study and not specific for the Sony Xperia™ T. In this IC study aggregated results for material and production processes were provided. Thus, the received data was included fully in the production process and not in the material stage. This choice was made based on the assumption that the production stage results in a greater impact than the material stage and thus it is better to have too high figures in the production stage. Similarly, as mentioned in section 4.4.3, production stage, the standard components that are based on generic GaBi models include the raw material acquisition which is allocated to the production stage. Table 5 provides a list over the components that have been accounted for in the production stage and not in the raw material acquisition stage.

Table 5 Phone components where the raw material acquisition stage has been included in the production stage.

Components
IC
Capacitor
Diode
Resistor
Transistor
Filter SAW
Inductor

4.4.2.1 Raw Material Processing

The raw material processing model has been constructed to represent the primary processing of the extracted raw materials into moldable and workable primary constituents. As raw materials are treated through various mechanical processes, the processing model is used to account for the production of raw materials into wires, sheets, coils etc. that make up the multiple components of the phone. Many of these components are made of sub-components which, due to time limitation, are not included in this study. The motive for creating and using such a raw material processing model is to attempt to close the data gap linked to mechanical part production by creating a simplified model which represents this production process. By assuming a raw material input 40 percent higher than the output (same as in the previous 2008 LCA study), the process is also designed to account for the material losses. A sensitivity analysis has been conducted in section 7.2 where the material input has been altered to investigate the importance of this assumption. As valuable metals are considered to be rare and precious, this raw material processing model is not applied to that group of metals since material loss is considered to be minimal.

Although this model is actually a production process, due to simplicity it has been allocated to the raw material acquisition stage.

4.4.2.2 Raw Material Acquisition Waste Treatment

Raw material acquisition and component production processes involved in the production of the smartphone contribute to waste generation and emissions. Both of these activities are included in the GaBi model where waste generated from raw material acquisition and production is treated under the following categories; hazardous waste, consumer waste, plastic incineration and paper incineration.

The treatments involve recycling, landfilling and incineration of the different waste categories where electricity or steam is regained and redirected back into the system.

The hazardous waste treatment model is based on previous 2008 LCA study where figures have been reused in this study.

The consumer waste model was built based on generic GaBi models, where landfill and incineration were chosen as the two alternative processes. As there are no exact figures, the end-of-life treatments for these two alternatives are considered to be equally frequent. Thus, values of 50 percent landfill and 50 percent incineration have been adopted for this study.

The generated plastic and paper waste during the raw material and production stages is assumed to be incinerated and this has also been modeled using generic GaBi models.

The waste treatment processes recover energy in the form of electricity and/or steam. A closed-loop approach has been implemented where the generated energy from waste processes is redirected as an input to other energy demanding processes. Due to lack of processes using steam, the recovered steam is not utilized unlike the recovered electricity has been.

4.4.3 Production Stage

The production LCI sub-model accounts for the suppliers' production processes i.e. the components that compose the mobile device. In GaBi, the production models are created for electronic components, standard components and the smartphone assembly. Each component production process is accounted for separately in GaBi as Figure 12 illustrates. The electronic components included in the study are; PBA, IC, LCD, Battery, Headsets, Camera, USB-cable and Charger. Data was mainly collected from suppliers and in circumstances where this was not achievable, data from the previous 2008 LCA study (Bergelin, 2008) and from the generic GaBi database was used. Prior to this LCA study an assessment was made to determine components that required an update and more accurate data. As the transition from feature phones to smartphones have required advancement in technological processes and production, some of the phone's components were considered to have a significant change in process and hence the previous data was out of interest and the importance of updating these data was emphasized. In order to collect data from suppliers, the questionnaire, accessible in Appendix E, was prepared where enquiries regarding energy consumption, emissions, and production locations etc. were formulated. Due to time limitation, this study only includes data obtained from the direct suppliers to the Sony Mobile assembly factory and not the subcontractors to these suppliers. In other words, the production chain of the device only includes processing data that are linked to the first degree suppliers. How the corresponding production data is collected is presented in Table 4.

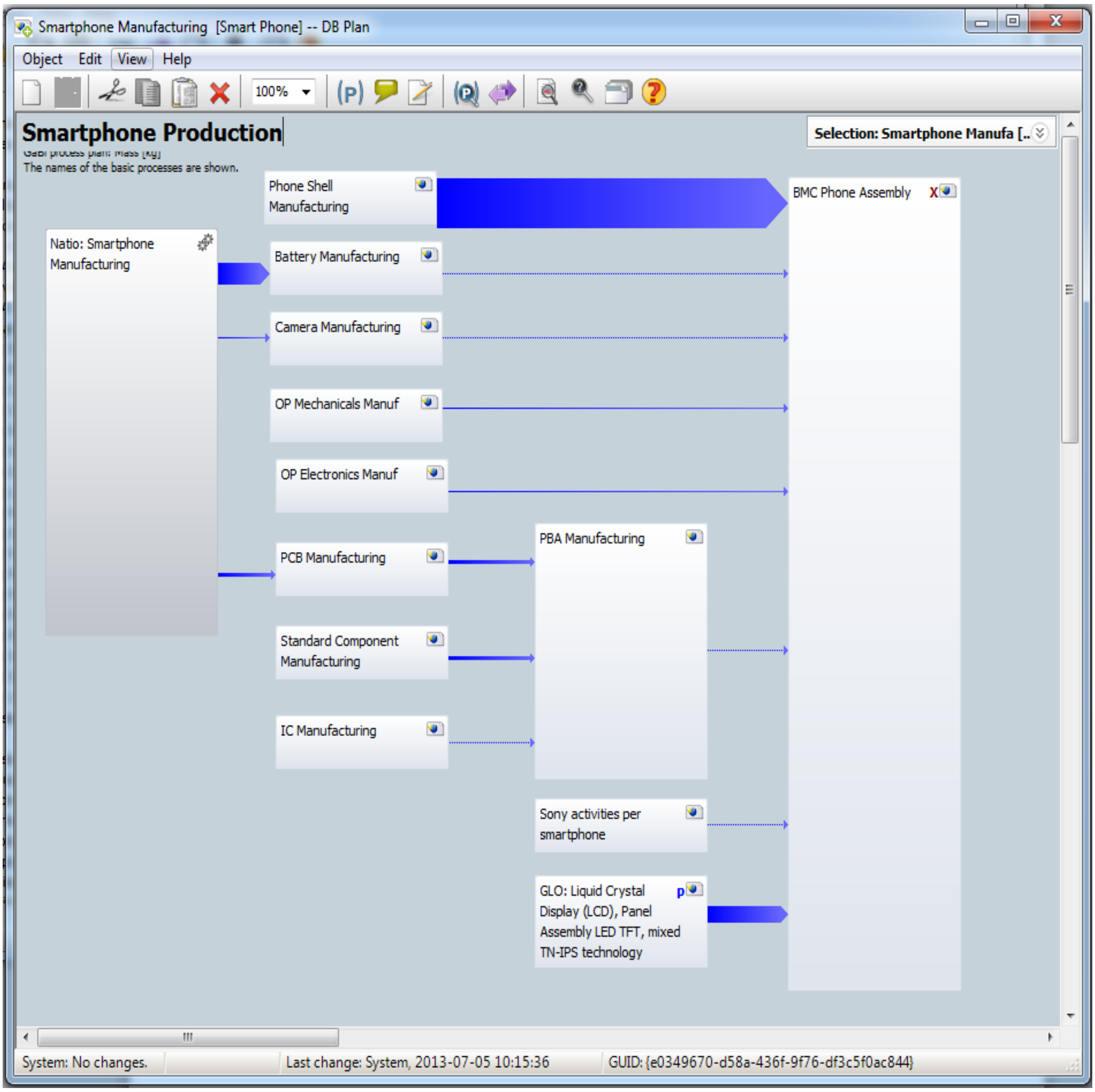


Figure 12 An illustration of the component production models in GaBi.

4.4.3.1 Printed Board Assembly, PBA Production

The Printed Board Assembly, (PBA) has been considered to be an important component of the smartphone that has undergone changes and technological advancements in comparison to feature phones. Thus, additional attention and high level of importance have been put on this component.

The PBA is divided into three sub-components; the *Integrated Circuit* (IC), the *Printed Circuit Board* (PCB) and the *Standard Components.*

Production of an *Integrated Circuit* is a very complex procedure and requires high technological processes as well as access to valuable metals and energy, not to mention its high cost (NobelPrize.org, 2013). Data for ICs were obtained from an unpublished IC LCA study conducted by an IC manufacturer. In this IC LCA the four main chips of a certain platform were studied. The chips in the IC LCA study are not used in the Sony Xperia™ T but are considered as a good representation. For more detailed information regarding the IC LCA refer to Appendix D.

Data for the *Printed Circuit Board*, PCB is primary data received from Sony Mobile and thus is assumed to be reliable.

Table 6 Standard components included in the smartphone and GaBi model. *For internal use only

Standard Component	Weight (g)
SUM of identified components	1.0
Total Standard Components	2.0
Other components lacking pre-made GaBi models	1.0

The total amount and type of *Standard Components*, assembled on to the PBA, were provided by Sony Mobile. Once reviewed, it was clarified that the PBA housed multiple types of standard components that could not be identified in the generic GaBi database and in the given time frame it was not possible to investigate the particular manufacturing processes of these components. Those components corresponded to about half the weight of standard components. As other components are available in GaBi; capacitor, diode, resistor, transistor filter SAW and inductor chip, the weight of these components have been scaled up to represent the total weight of standard components as presented in Table 6 to avoid data gaps. These components are therefore over-represented and the standard components may require further attention in future studies. However, this scaling is not considered to have a significant effect on the overall result of this study as standard components represent only a small fraction of the total smartphone weight.

The component processes taken from GaBi comprise of cradle to gate approach and therefore include raw material acquisition in the sub-models which results in additional impact for the production stage. This being said, the impact caused by the addition of the raw material acquisition to the production stage is also not considered to have a significant impact on the final results.

4.4.3.2 Battery Production

The battery model used in the previous 2008 LCA study was based on a lithium-ion battery. The Sony Xperia™ T contains a lithium-polymer battery and hence presents some technical differences. Based on Sony Mobile expertise these differences were evaluated in order to determine the required data updates.

Lithium-ion batteries have high energy densities and lower production costs in comparison to lithium-polymer batteries but, suffer from aging. Lithium-polymer batteries are lightweight and, while the li-ion battery due to its chemical construction is limited to a rectangular shape, can be produced in various shapes. Additionally, li-polymer batteries are considered to have an improved safety assurance (Battery University, 2010).

From this information it was determined that the production processes varied between the two types of batteries and hence new supplier data was considered important to collect. As for the material information of the battery, due to time limitation and the similarities between the batteries used in the present study and in the previous 2008 LCA (Bergelin, 2008), data from that study was reused and scaled based on weight.

4.4.3.3 Camera Production

Technological advancements, in regards to the camera, have been determined in the smartphone compared to the feature phone studied in the previous 2008 LCA study. Both phone models are equipped with a primary and a secondary camera. Additional features in the smartphone including geo-tagging, touch focus, face detection and image stabilization (Sonymobile, 200-) could indicate a changed production process. The primary camera has been improved from 3.15MP and 2048x1536 pixels for the feature-phone to 13MP and 4128x3096 pixels for the smartphone (GSMarena, 2000, Sonymobile, 200-). These amendments have been considered to have significant effects on the environmental impact of the phone and thus primary data have been received from Sony Mobile and used in the study.

4.4.3.4 Headset Production

The previous 2008 LCA study did not include the headsets in the analysis. The headset is considered to be a common component that is included for the customers when purchasing the phone-kit. The decision to include this component into this LCA study has been made and thus new primary data has been obtained for both the material information and production process from Sony Mobile.

4.4.3.5 LCD Production

The LCD production process is based on a generic model available in GaBi, built on a cradle-to-gate study including data both from literature and industry. By setting the screen size and mass, the results are estimated by GaBi for the production of the specific LCD. The raw material acquisition stage is also accounted for in this model. Though this generic model is not specific for touchscreens, as most modern touchscreens are integrated and built-in the screen, the additional material and processing is considered minimal and thus the model is considered to be a good representative substitute.

4.4.3.6 USB-Cable Production

The USB-cable is considered to be a component that has not undergone a substantial technological transformation since the previous 2008 LCA study. New primary data for the material information has been received from Sony Mobile and the production process data has been reused from the previous 2008 LCA study.

4.4.3.7 Charger Production

The charger considered in this study represents the Sony quick charge models and is assumed to be the general type included in the phone-kit. New primary data for the material information and production process have been received from Sony Mobile.

4.4.3.8 Sony Mobile Support Activities

Sony Mobile activities are based on data for electricity use from their 10 biggest sites for the year 2011. The data was scaled up by number of employees and divided by the number of Sony Mobile smartphones produced the same year in order to obtain results per smartphone. The electricity distribution was divided between USA, UK, Germany, Sweden, Taiwan, China, Singapore and Japan based on information received from Sony Mobile. Sony Mobile support activities are considered to represent soft- and hardware development as well as other company activities such as sales and marketing.

Travelling activities of employees have also been included in the LCA study but are allocated to Transportation and further details can be found in section 4.4.6.

4.4.3.9 Production Waste Treatment

Same waste treatment models described in section 4.4.2.2 Raw Material Acquisition Waste Treatment has been used during the modeling of the production stage based on information provided by the component suppliers.

4.4.4 Use Stage

In this LCA the use stage includes alternative user scenarios i.e. how the smartphone is utilized during its assumed life time and the corresponding smartphone network usage. Additionally the Internet Protocol, IP network is included in the LCA and the parameter model where this data is obtained from a previous study conducted by Ericsson Research and TeliaSonera (Malmodin, et al., submitted).The ICT network is further explained in section 4.4.4.2.

4.4.4.1 Smartphone Usage

Three scenarios specifying the electricity consumption of the smartphone; heavy, moderate and light users were created to represent the different types of smartphone users. The scenarios were adapted from a study conducted by Delft University of Technology (Flipsen, et al., 2012) presented in Table 7. The Delft study was conducted on five models of smartphones; Blackberry Torch, HTC-7 Trophy, Nokia N8, Samsung Galaxy S2, Sony-Ericsson Xperia™ Mini; taking into account user profiles of around 20-35 users.

The heavy user scenario assumes users to utilize their smartphones substantially more which results in higher daily energy consumption and daily battery charging than for the other scenarios. In all three scenarios the smartphone is predicted to be used for 2G and 3G calling, messaging, 3G internet roaming including downloading and streaming as well as for media, music and taking photos with the camera (Flipsen, et al., 2012).

Additionally for heavy and moderate user scenarios, i.e. not for light user, it is assumed that the charger is left on standby-mode during the entire day. Light users are considered to disconnect the charger when it is not used. Thus, the average standby-mode is calculated in consideration to the circumstance that the device is most likely to be charged during the evening and hence is remained plugged-in until the morning time. From information provided by Sony Mobile Communications, the standby-power is set to maximum 30 mW. Table 7 presents the average energy consumption values used for the three user scenarios.

Table 7 Average energy consumption per defined mode for the three user scenarios (Flipsen, et al., 2012). *Estimated figures based on Ericsson expertise (only used for network usage)

	Heavy User	Moderate User	Light User
Daily Energy Consumption (mWh)	4546	2880	2279
Idle Time (%)	79	89	93
Active Time (%)	21	11	7
Maximum Charge Cycle (days)	1	1.7	2.14
Average Battery Capacity Consumption (%p.day)	95	60	47
Power Consumption of Battery Charger while Charging (W) **(Full charging time 2h 20min)**	8.86	8.86	8.86
Charger Standby-Mode (%p.day)	90	90	30
Data traffic (GB/year)*	30	8.5	2
Total Energy Consumption (kWh/3years)	23.3	14	10.8

The total energy consumption for the full usage period has been calculated for all three scenarios using the following calculations.

$$\boldsymbol{Total\ Energy\ Consumption[kWh/3years] = Total\ Charging + Total\ Standby\ Mode}$$

$$\boldsymbol{Total\ Charging}\left[\frac{\boldsymbol{kWh}}{\boldsymbol{3years}}\right] = 3 \times \frac{365}{Charge\ Cycle} \times Full\ Charging\ Time \times Power\ Consumption\ of\ Battery$$

$$\boldsymbol{Total\ Standby\ Mode[kWh/3years]} = \frac{Charger\ Standby\ Mode}{100} \times 24[hr] \times Standby\ Power \times 3 \times 365$$

4.4.4.2 ICT Network Usage

This study includes life cycle impact from the usage of the ICT network as applicable to one subscription

The referenced LCA study of TeliaSonera's ICT Networks and Services applies to a national level for Sweden (Malmodin, et al., submitted). The data presented in this study covers life cycle impact of 2G and 3G mobile networks (not 4G), and dates to 2006 and onwards. Additionally the Internet Protocol, IP, network is included. For detailed description and methodology for the network modeling refer to Malmodin, et al., submitted). The study is based on measured energy and data traffic for Sweden during 2010 meaning that the figures represent momentary values and hence require consideration and update during future use of this data.

In the ICT network study the ICT Network is divided into operational units as follows: user equipment, base station sites (RBS), control and core nodes, operator activities, transmission and IP core network, and data centers. The electricity consumption data used for base station sites corresponds to the combined 2G and 3G average. The average RBS site manufacturing data is collected for a site installed in Sweden prior to 2005. The included operator activities in the study are based on TeliaSonera's own in house activities such as business travels, office activities, private commuting etc. thus do not include the manufacturing of infrastructures nor vehicles. As for transmission and IP core network, electricity consumption and manufacturing is based on an average model developed for Sweden where the average data traffic for a 3G subscription is set to 8.5 GB/year. The study is focused on Swedish use only, however 25 percent of data centers are assumed to be located internationally (Malmodin, et al., submitted). By changing the Swedish electricity mix (0.06 kg CO_2e/kWh) in the study for use stage to world average (0.6 kg CO_2e/kWh), a global value for the network usage is estimated.

The use of network was not the main focus on this study and the reuse of an existing study was found appropriate to focus data collection efforts on the smartphone specific sub-models.

4.4.5 End-of-Life Treatment

The end-of-life stage for the smartphone is based on an LCA study conducted by Apple on the smartphone model iPhone 5 (Apple Inc., 2012). In the Apple study the recycling stage is estimated to account for 2 percent of the total life cycle impact of GWP and similarly, in this study, the same factor has been adopted respectively, where 2 percent of the total results have been calculated to account for the end-of-life stage. This factor is assumed to include also the battery recycling. Background information on how the Apple study calculates the 2 percent is unknown to public; if it is based on an assumption or calculated from results, as this information is not available.

Note! An additional model for battery recycling was developed in this LCA study and was modeled in GaBi but never used. This model is described in Appendix C.

Waste treatment of raw material acquisition and production is included in raw material acquisition stage and production stage respectively, see sections 4.4.2 and 4.4.3.

4.4.6 Transportation

Data for the main transportation model, capturing the transport of the assessed components and accessories from the suppliers to Sony Mobile factory, were obtained from the suppliers through the questionnaire. All components are transported to the final Sony Mobile phone assembly factory in Asia. In cases where the supplier failed to provide transportation data the distance to the Sony Mobile factory was estimated in Google Earth

(Google Earth, 2013) based on the location information provided by the suppliers through the questionnaire. Using this method to measure the transportation distance provides figures, especially for road, where an under-estimation of distance seems likely. Some components have multiple suppliers and in most cases only one supplier have been contacted for production data. In these situations the difference between suppliers locations are not accounted for in the study and thus the figures represent one scenario. Table 7 gives an overview for the chosen distances for different components and accessories and from where the data has been collected or how this has been estimated. Additionally, Sony Mobile business travels are included in the transportation model, where carbon footprint figures provided by Sony Ericsson Sustainability Report 2011 are used. The Sony Mobile travels included in this study is limited to total air travel for the year 2011 when the emissions equaled 22 447 594 kg CO_2e when excluding employee travels by private vehicles etc. (Sonymobile, 2011)

Table 8 Means of transportation of phone components to Sony Mobile Warehouse.

Component	Data Source	Means of transportation
Charger	Primary Data	Road
IC	Secondary Data IC LCA study estimates	Road Air
Battery	Primary Data	Road
Handsfree	Primary Data	Road
Shell	Secondary Data; Approximation based on location data provided by Sony M. C.	Road
LCD	Secondary Data; Approximation based on location data provided by Sony M. C.	Road Air
PCB	Primary Data	Road
USB-Cable	Secondary Data; Data from previous 2008 LCA study applied.	Road
Camera	Primary Data	Road Air

As it was not possible to collect detailed data in regards to vehicle and aircraft types and freight loads, due to time limitations for the study, average models for both lorry and aircraft have been created in GaBi using generic data from the Ecoinvent database. The data used for building the average lorry and aircraft models can be found in Appendix B.

Instead of distributing the transportation activities in the system between the life cycle stages; raw material acquisition, production etc., a separate transportation model has been created. This choice of modeling allows the environmental impacts and effects, caused by transportation, to be more visible and thus makes it possible to distinguish these effects on the overall results of the LCA. Raw material transportation has been included in most pre-made raw material models in GaBi but is not transparently modeled.

All components arriving to Sony Mobile factory is expected to be preliminarily packaged to avoid damages while transporting the goods. The weight of the packaging materials was included in the same manner as in the previous 2008 LCA study by reuse of its packaging factor (1.25 for all components). The importance of this factor was checked with sensitivity analysis as presented in 7.2. The final assembly of the smartphone takes place in a Sony Mobile factory situated in Asia, from where the finished product is distributed to retailers all around the world. The total phone-kit; including packaging materials, charger, USB-cable, headsets and the smartphone was estimated to have a total weight of 338 grams, by weighing a Sony Xperia™ T phone-kit on a scale.

The route scenario is selected to represent the smartphone distribution from the final assembly site to the final destination; the stores. In this scenario, which takes into account information from Sony Mobile, it is assumed that transportation is made by air to Copenhagen, from where the smartphones are further distributed to resellers and operators in different locations. The route scenario of this study assumes that, after reaching Copenhagen, the freight is transported by road to a hub in Malmö, Sweden, for further distribution within the country. The total air travel from Sony Mobile factory to the hub is estimated to be 7 200 km and the road travel 800 km.

5 Life Cycle Impact Assessment (LCIA)

The following section aims to assess the potential environmental consequences of the environmental inventory quantified in the inventory analysis. In this study the only environmental impact assessed is Global Warming Potential.

5.1 General Allocation Procedure

Generally when classifying the LCI data, assigning the results into the different impact categories can prove to be challenging as the substances can contribute to several impact categories. This problem with allocation between the multiple impact categories are not addressed in most LCA studies. In this study only the GWP impact category has been analyzed and thus this allocation problem has not been considered.

5.2 Definition of Impact Categories and Characterization Factors

The Global Warming Impact Potential (GWP) in the CML 2001 (Nov. 10) characterization database in GaBi has been selected for the result analysis. The CML GWP impact equivalents for emissions with a GWP impact potential are presented in Table 9 which is accessed from the built-in default data in GaBi. The remaining CML impact categories and their unit of measurements are available in Appendix A. LCI data has been collected for all CML impact categories but results have not been calculated and no analysis has been made in this study.

Table 9 CML 2001 - Nov. 2010, Global Warming Potential (GWP 100 years) equivalents for some emissions with a GWP impact potential (GaBi, 2012).

Substance	1 kg CO_2 e	Units
Carbon dioxide [Inorganic emissions to air]	1.0	kg
Methane [Organic emissions to air (group VOC)]	25	kg
VOC (unspecified) [Hydrocarbons to fresh water]	7.5	kg
VOC (unspecified) [Organic emissions to air (group VOC)]	7.5	kg
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	13	kg
Hydrocarbons (unspecified) [Organic emissions to air (group VOC)]	7.5	kg
Sulphur hexafluoride [Inorganic emissions to air]	2.3 E04	kg

5.3 Classification and Characterization Summary

The classification procedure involves sorting the inventory results in accordance with the selected impact categories, in this case the GWP category. This sorting takes place GaBi, where the LCI data is automatically converted to common units and the results are combined. Calculation Procedure

The LCI data is multiplied with the relevant characterization factor in order to obtain LCIA results for the GWP impact category. The factor is conveyed as global warming potential for the period of time of 100 years, in kg carbon dioxide/kg emissions (Goedkoop, et al., 2008). This process is automated in GaBi.

The software allows analysis of the entire system as well as sub models and individual processes. As this allows the distribution of the total impact to be observed, the analysis has been performed on the entire model but also on sub-models and single processes.

6 Results

The results of the life cycle impact assessment are presented in various ways in the following sections. First the entire life cycle, followed by the different life cycle stages are analyzed separately in the following sections. Figure 13 below displays the total results for the smartphone, excluding the accessories, for this LCA study. As decided during the study, the results are presented for the Global Warming Impact Potential (GWP) for the full life cycle of the smartphone and are based on the moderate user scenario for Sweden which is set as the baseline scenario and used where nothing else is stated.

Table 10 presents the most significant greenhouse gases of the assessed smartphone.

Figure 13 presents the total GWP of the entire life cycle of the smartphone. The smartphone, excluding the accessories and the use stage, corresponds to 45 kg CO_2e. where usage represents 3.8 kg CO_2e. The network usage on its own stands for another 20 kg CO_2e and all the accessories together add 2.8 kg CO_2e, thus giving a total life cycle impact of 68 kg CO_2e.

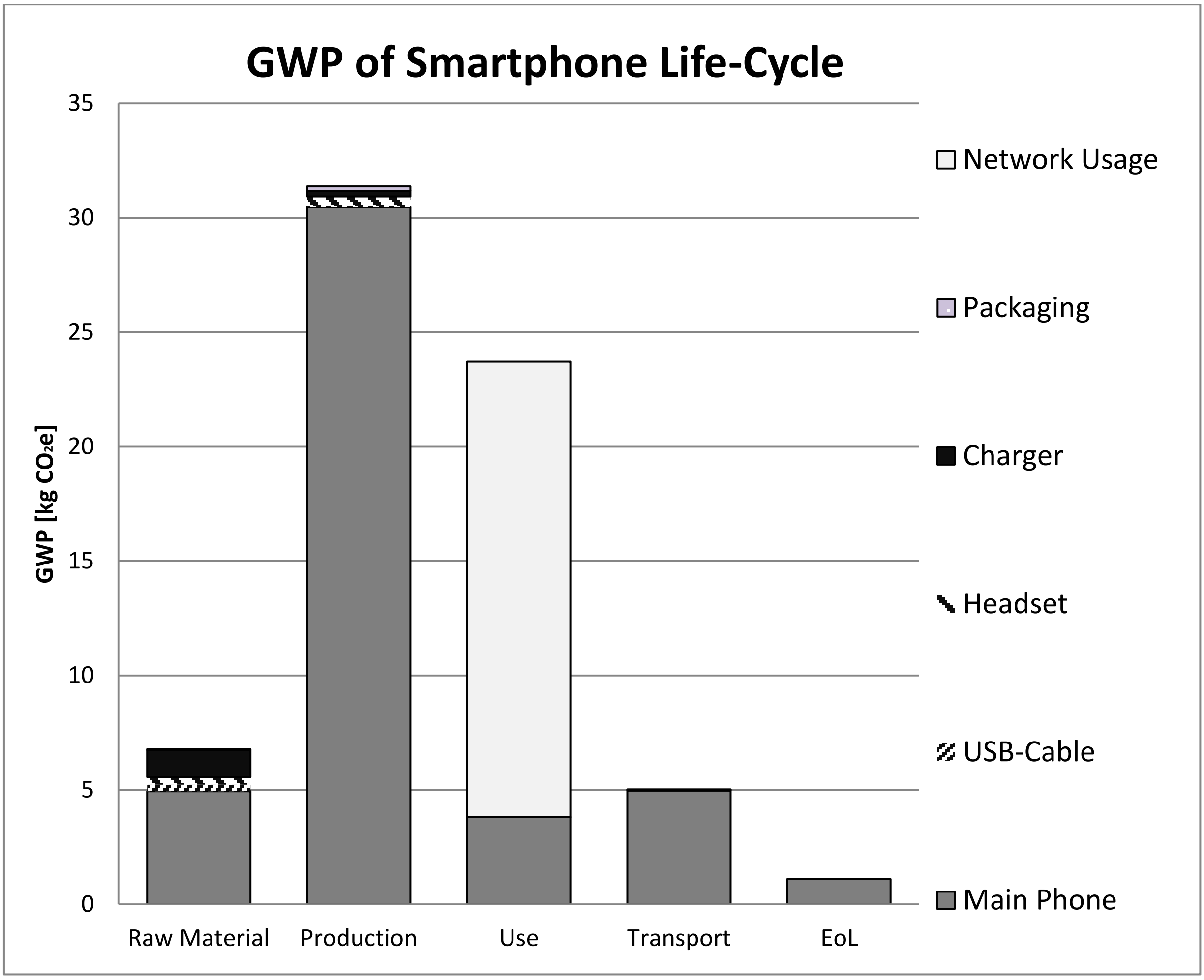


Figure 13 Total life-cycle results for a smartphone. Results are presented as GWP for the moderate user scenario in Sweden with the given life time of 3 years.

Table 10 The most significant greenhouse gases of the assessed smartphone

Substance	Impact Media	Amount (kg)
Carbon dioxide, CO_2	Air	47
Carbon dioxide, CO_2 (biotic)	Air	2.2
Methane, CH4	Air	0.11
Nitrous oxide, N_2O	Air	0.0076
Sulphur hexafluoride, SF_6	Air	1.4×10^{-5}
Volatile organic compounds, VOC	Air	0.17

6.1 Raw Material Acquisition Stage

Figure 14 represent the relative climate impact category results obtained for the raw material acquisition stage where the materials are categories in to the groups; main phone and accessories, including packaging, USB-cable, headset and charger. The figure shows that the raw material acquisition for the main phone accounts for more that 60 percent of the total climate change impact of the raw material acquisition stage for the device.

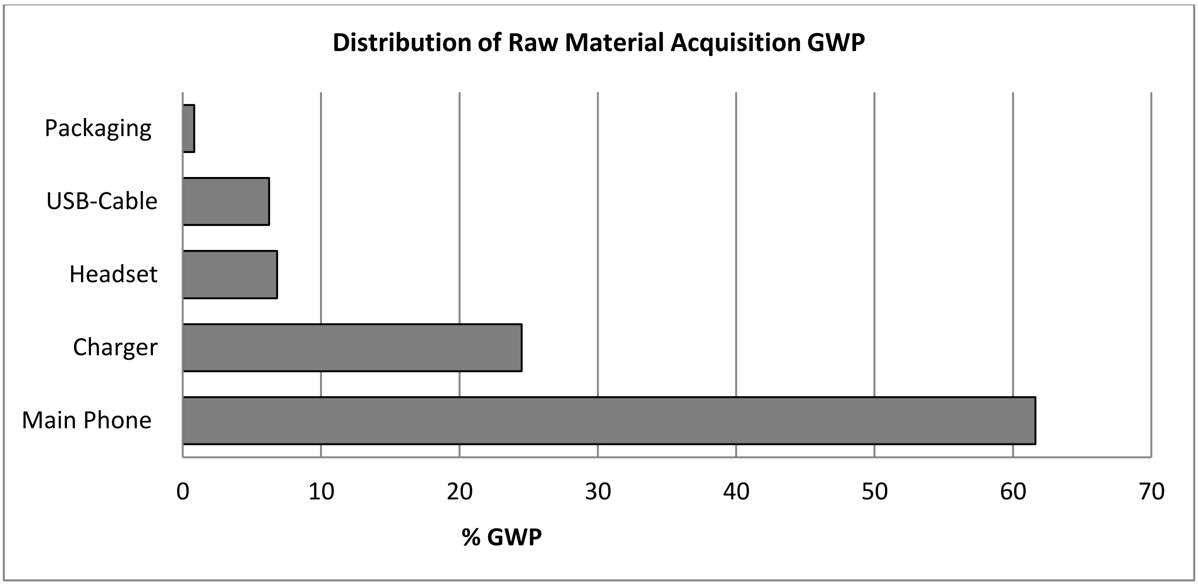


Figure 14 Percentage values for contribution to GWP of the smartphone and its accessories during the raw material acquisition stage.

To further evaluate the main phone, Figure 15 shows the distribution of climate change impact for the raw material acquisition stage between the different smartphone components. As raw material acquisition of IC and standard components is allocated to the production stage due to lack of data transparency (see 4.4.3) they are not included in this figure.

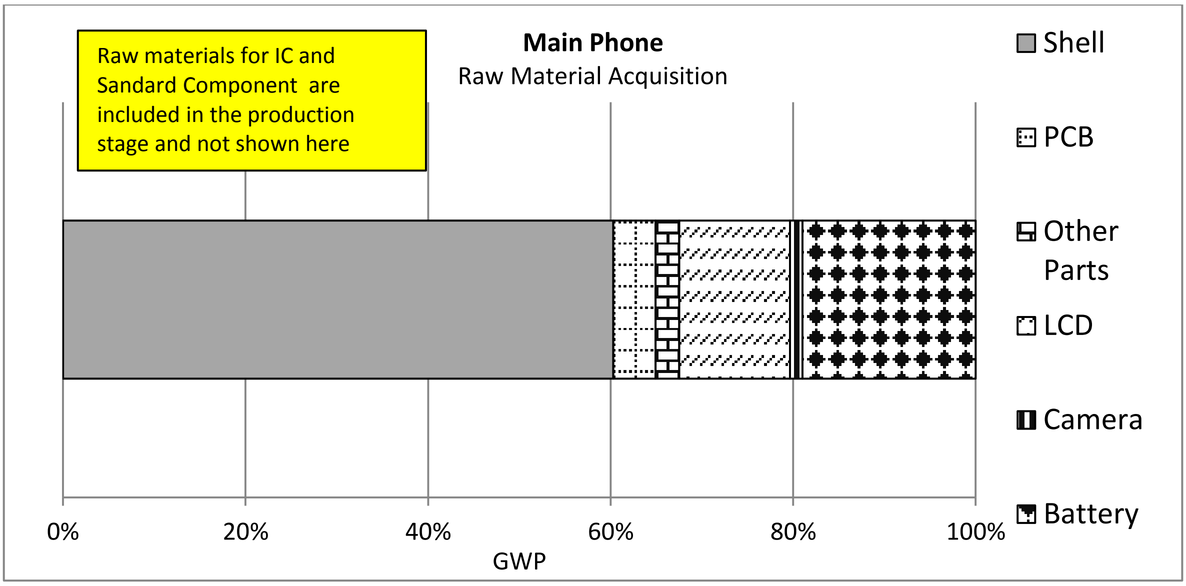


Figure 15 Distribution of climate change impact for the raw material acquisition stage between the different smartphone components.

Figure 16 on the following page illustrates the climate change impact of the raw materials acquisition stage distributed on extraction and processing (the first four bars). In contrast to figure 15, this figure does not include the waste treatment of the raw materials acquisition.

Figure 17 shows the impact of the most contributing materials of the smartphone and its accessories and Table 11 provides a list over these materials and shows their contribution for 1 gram of material.

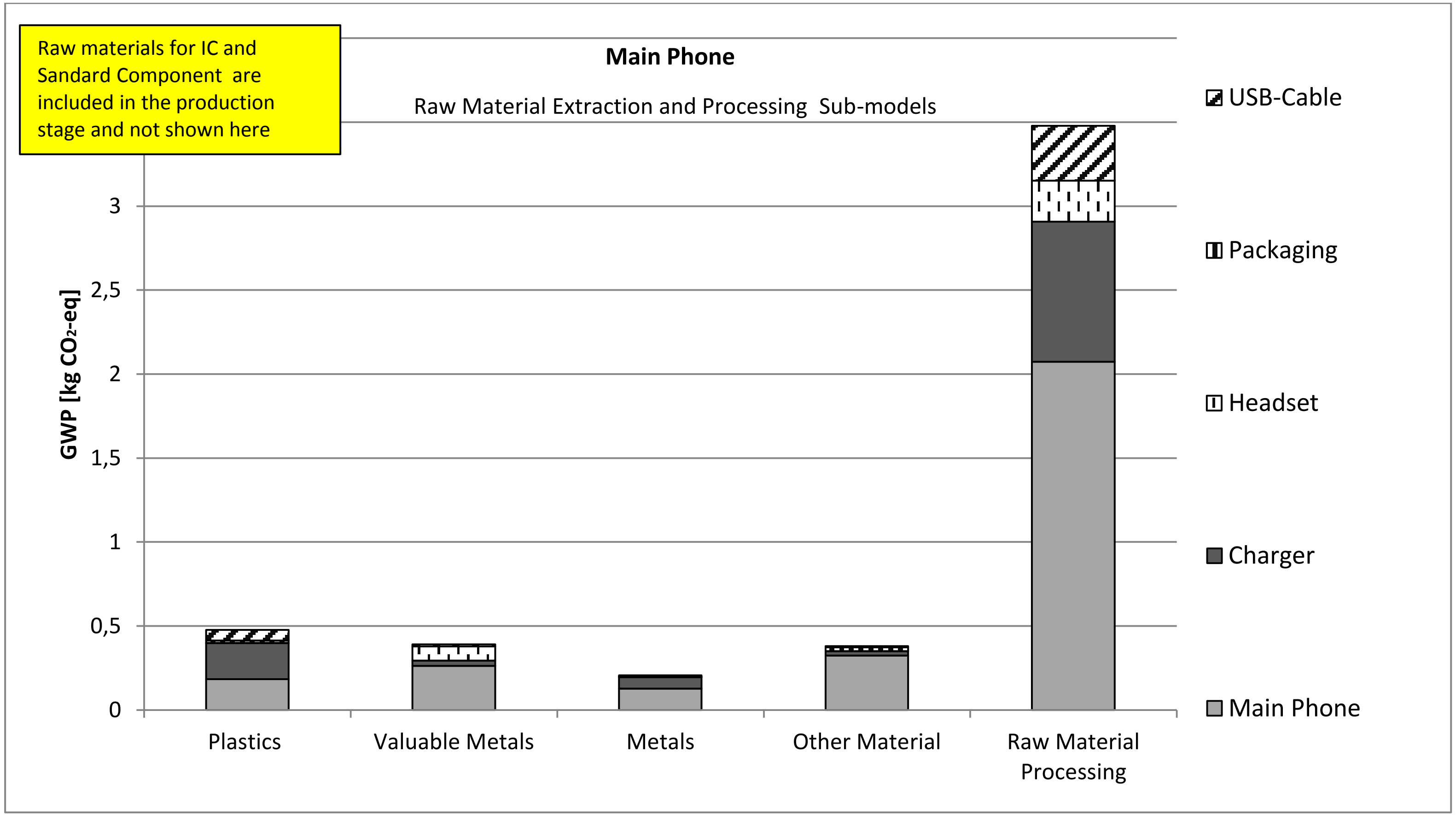


Figure 16 Absolut GWP for the different raw material sub-models for the 3 year life span of the smartphone.

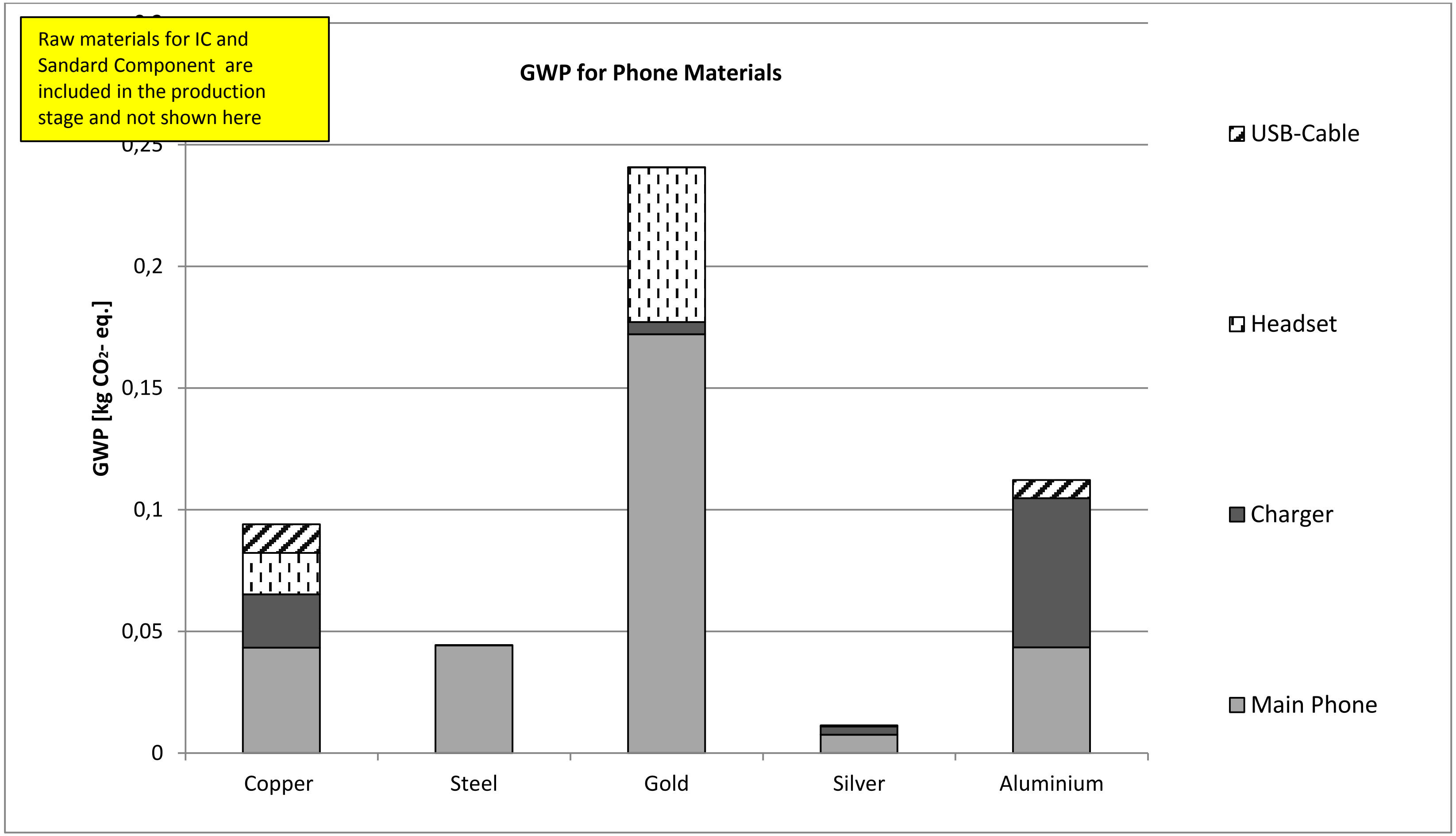


Figure 17 Total contribution to GWP for the materials in the smartphone with highest impact potential. The figure represents the results for the total life time of the device (3 years).

Table 11 Contribution from the production of 1 g of material excluding waste treatment (GaBi, 2012).

Material	Climate Change [kg CO_2-e/g]
Copper	0.024
Nickel	0.072
Tin	0.0030
Silver	0.10
Gold	19
Steel	0.0040
Stainless Steel	0.010
Aluminum	0.011
Plastics	0.0040

6.2 Production

Figure 18 presents the contribution from all the smartphone components and accessories production processes and activities to the GWP. The figures are representative for the total life cycle of the smartphone. The figures in light grey represent the phone components, while darker grey coloring represents the accessories production and other activities. The production stage includes the raw material acquisition for ICs and Standard components, i.e. due to lack of data transparency it is not possible to tell whether the impact from the main contributor, IC, is mainly associated with the raw material acquisition or the production stages. Different allocations of these data are therefore further investigated in the sensitivity analysis.

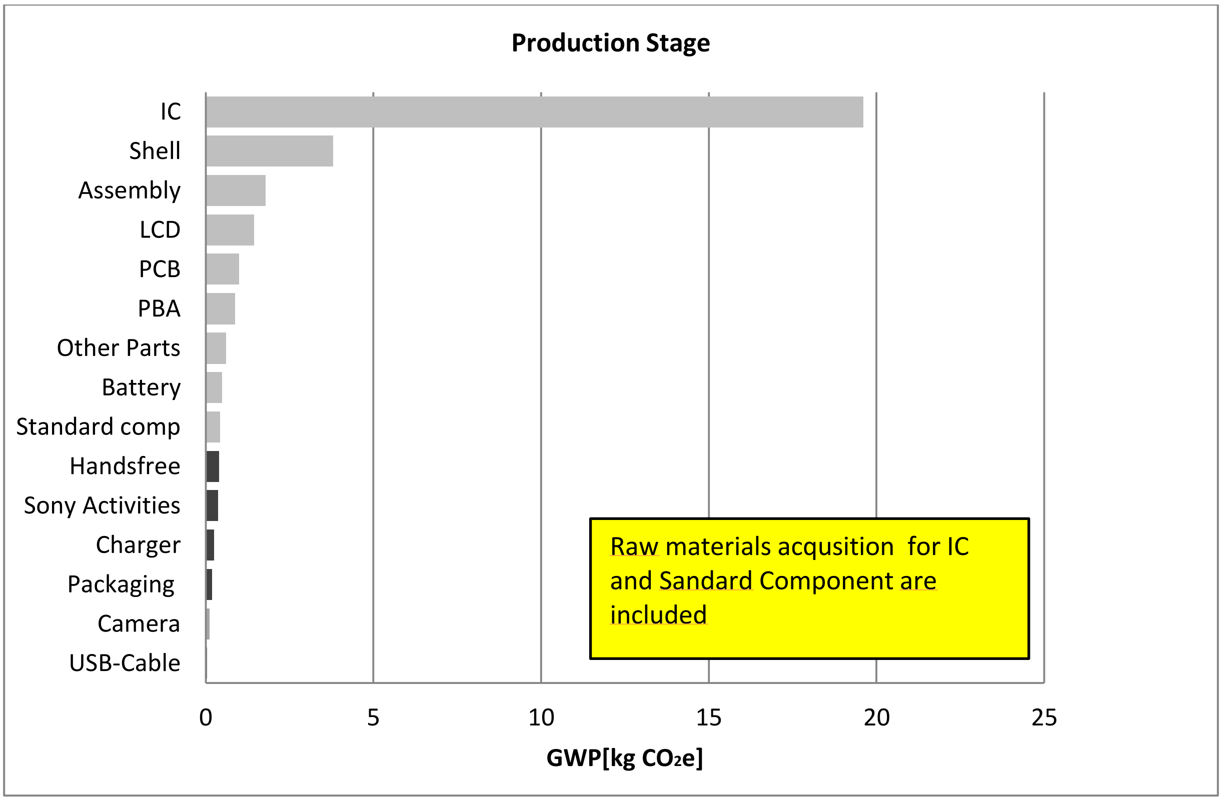


Figure 18 Figures of the smartphone components/activities contribution to GWP for the 3 year life time.

6.3 Use Stage

As described in section 4.4.4, the use stage of the smartphone life cycle is divided into network usage and smartphone usage where network usage refers to the life cycle impact of the network usage and smartphone usage refers to the electricity consumption of the device itself while charging. GWP results for both a Swedish electricity mix and a global electricity mix for the three user scenarios were created; heavy, moderate and light user for the use stage.

Figure 19 shows the climate change impact for the use stage, which includes smartphone usage and network usage for the three scenarios, for both Swedish and global electricity mix. As stated the network usage includes the entire network infrastructure life cycle allocated to the smartphone, and not only the use of the network and lies in the use stage.

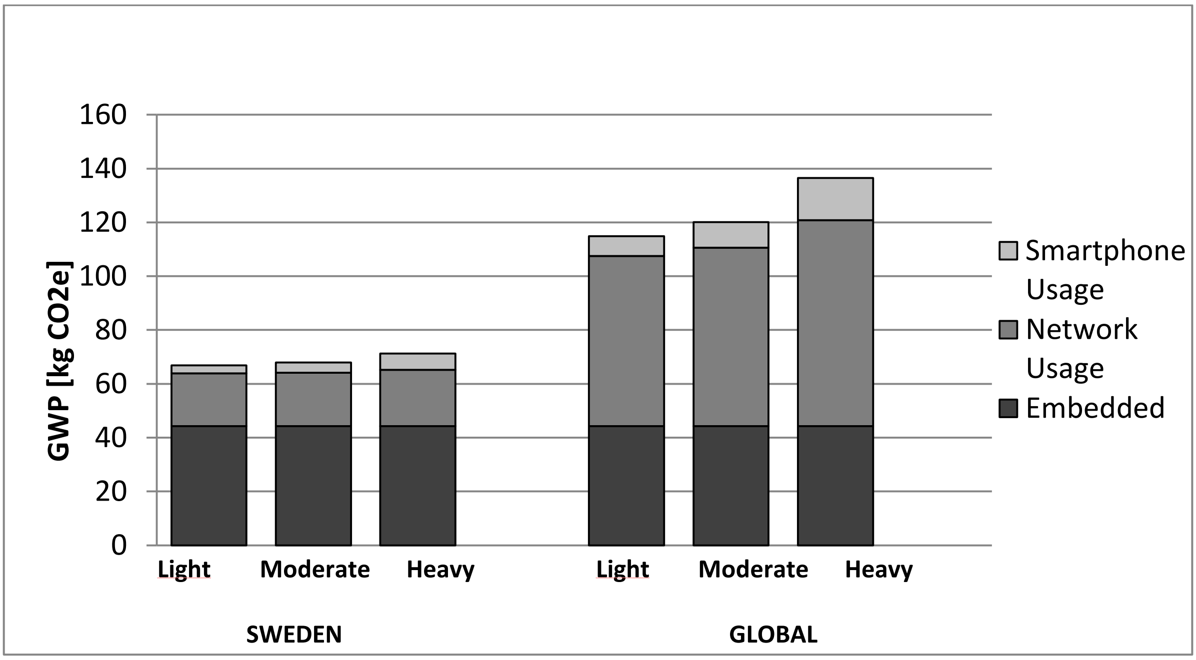


Figure 19 GWP for the three use stage scenarios for Swedish and Global electricity mix. The figure represents the results for use stage only for the total life span of the device which is 3 years.

Table 12 below present the total results for the use stage for all three scenarios, for both Swedish and Global electricity mix.

Table 12 GWP results for the three user scenarios with respective electricity mix, for the time of 3 years.

	Sweden (kg CO_2e)	**Global (kg CO_2e)**
Light User	23	71
Moderate User	**24**	76
Heavy User	27	92

6.4 Transportation

For simplicity the transportation model has been divided into two parts. The distribution of the final phone-kit to resellers and operators represent one part. The transportation of components and accessories to Sony Mobile factory and Sony Mobile business travels represents the other. Transportation of raw materials are aggregated in the raw material acquisition stage and thus not included in the transportation model. Figure 20 below illustrates the distribution of climate change impact between these two parts that make up the transportation model.

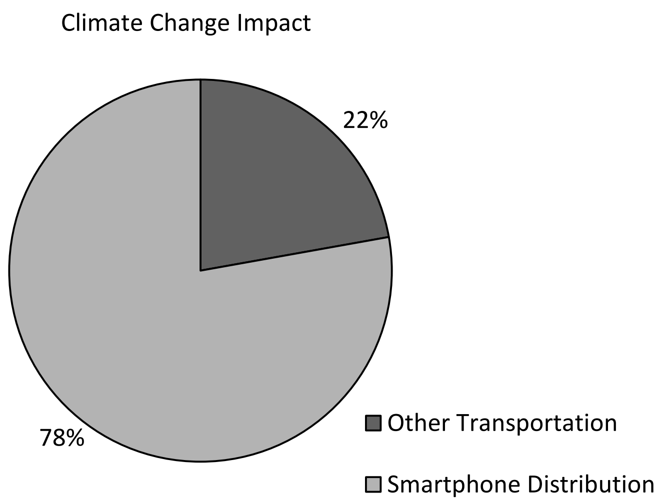


Figure 20 Percentile figures between smartphone distribution and other transportation for the climate change impact category. Other transportation includes component transportation and business travels.

From this figure it is clear that the smartphone distribution accounts for and causes most of the climate change impacts in the transportation stage. As air and road transports were used as the means of transportation in the smartphone model, Figure 21 shows the percentile distribution between these two modes with respect to distance and climate change impact.

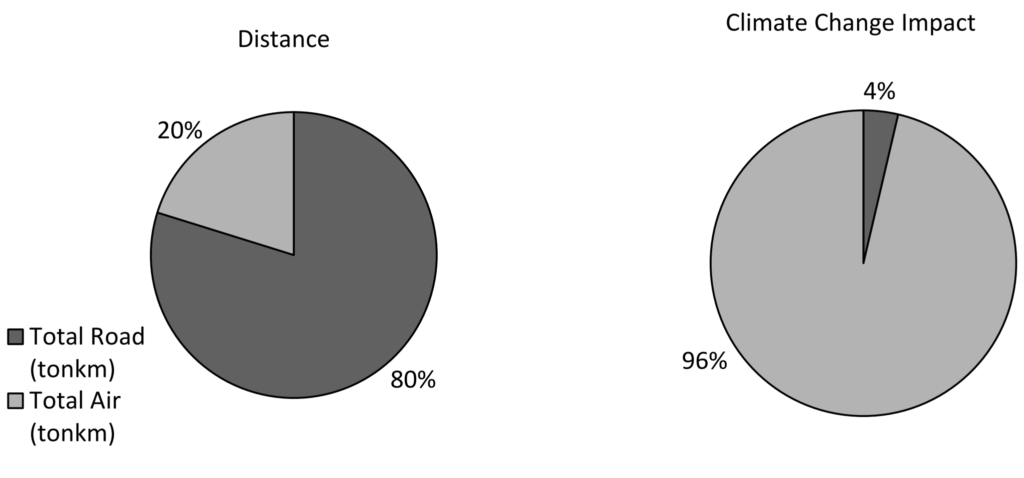


Figure 21 Figure to the left illustrates the total distribution of the transportation distances per modes; road and air transport. Figure to the right demonstrates the distribution of the climate change impact of both these transportation modes.

The figures above, presented for the transportation model, include a packaging factor of 1.25 which is described in section 4.4.6. As the factor increases the weight of the goods, the subsequent environmental impacts expressively result in higher values. When the packaging factor was not included in the model at all, the resulting figures showed a total of approximately 18 percent decrease in the climate change impact for the transportation stage. If the finished product only contained the smartphone and the accessories, hence not the manual, packaging, box and the packaging factor, the transportation results would indicate a 9 percent decrease in climate change impact in comparison to the original scenario.

7 Life Cycle Interpretation

The following section will provide analysis to further understand and clarify the LCA results.

It is important to note that this LCA study has only presented results for the climate change impact category. The relative impact contribution from the different life cycle stages differs depending on the impact category that is being analyzed. Further explained, while a life cycle stage may present a minor relative amount of environmental impact for one of the impact categories it may also present a significant relative effect for another. Thus conclusions from this study do only give information on GWP and no conclusions are made related to overall environmental performance.

7.1 Results Interpretation

7.1.1 Overall Results

During the total life cycle of the smartphone, including the accessories and network usage, it is estimated that approximately 68 kg CO_2e are released, when considering a moderate user in Sweden. Similarly, the results are approximately 120 kg CO_2 e for the moderate global user scenario. Both these amounts include all the life cycle stages of the full system.

Usually other external LCAs conducted on smartphones, unlike this study, do not include smartphone accessories and network, see section 11 benchmarking for main phone. Thus, if the results from this study were to be compared with results of other LCA studies only the smartphone results should be taken into account. Even in that situation, comparisons would not be possible unless conditions and assumptions could be analyzed and would be found comparable.

7.1.2 Main phone

The smartphone itself, *excluding* the accessories and network usage, represents approximately 45 kg CO_2e, for the moderate user in Sweden. Similarly, the results are equal to 51 kg CO_2e for the moderate global user scenario. Again these amounts include all the life cycle stages of the device. Table 13 below displays the distribution of CO_2e of each life cycle stage in kg and percentage for both the global and Swedish cases. As can be seen, the production stage accounts for 31 kg which is equivalent to 67 percent of the total GWP impact of the phone. Hence, from these figures it is possible to see that the production stage of a smartphone is estimated to have the largest impact on the climate change category. This comprehensive result is in agreement with the previous 2008 LCA results and it is possible to see a trend, where the production stage is shown to be the most environmentally impact intensive stage with respect to the climate change impact category.

The component that is considered to result in the highest climate change impact for the raw material and production stages combined was identified as the IC. As this was also the case in the previous study, this outcome was anticipated, particularly due to the advanced technology used in the production of this component. No further analysis was possible based on the aggregated data used.

Table 13 Climate change impact results of the smartphone life cycle based on the moderate usage scenario

Life Cycle Stages	SWEDEN Total : 45 kg CO_2e		GLOBAL Total: 51 kg CO_2e	
	kg CO_2e	The total % of life cycle GWP	kg CO_2e	The total % of life cycle GWP
Raw Material Acquisition	4.9	11	4.9	10
Production	30.5	67	30.5	60
Transportation	5.0	11	5.0	10
Smartphone Usage	3.8	9	9.5	18
End-of-Life	1.0	2	1.0	2

7.1.3 Accessories

The smartphone accessories, when included in the results, show a relatively insignificant impact for the production stage which could be explained by the relatively low technological processes used during the production of these parts. As for the raw material acquisition stage, a considerably higher contribution to climate change is observed which can be explained by the relatively large weight of these parts as seen in Figure 14.

7.1.4 Network

Network usage has been included in the result which is considered unique for this LCA study. The results give higher impact values for global electricity mix in comparison to Swedish electricity mix, as expected, as its production has higher impact. Similarly, the adopted user scenarios present different results. When considering the total life cycle of the smartphone, including network and accessories, it can be seen that the network usage has a significant impact on the results which is equal to 30 percent of total life cycle for the Swedish moderate user scenario.

7.1.5 Materials

As mentioned earlier, the raw material acquisition stage (excluding IC and standard components which were accounted for in the production stage) has a relatively low climate change impact on the results for the smartphone itself. It accounts for approximately 4.9 kg hence 11 percent of the total results.

The composition of the phone has been presented in Figure 10, and as can be seen, the main materials of the phone are plastics and valuable metals followed by other materials. Valuable metal acquisition, especially gold, has been previously noted as an energy intensive processes and thus as important contributor. If considered in more detail, though the amount of gold used in the phone is from the weight perspective very low, due to its high climate change impact which can be seen in Table 11, gold production contributes with approximately 5 percent to the material stage including the smartphone accessories. Similarly, as Table 10 shows impact contribution from, gold acquisition is followed by silver, nickel and copper.

Due to the large amount of plastics present in the smartphone, even if the climate change impact per gram of plastics is less then gold, its overall contribution is approximately 10 percent.

7.1.6 Production

As the previous 2008 LCA study (Bergelin, 2008) indicated that the production stage resulted in the highest impact of all stages, a similar outcome was expected for this LCA study as well due to the high technological and energy demanding production processes. This expectation was confirmed. The production stage accounts for approximately 30.5 kg CO_2e where is can be seen from Figure 18 that the IC is the main contributor with 19.6 kg of CO_2e where the raw material acquisition is also included in this number.

7.1.7 Use Stage

The use stage comprises of the network usage and the utilization of the mobile device and is representative for the use of the smartphone for the life cycle. As Figure 19 illustrates, the network usage accounts for the greater contribution to the climate change impact of the use stage. Subsequently, the utilization of the device consists of electricity consumption, and thus the electricity mix determines the climate change impact. Swedish electricity mix is considered to result in 0.06 kg CO_2e/kWh electricity produced, while the global mix is reported to be 0.6 kg CO_2e/kWh (Malmodin, et al., submitted). Sweden's main source of electricity production is nuclear and hydropower while the global mix includes a great portion of coal and fossil-fuel power (Schakenda, et al., 2008). These figures clearly explain why the global electricity mix result in larger amount of climate change impact for the use stage.

The utilization results show a greater increase from a moderate user to a heavy user in comparison to the increase from a light to a moderate user. The Swedish electricity mix shows a 5 percent decrease from a moderate to a light user, and an increase of 19 percent from a moderate to heavy user. Similarly, the global electricity mix results in a decrease of 7 percent to a light user, and an increase of 31 percent to a heavy user in comparison to the moderate user scenario.

7.1.8 End-of-Life Treatment

The end-of-life treatment stage of the smartphone has been presumed to represent 2 percent of the total life cycle results and hence is equal to approximately 1 kg CO_2e.

7.1.9 Transportation

The transportation model is based on air and road travel and is estimated to have an impact on climate change of 5 kg CO_2e during the life cycle. Of the modeled transports, the distribution of the final product is accounted to contribute to 78 percent of the total transport related climate change impact while the remaining 22 percent is caused by the component transportation to the Sony Mobile factory by the suppliers. As the distribution of the smartphone accounts for most of the climate change impact, and is mainly based on air transport, opportunities for improved environmental performances for transportation should be focused on decreasing air transports. It can be seen in Figure 21 that the air transportation for distribution and component transportation is responsible for 96 percent of the total climate change impact for the transportation model even though it only represents a smaller portion of the transportation distance.

The transportation model is constructed so that it is reliant on the distance multiplied by the weight. Thus, the weight of the transported goods plays a key role in the amount of climate change impact produced. As the final phone-kit includes packaging box, plastic wrappings and instructions manual, by producing these locally instead; the climate change impact due to transportation could be decreased by approximately 20 percent. The results represent a rough estimation since the smartphone distribution model has been simplified and also adjusted to one scenario where the transport route is set from Beijing to Copenhagen to its final destination; Sweden.

7.2 Sensitivity Analysis

7.2.1 Analysis

Sensitivity analysis is performed to assess how uncertainties and assumptions in the model could affect the study results. Thus, this procedure tries to quantify uncertainties and provide an understanding of the accuracy of the model.

Various scenarios have been formulated for the sensitivity analysis of assumptions and uncertainties as well as the methodological framework of the study which have been presented in Table 14.

Table 14 Sensitivity analysis scenarios.

Name	Description	Motivation
Assumptions, Uncertainties		
Transportation	The average 100 km distances were increased to 1000 km in order to assess likely under estimations	Assumption/ Uncertainty
Packaging Factor	The 1.25 packaging factor was **1.)** removed entirely and **2.)** increased to 2.50 to assess likely over/under estimations	Assumption/ Uncertainty
Use Stage	The moderate user scenario was compared to a **1.)** light and **2.)** heavy user scenario with both global and Swedish energy mix	Assumption/ Uncertainty
Raw Material Processing	The 40% higher raw material loss was **1.)** removed entirely and **2.)** increased to 80%	Assumption/ Uncertainty

Materials Acquisition share of IC model	Allocation of 5%-50% of the IC cradle-to-gate impact to material acquisition stage. Variation of the raw material stage is analyzed more in detail.	Uncertainty
Methodology		
Recovered Electricity	Recovered electricity from waste treatments is not recirculated to energy demanding processes	Uncertainty

The scenarios, according to Table 14 above, were applied to the model one at a time where the input parameters were altered accordingly. These alterations apply for the phone including the accessories.

7.2.2 Results

The sensitivity analysis results are presented in table 15 as a percentage increase or decrease from the original total life cycle results as well as impact on individual stages, for the climate change impact category.

		Variation on Total Life Cycle Results (%)	Variation in Effected Life Cycle Stage (%)
Transportation Increased		~0	+2 (Transportation)
Packaging Factor	**Removed**	-1	-18 (Transportation)
	Increased	+6	+86 (Transportation)
Use Stage Sweden	**Light User**	-2	-5 (Use)
	Heavy User	+5	+14 (Use)
Use Stage Global	**Light User**	-4	- 7 (Use)
	Heavy User	+14	+22 (Use)
Raw Material Processing	**Removed**	-1	-6 (Raw Material Acquisition)
	Increased	+1	+6 (Raw Material Acquisition)
Recovered Electricity No Recirculation		+2	+4 (Production)

Table 15 Sensitivity analysis results

7.2.3 Interpretation

From Table 15 it can be concluded that the global heavy usage scenario, followed by the parameter packaging factor have the largest percentage impact on the results. The global heavy usage scenario increases the total results by 13 percent due to the big impact the electricity mix has. When the packaging factor is removed the climate change impact decreases with 1 percent while increasing it to 2.5 results in a 6 percent increased climate change impact on the total results.

The raw material processing parameter results range within +/- 1 percent with the removal and the addition of 80 percent of the excess materials. Similarly, the heavy and light use stage scenarios compared to the moderate user expectedly affect the total results. The energy consumption for the heavy user increases the total results with 5 percent and 13 percent increase for the Swedish electricity mix and the global electricity mix respectively. Accordingly, the light user results in a decrease of 2 percent and 4 percent respectively.

When the transportation and recovered electricity parameters are considered, the sensitivity analysis indicates transportation has no detectable impact and recovered electricity presents a 2 percent increase on the total results which is considered to be minor and insignificant.

From this sensitivity analysis it is concluded that the model is considered to be relatively stable with respect to the parameter values that have been altered as there is no drastic change in the total results. The global electricity mix and usage scenario variations are more related to system definition than to uncertainties and hence the big variations observed for these scenarios are related to model stability, but also reflects real variations in use.

The results for the Materials Acquisition share of IC model do not affect the total results. Figure 23 presents the impact the variation has on the raw material acquisition stage. When the percentile ratio of production versus raw material acquisition is altered, the results for the raw material acquisition stage vary between 9.8 to 0.98 kg CO_2e.

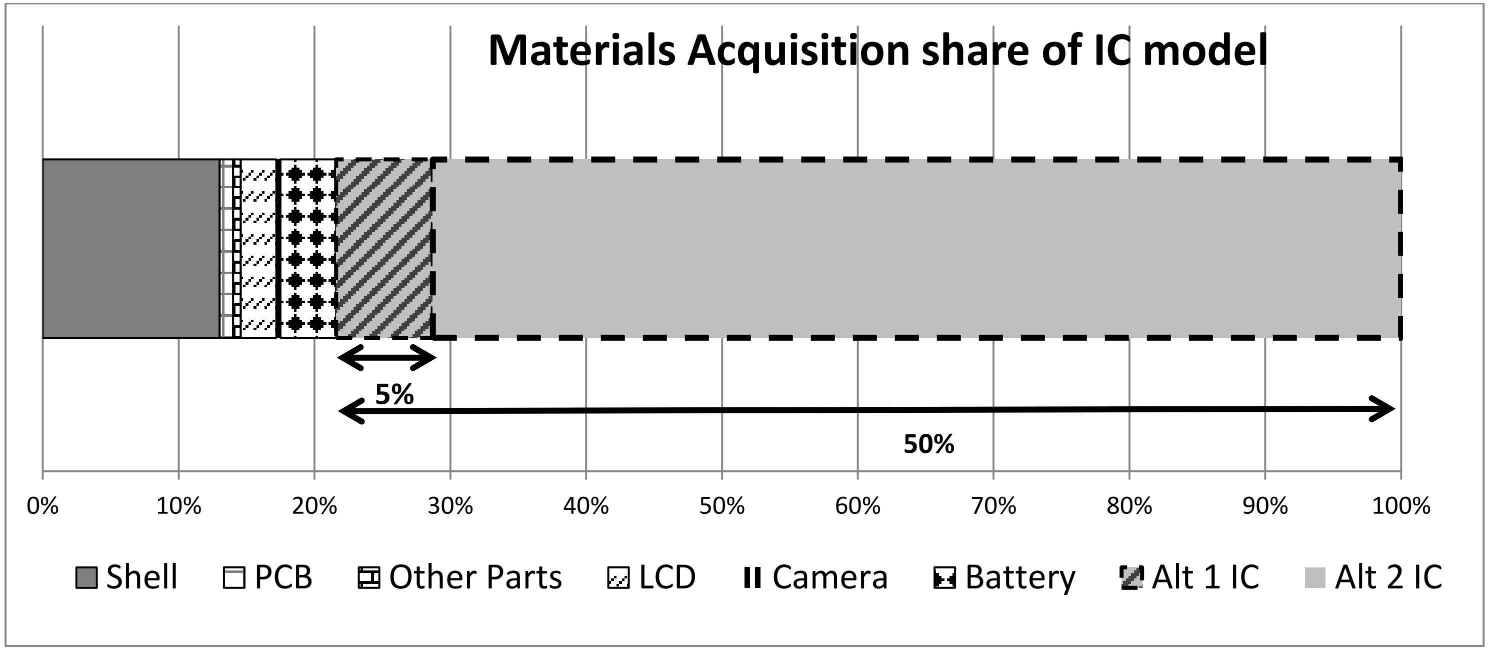


Figure 22 Raw material acquisition stage results in percentage when IC is included.

Part 2

Parameter Model

Parameter Model in Other Contents

Benchmarking

8 Parameter Model

As a part of the thesis work, a task to update the parameter model created during the previous 2008 study was embedded in to the study. As the previous model was constructed in Microsoft Office Excel, the decision to use the same software was taken. This choice of software provided easy accessibility and use.

The purpose of creating a parameter model is to be able to adapt the results obtained for the Xperia™ T model to other smartphones and thus to get an estimated value of the life cycle impacts of other smartphones. The parameter model is aiming at global warming potential only. The applicability to other mobile devices is also investigated. Evaluations of other mobile devices will be based on the assessed Sony Xperia™ T characteristics. The input parameters in the Excel model are presented in Table 16.

Table 16 Input parameters possible to vary in the Excel parameter model and their respective units.

Parameter	Unit
Standard Components	kg
IC	cm^2
Printed Circuit Board (PCB)	kg
Phone Shell	kg
Main camera unit	Number of camera units
Battery Unit	kg
LCD unit	cm^2
Other Parts	kg
Charger	kg
USB-cable	Number of USB-cable
Headsets	Number of Headsets
Packaging and documentation	kg
Electricity Mix	Global, Swedish (CO_2e/kWh)
Smartphone Usage	Light, Moderate, Heavy (kW/3 years)
Transportation	kgkm
Sony activities	Number of phones

Additional sub-models added to the parameter model compared to the previous parameter model include the headsets component and the network in the use stage. As the network has been based on a previous LCA study for Sweden (Malmodin et al., submitted) the results for this sub-model are based on Swedish figures but can be adapted in the parameter model to represent global values by changing the Swedish electricity mix to global for its use stage. The model is built so that in future studies additional electricity mixes can be added and results obtained for these other regions in the world. Since network usage is rapidly changing with the addition of 3G and 4G, and differs between operators, it is important to note that the network figures could not give but a coarse model and should also be updated during the following years as the technology is developing.

For practicality and functionality of the parameter model, simplification was inevitable. When analyzing the life cycle of the device in GaBi, not only different stages were defined for all the phone components but data was also categorized into different material groups and component production processes. The parameter model is simplified and does not divide neither the material groups nor components present in the device, but rather bases the results on the total mobile phone weight. This generalization implies the assumption that the targeted mobile device is composed of the same materials as the Sony Xperia™ T which does not necessarily have to be the case. Thus, obtained results for the materials may be ambiguous and misleading. Nevertheless, if the overall life cycle of the device is taken into consideration for the moderate Swedish usage scenario, it presents that the material acquisition stage accounts for 11 percent of the total results for climate change and therefore the potential difference in materials is not considered to have a significant impact on the total result.

The calculation processes for the parameter model involve, in the case of phone weight, that the investigated mobile device is divided by its weight and then multiplied with the results per kilogram for the Sony Xperia™ T for all life cycle stages. Similarly, the other parameter results are calculated. The production processes are divided based on the components, such as camera unit and battery, present in the device which are scaled independently. Depending on the component, the calculations are based on weight or area. The PWB, LCD and IC production results are based on the total area of these components that are present in the investigated mobile device. The ICs that are used in smartphones are considered to be advanced and high technological components and thus the LCA results received for the production is applicable for advanced and similar technical level devices. If the parameter model were to be implemented for a feature phone or any other less advanced mobile device there may be an overestimation of the impacts. Phone assembly and Sony Mobile activities are allocated per unit phone and is counted for in the parameter model. The use scenario includes the network usage and the use of the mobile device. As the electricity mix affects the results for the use stage, the parameter model is adjusted to have a global and a Swedish electricity mix option. The end-of-life treatment of the mobile phone is calculated based on the weight and inserted as parameters in the model. For simplicity, the transportation of the phone components to the assembly site has been kept fixed and thus represents the transportation web for Sony Xperia™ T. In the parameter model the results are based on the total weight of the phone kit, where the box containing the phone, manuals and all accessories are included. The additional accessories; headsets, charger and the USB-cable are included in the parameter model separately and are based on the weight of the components.

The final results of the parameter model are presented for global warming potential both for yearly impact and total life cycle for the stated life time of the mobile device. The parameter model also allows alternation of the life time. The final results are presented per life cycle stages; raw material acquisition, production, transportation, use and end-of-life treatment. Figure 23 presents a snapshot of the parameter model created in excel.

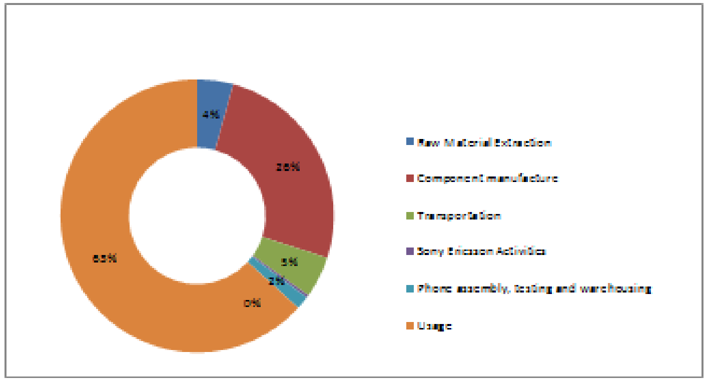
As the LCA study was based on the Sony Xperia™ T smartphone, it is important to realize that the results from the parameter model are not only simplified and should be recognized as estimations but also provides only indicative figures for other smartphones. As differences in results when using the parameter model and performing a full LCA on another smartphone have not been explored, the uncertainties that accompany the results are unidentified and unknown.

Figure 23 Snapshot of the parameter model created in Microsoft excel.

A	B	C	D	E	F	G	H	I	J	K	L
Mobile phone Carbon Footprint	**Main unit**		**Comp. unit**		**C-LCA data (CO_2e EF)**		**Results**		*Comments*		Global
Component specification					**Raw Material Acquisition Res**	**Units**	**Component Manufacturing**				
Other Parts	0,00496	kg			0,0771	kg CO_2e	Other Parts	0,60079	kg CO_2e		
Printed Circuit Board (PCB)	0,00811	kg			0,137	kg CO_2e	Printed Circuit	1,867	kg CO_2e		
Phone Shell	0,0807	kg			1,79	kg CO_2e	Phone Shell	3,8	kg CO_2e		
Main camera unit	1	unit	0,0011	kg	0,041	kg CO_2e	IC	19,602	kg CO_2e		
Battery Unit	0,035	kg			0,563	kg CO_2e	Camera	0,114	kg CO_2e		
LCD unit (the driver IC is included in ICs)	87,1	cm2			0,36	kg CO_2e	Battery	0,4674	kg CO_2e		
Charger	0,06	kg			1,18	kg CO_2e	LCD	1,4499999	kg CO_2e		
USB cable	1	unit	0,024	kg	0,301	kg CO_2e	Stand comp	0,434	kg CO_2e		
Headsets	1	unit	0,021	kg	0,328	kg CO_2e	Charger	0,249	kg CO_2e		
Packaging and documentation	0,0827	kg			0,0393	kg CO_2e	USB	0,0432	kg CO_2e		
Standard Components	0,00197	kg					Headset	0,397	kg CO_2e		
ICs, Integrated circuits (total in phone incl. cards)	6,6	cm2					Packaging	0,195	kg CO_2e		
Total component transports											
Air	0,01975	kg	20800	km	0,655646755	kg CO_2e					
Road	0,33817	kg	12600	km	0,974686305	kg CO_2e					
Sony activities	1	phone									
Final Phone assembly					1,78	kg CO_2e					
Sony business activities					0,363	kg CO_2e					
Transports to market											
Air	0,338	kg	7200	km	3,884634	kg CO_2e					
Road	0,338	kg	800	km	0,061854	kg CO_2e					
Total cradle-to-store LCA result						**TOTAL:**					
Raw Material Acquisition							**4,8164**	**kg CO_2e**			
Main Phone Manufacturing							**28,54265**	**kg CO_2e**			
Accessories Manufacturing							**0,6892**	**kg CO_2e**			
Global											
Subscriber	1										
Life time (years)	3										
USE PHASE											
Smartphone Usage											
Light User	7,31										
Moderate User	9,45										
Heavy User	15,7										
Moderate User	9,45										
Network Usage											
Base Station Sites											
Operation					41,4	kg CO_2e/3subyear					
Manufacturing					7,2	kg CO_2e/3subyear					
Control & Core Nodes											
Operation					1,8	kg CO_2e/3subyear					
Manufacturing					0,3	kg CO_2e/3subyear					
Operator activities											
Operation					4,5	kg CO_2e/3subyear					
Transmission & IP Core Network											
Operation					1,62	kg CO_2e/GB					
Manufacturing					7,2	kg CO_2e/3subyear					
Data Centers											
Operation					2,4	kg CO_2e/GB					
				NETW	**62,4**	**kg CO_2e**					
End-of-life treatment					**1,024361325**	**kg CO_2e**					
Total Smartphone results					**104,4244065**	**kg CO_2e**					
Total life cycle results					**114,6424276**	**kg CO_2e**					

Yellow marked boxes can be subjected to alterations which will provide correct LCA results and can be seen in the figure as percentile values.

Network usage choice involves setting an electricity mix either global or Swedish as well as choosing a user type; light, moderate and heavy user.



9 The Parameter Model Applicability for Other Devices

This LCA study is based on the particular smartphone model, Sony Xperia™ T. By comparing basic features of different smartphones on the market it is possible to say that they have very similar core functionality. Smartphone models differ in size and shape hence also differs in the components design and structure. The size and complexity of the PWB, the LCD, and the ICs are varying factors depending on the investigated smartphone model. Similarly the different phone models may have different component suppliers as well as different production processes and geographically located in different places. Further, supply chains are dynamic and change over time. These varying factors may correspondingly bring forth other environmental impact than those resulted for this specific model.

The display screens, measured diagonally, range from 3 inches to over 5 inches and the components that constitute the device can be considered to have similar technical specifications (Top ten reviews, 2013). In the parameter model the production processes are geographically located mainly in Asia and thus, for many processes Chinese or global electricity mixes have been used. Although the electricity mix for production has a substantial impact on the global warming potential, this data has not been parameterized. Chinese electricity mix is coal dominant, and thus if the production processes of the phone would use another electricity mix, the obtained results from the parameter model would not represent the real situation well. As the main smartphone production takes place in Asia, the parameter model is considered to model the real state of affairs relatively well (IER, 2009).

To see if the parameter model is applicable to other devices or not, the technical specifications of a smartphone will have to be compared to the investigated device.

One of the most recent trends, the emerge of smartphones, have been followed by the development of tablets where multiple major brands including Sony Mobile have invested in this product development. Tablets, in comparison with smartphones, have multiple features and functions that overlap with smartphones but also have distinctive unique features which have resulted in popularity for both types of devices (Mobithinking, 2012).

The operating system is compatible for both devices and the most common systems today include Apple's iOS and Google's Android. The chief differences involves their connectivity; as a smartphone connects through Wi-Fi and 3G the most common tablets so far only have Wi-Fi connectivity. Wi-Fi supplies internet connectivity, while 3G networks additionally provide calls, short message service (SMS) as well as data download and send functions. Thus, tablets are adapted to fulfill the same functionalities as a smartphone with the exception of calling and sending SMS, and for the most popular models, for a more limited mobility. The general characteristics of tablets are that they are a combination of a smartphone and a laptop and thus tend to have a bigger screen compared to the smartphone, measuring between 7 to 10.5 inches while keeping its touch functionality. The internal memory is larger than in the smartphone and most of the parts are bigger as well as there are additional amounts of some of the device components, such as the speaker, screws, and battery.

A video, available on the internet, illustrates the dismantling of a Sony Xperia™ Z Tablet where a collection of tablet parts are exposed (SGNL, 2006). Figure 24 below present a snapshot from this video, where the main components of the Sony tablet are displayed. This specific tablet model included an additional speaker, similar cameras, PBA in another arrangement and the similar li-ion battery where three batteries are combined to form a large battery set. These characteristics of the tablet were compared with those of the smartphone and it was concluded that the parameter model could be applied also to tablets due to the similarities in physical properties.

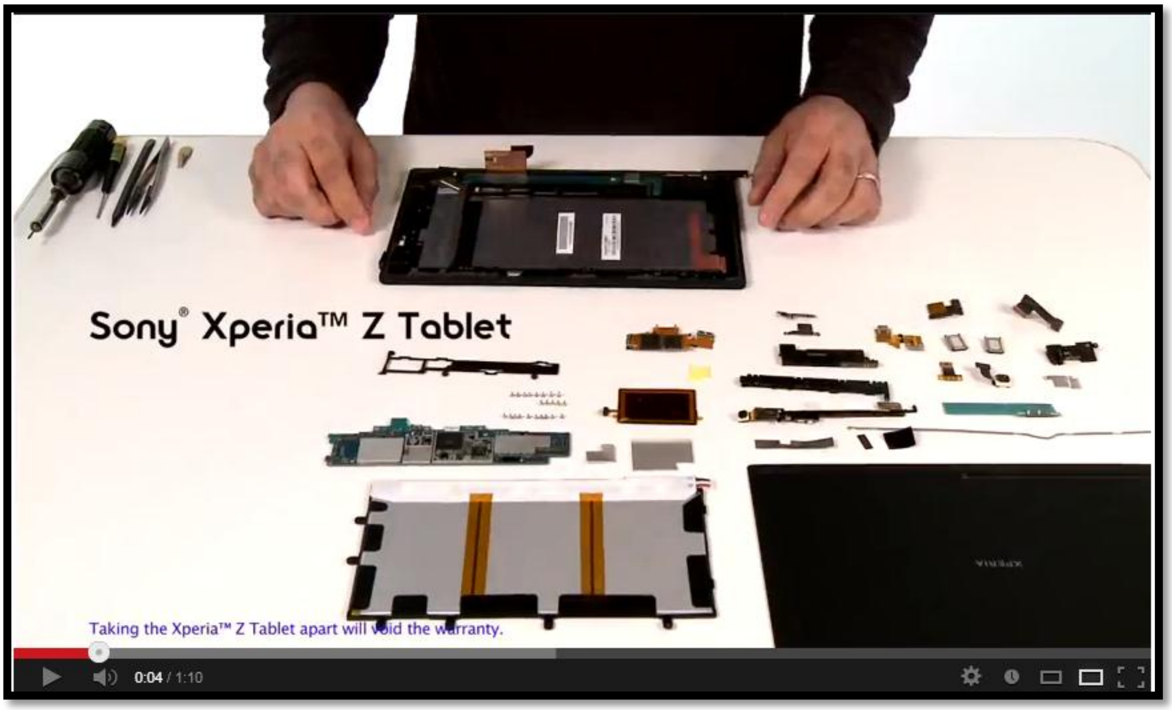


Figure 24 Main components of a Sony Xperia™ Z Tablet.

If the parameter model is considered in other contexts, where the range of devices are expanded, the technicalities of the smartphone is likely to differ more than it differs from tablets. As computers can be seen as the next advanced level of device, it also includes more advanced technology and features that could result in an over or underestimation of the device's impacts if the parameter model were to be applied. Thus the parameter is not intended for computers.

10 Maintenance Strategies and Future Improvements

The LCA model developed is considered as stable and does not need maintenance as long as the smartphones do not deviate too much from today´s phones, In contrast the data should be reviewed on a regular basis.

In order to guarantee the maintenance of the LCA model developed in this study, a continuous dialogue and close contacts with suppliers could allow data collection to be performed on a regular basis which would make the future update of the model to be easier and more time efficient.

The overall maintenance and future improvements of the LCA model include updating data that is received from suppliers on a regular basis as well as collecting new data for the components including the battery and USB-cable, where previous 2008 LCA data was reused.

Both primary and generic data have been used in this study and thus, the generic GaBi data also requires regular updates as some processes used during modeling stage dates back to 1990s. As GaBi does not divide its generic processes into the life cycle stages, it has caused difficulties in the analysis of the raw material acquisition and production stage of the results. In order to overcome this limitation, other LCA tools could be explored or GaBi could be asked to split the processes into the life cycle stages that are used in the international standards. A potential improvement area would be to replace part of the generic data with primary data. Table 17 below provides a list of suggested updates for components that could be considered for such improvement.

Table 17 List of components that require future update

Component	***Current Status***	***Suggestions***
Network	Figures based on a study conducted year 2006	Annual updates
LCD Screen	Aggregated raw material acquisition and production data Based on generic GaBi Data	Acquire primary data for the production process
Integrated Circuit	Production data based on IC LCA study	Acquire primary data for the production process
PCB	Production data based on generic GaBi Data	Acquire primary data for the production process
Standard Components	Aggregated raw material acquisition and production data Based on generic GaBi Data	Acquire primary data for the production process and material information
Battery	Material and production stages based on previous 2008 LCA study	Acquire new primary data for material and production stage

11 Benchmarking

The previous 2008 LCA study resulted in 17 kg CO_2e after having recalculated the results for a life time of 3 years in order to match the life time of this study. The present LCA results gives higher GWP values, at 51 kg CO_2e, in comparison to the previous 2008 LCA study, as expected, due to the more advanced technology of the smartphones.

Similar LCA studies, conducted by leading corporates for their own line of smartphones, can be found publically. As these studies provide only an overlooking portrayal of the results, the methodological procedures of the studies are unknown. This limits the possibility to compare the LCA studies with one and the other as it may result in misrepresentative comparisons. Keeping this in mind, LCA studies lead by Apple and Nokia have been included in this report for benchmarking

The Apple LCA studies, Figures 25 to 27, as they state, are in accordance with the ISO 14040 and ISO 14044 standards. As for this study, the results are only reflecting GWP (100 years). The included life cycle stages consist of production, transportation, use and recycling. Production comprises of extraction of raw materials, production, and transportation of raw materials and manufacture, transport, and assembly of all parts and product packaging. The transportation stage includes the air and sea transportation of the final product and its packaging from production site to the hubs. The use stage includes the power consumption for the period of 3 years where the energy mix is set to the global emissions level. Recycling comprises of the transportation to the recycling centers and the energy consumption of the mechanical separation and shredding processes (Apple, 2012).

The Nokia LCA studies, Figures 28 to 30, are also stated to be in accordance with the ISO 14040 and ISO 14044 standards and covers the raw materials acquisition, component production, Nokia's own factory processes, inbound & outbound logistics, usage (3 years) and recycling stages. Data sources include Nokia's own data for facilities and operations and data from suppliers as well as LCI databases where no specification for these databases is given.

The Nokia studies do not include smartphone accessories, packaging, and Nokia travel activities (Nokia, 2012). Thus, when comparing the results of this study with results from Nokia and Apple the corresponding modules were excluded.

Product: iPhone 5

Weight: 112 g

Dimensions (LxWxH): 123.8x58.6x7.6 mm

Package weight: 149 g

Battery: Li-ion Battery

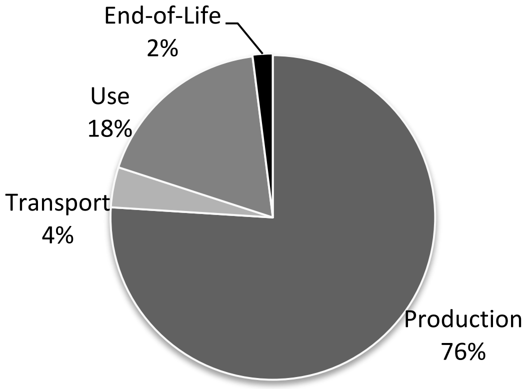


Figure 25 iPhone 5, Total greenhouse gas emissions: 75 kg CO_2e (Apple, 2012).

Product: iPhone 4S

Weight: 140 g

Dimensions (LxWxH): 115.2x58.6x9.3 mm

Package weight: 133 g

Battery: Li-ion Battery

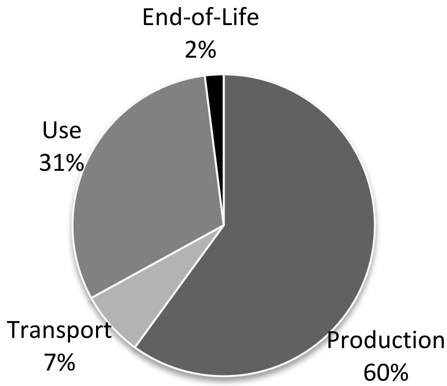


Figure 26 iPhone 4S, Total greenhouse gas emissions: 55 kg CO_2e (Apple, 2012).

Product: iPhone 4

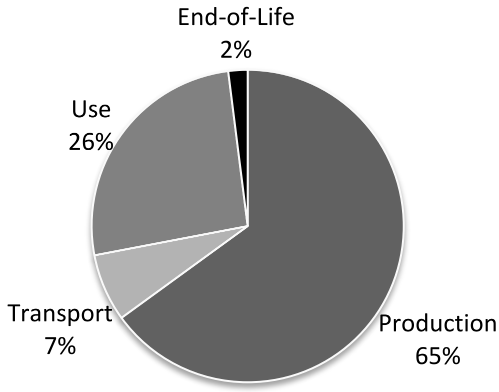
Weight: 137g

Dimensions (LxWxH): 115.2x58.6x9.3mm

Package weight: 133g

Battery: Li-ion
Battery

Figure 27 iPhone 4, Total greenhouse gas emissions: 55 kg CO_2e (Apple, 2012).



As the Apple study presents global results, the results are compared with the Sony Xperia™ T results obtained for the global electricity mix. The Apple figures, presented above (Figures 25 to 27), combine the raw material acquisition stage with the production and hence in order to compare the two studies the Sony Mobile results have been presented accordingly in Figure 28 to 30 below. The Sony Xperia™ T has been calculated to produce 51 kg CO_2e whereas the three Apple smartphones are reported to produce 55 or 75 kg CO_2e with a global electricity mix. From these values it is possible to say that the results are relatively similar, but more details on study scope and limitations are required to draw conclusions on the actual coherence,

Product: Nokia Lumia 822

Weight: 141.6 g

Dimensions (LxWxH): 127.8x68.4x11.2 mm

Package weight: 204 g

Battery: Li-ion Battery

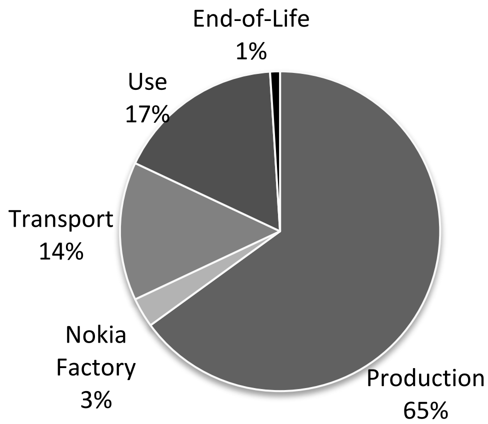


Figure 28 Nokia Lumia 822, Total greenhouse gas emissions: 16 kg CO_2e (Nokia, 2012).

Product: Nokia Asha 309

Weight: 102 g

Dimensions (LxWxH): 109.9x54x13 mm

Package weight: 34 g

Battery: Li-ion Battery

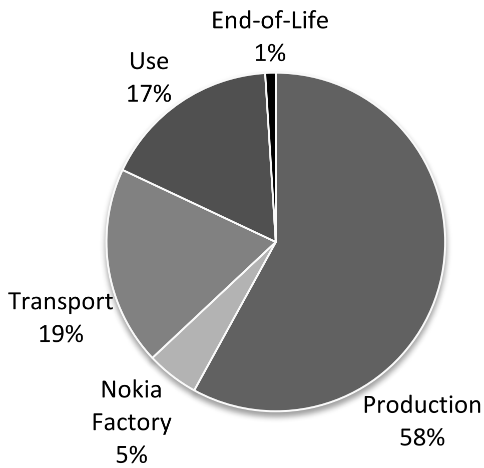


Figure 29 Nokia Asha 309, Total greenhouse gas emissions: 9 kg CO_2e (Nokia, 2012).

Product: Nokia Lumia 620

Weight: 127 g

Dimensions (LxWxH): 115.4x61.1x11 mm

Package weight: 74.5 g

Battery: Li-ion Battery

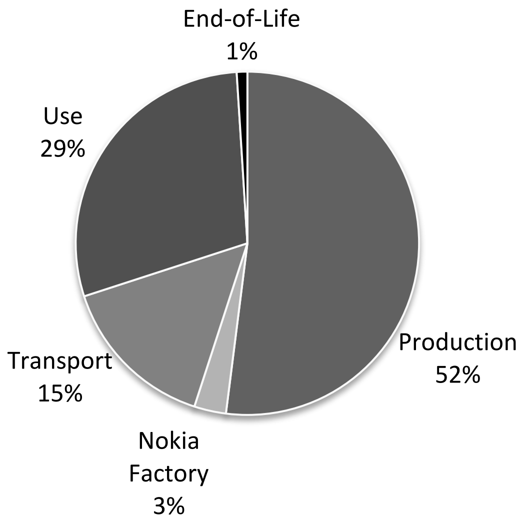


Figure 30 Nokia Lumia 620, Total greenhouse gas emissions: 13 kg CO_2e (Nokia, 2012).

Similarly to the Apple study, the LCA results have been compared to Nokia Smartphones (Figures 28 to 30) where Nokia have also performed LCA studies on their mobile devices. As the Nokia study has different boundaries between their life cycle stages, the equivalents of this study has been calculated and presented in Table 18 below. Nokia total LCA results range between 16 to 9 kg CO_2e which, when compared, show a significant difference to the study results for Sony Xperia™ T. As the methodological framework of the Nokia study is not clear, the result of that study and the present study cannot be compared.

Table 18 Summarizing results, in percent, for the different smartphone models in comparison to the Sony Xperia™ T for the life cycle period of 3 years.

Smartphone	Use Stage (%)	Production Stage (%)	Transportation Stage (%)	EoL Stage (%)	Total GWP (kg CO_2e)
Sony Xperia™ T	**18**	**70**	**10**	**2**	**51**
Sony Ericsson W890	20	66	13	1	17
iPhone 5	18	76	4	2	75
iPhone 4S	31	60	7	2	55

iPhone 4	26	65	7	2	55
Nokia Lumia 822	17	68	14	1	16
Nokia Asha 309	17	63	19	1	9
Nokia Lumia 620	29	55	15	1	13

12 Discussions

12.1 This Study

This section will focus on an overall discussion on the relevant issues linked to the LCA results as well as the parameter model and the use of results.

The conducted LCA study has been executed with the intention to consider international standards. ISO 14040 and ISO 14044 have been used as the base with additional supportive standards specifically for the ICT sector including ITU L 1410 and ETSI TS 103 199. The given requirements and guidelines have been followed as far as possible and based on this, it can be stated that this study follows ISO standards with some exceptions. Only GWP impact category has been studied and thus remaining impact categories have not been included and additionally, the critical review procedure does not follow the ISO standards.

GWP has been selected for the result analysis of this LCA study and this study does not further analyze the remaining impact categories. Thus general conclusions cannot be drawn regarding smartphone's overall environmental impact. For future studies, there is possibility to extract results for the remaining categories as LCI data have been collected. As the intention of this study, from start, has been set to investigate GWP, the modeling of the system has been focused and based on this impact category. No consideration has been taken in regards to if the model is applicable for the remaining impact categories and hence will require additional attention and consideration if such a study is conducted for the other impact categories.

If the study results are compared to the previous 2008 LCA study, it can be seen that today's study gives higher results. These is expected as smartphones are technologically more advanced than feature phones and thus require more natural resources and has more energy demanding production processes.

The results show that the production stage clearly dominates the climate change impact category. This result is expected as the production processes are known to be energy demanding and involve high technological activities. From the suppliers it is known that most production factories are located in Asia, which in terms indicates an electricity mix that has a higher percentage of coal power in comparison to Europe.

As the transportation model is based on a determined scenario, the results give representative figures only for this scenario. The climate change impact of the transportation model is directly related to the distance and the weight of the load. As the load increases, also the climate change impact increases, which imply that by getting more detailed data on the overall load the accuracy of the transport model, could be increased.

The use stage gives varying results depending on the choice of electricity mix, which has a major impact on the climate change for this stage. A unique feature of this specific LCA study, in comparison to other relevant LCA studies conducted on mobile devices, is that it includes the network usage in the use stage. The choice of including the network is based on the fact that the mobile device cannot be utilized unless there is no network coverage and hence the use stage results of the LCA study will not be representing the entire stage. The network has been based on a study where figures are taken from Sweden the year 2010. As the world's active subscriber number and the data traffic increases rapidly, the network usage requires updates as it may not use figures that are representative in the future. Thus, also as most smartphone LCA studies have not included the network in the use stage of their study, the network results have been kept separately in this study as well.

The end-of-life treatment stage for the smartphone is based on an Apple LCA study which includes only one end-of-life treatment scenario; considering that the smartphone is recycled. Figure 31, taken from ABI Research, represent the discharging alternatives consumers have adopted during the years 2004 to 2006 (ABI Research, 2007). As the figure illustrates, in fact only 7 percent of all phones are returned for recycling and refurbishment.

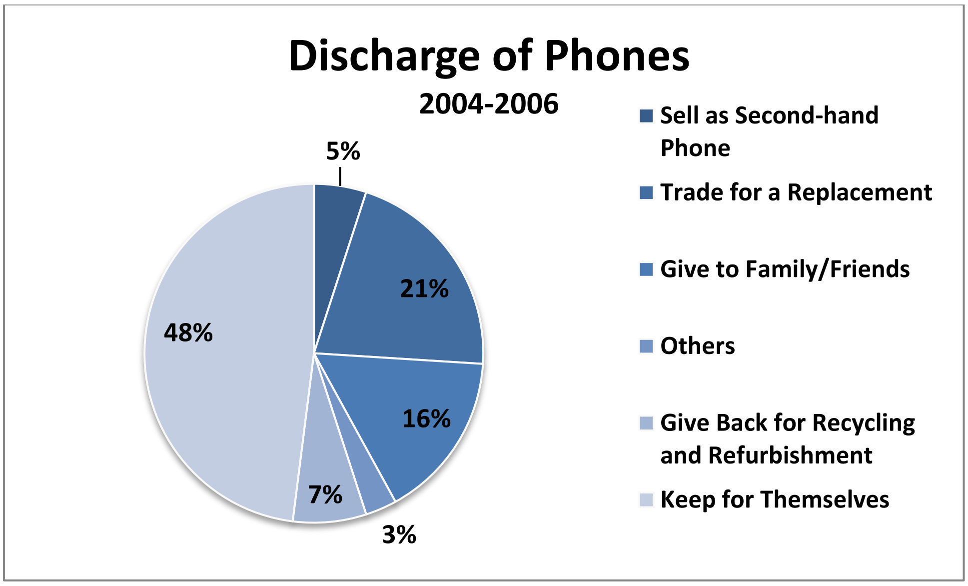


Figure 31 Alternatives of phone discharge during the years 2004 and 2006 (ABI Research, 2007).

It is important to keep in mind that due to the dimension of mobile phone usage and distribution, it is not possible to forecast any accurate figures in regards to number of phones being circulated in secondhand selling or giving away to individuals of ones near social network. The study only represents the end-of-life treatment for the recycling and ethically disposal processes and does not address the potential climate change impact the recirculating devices may have. As the percentage that represents the collected phones is relatively low, it is important to note that there could be a significant environmental effect of the remaining share that has not been addressed in this study. As there was lack of data for the remaining alternatives, in order to avoid data gap, the recycling option was used in this study. Additionally, for GWP, the potential environmental impact is accounted to be relatively low on the total life cycle of the smart phone and hence choosing the Apple study is considered to be arbitrary.

An LCA study is not only a time consuming but also very complex process depending on the complexity of the product that is being studied. As the mobile device is composed of multiple components, the web of suppliers is very large and hard to trace back. The outsourcing of the phone components presents an additional difficulty, as most of the suppliers are geographically located in other parts of the world, creating an extra effort on communicating successive and efficiently.

This LCA study, as it is in most LCA studies, does not include the full spectrum of data that is involved in the entire life cycle of the mobile device. Though incomplete data has been received from some suppliers, the factors that are considered to be most important in the mobile phone life cycle have been included and accounted for.

The sensitivity analysis shows how the limitations linked to the study can possibly affect the final results. Although the methodological choices made in this study affect the results the sensitivity analysis shows that these effects on the final results are not particularly significant. The alterations on the use stage indicated that the choice of electricity mix and usage scenario alters the results considerately. These variations are related to system definition and thus related to model stability. Sensitivity analysis results are presented in section 7.2.

12.2 LCA Benefits and Limitations

When conducting an LCA an extensive amount of product-related data is collected and analyzed. LCA studies possess a holistic nature which is both a strength and a limitation; the extensive scope of the LCA includes studying the entire life cycle of the product and this is achieved at the cost of simplifying certain stages (Baumann and Tillman., 2004).

Having stated this, it is relevant to say that LCA studies are simplified representations of real situations and this should be taken into consideration when analyzing and interpreting obtained results. While studies contain technical assumptions and value choices it is important to make such decisions as transparent as possible and thus following international standards helps to avoid arbitrariness. In order to evaluate the impact of such assumptions have on the results, a sensitivity analysis has been undertaken for each process.

In LCA studies a prediction is made for the future use and end-of-life treatments as these cannot be foreseen in advance. Scenarios are created and implemented in the model which therefore does not fully reflect what happens in reality as the real conditions are too complex. These scenarios are also hard to interpret as the full complexity of the reality is hard to capture, the degree of mislead from the actuality also remains unknown. Thus, any obtained results for an LCA study is limited, hence valid, for the defined conditions, assumptions and boundaries of that study. Also, important to note, an LCA study is not adaptable to future changes in technology and demand and thus does not include nor recognize such alternating variables of a product (Schepelmann, P. undated). Uncertainties in an LCA study is inevitable and these can be summarized in three categorize. Parameter uncertainties arise from the reliability of the provided input data. Secondly there are scenario uncertainties depending on the methodological choices adopted in the LCA study. Finally, model uncertainties due to lack of understanding the studied system can result in unsuitable assumptions (Nokia, 2011).

As an LCA study assess the life cycle stages and activities of a product that produce the highest environmental impact, this furthermore can allow the development of better processes and activities that can improve the environmental performance and prevent many product related impacts (Baumann and Tillman, 2004.). Clearly, LCA studies from an ICT sector perspective, present a complex life cycle and challenging modeling process as well as complicated data gathering and measuring. This being said, the positive aspects of LCA include its ability to identify places where improvements in the environmental performance of goods, networks and services can be made. While doing so, it also plays an informative function for the decision-makers by updating their product performance (Nokia, 2011).

When comparing LCA studies to one another, especially when considering ICT products, there is a risk that the simplifications made during the study will give misleading results that differ from the actual relation in product performance. Accumulation and double-counting of data for different processes are likely to occur. The methodology and scenarios also need to be specified in detail in order to enable comparisons between two LCAs. Though there are international standards that can provide a framework in how to conduct an LCA which requires transparency to the highest level, these factors mentioned above may yield false comparative results (Nokia, 2011). The restricting aspects of LCAs arise when quantitative benchmarking and comparisons are made between LCAs and when results from different LCA studies are aggregated. Also the alternative selections of allocation, system boundaries and recycling scenarios present data inconsistencies as we as double counting, as mention earlier and therefore require attention in further standardization of LCA studies. As we are considering the ICT sector, another limitation related to this sector is the aspect that LCA does not include risks, benefits and costs which are usually the main driving force for decision making in the industrial world (Schepelmann, P. undated).

The characteristics mentioned above, including the complexities indicates that LCA is a powerful tool used once the difficulty of communicating its complexity can be overcome and the uprising uncertainties minimized.

13 Conclusions

Based on the methodological choices made in this study the main conclusions are as follows:

- The life cycle impact of the Sony Xperia™ T smartphone, excluding accessories and network usage is 45 kg CO_2e over the 3 years life time, when considering a moderate usage scenario and a Swedish electricity mix. This corresponds to the amount released when driving an average European car for approximately 300 km (KO, 2012).
- The life cycle stage that causes the greatest impact on the total results is the production accounting 68 percent when only considering the smartphone. Use stage accounts for 8 percent, raw material acquisition stage for 11 percent, transportation stage for 11 percent and end-of-life treatment for 2 percent. Activities with main impact include the production of the IC followed by the raw material acquisition and production of the phone shell.
- If accessories and network are included, the total life cycle impact is 68 kg CO_2e where the network accounts for 30 percent.
- If a global electricity mix is applied the total results for the smartphone including accessories and network usage increase to 117 kg CO_2e for the moderate user scenario for the 3 year life cycle period. This corresponds to approximately 40 kg CO_2e per year which is equivalent to the amount released when driving an average European car for 270 km (KO, 2012). Excluding accessories and network usage, the life cycle impact for the smartphone for this alternative is 51 kg CO_2e.
- A sensitivity analysis was performed showing that the model is relatively stable. Of the analyzed parameters the most influencing one was applying a global electricity mix for the use stage.
- The smartphone LCA result compared to previous 2008 feature phone result shows an increase in 34 kg CO_2e (triple the feature phone results).

- Benchmarking towards Apple and Nokia studies showed varying results where Sony Xperia™ T was closer to Apple and greatly higher than Nokia results. As the methodological framework of both Nokia and Apple studies are not clear, the results are considered to be incomparable but show results within the same magnitude.

- A parameter model has been developed from the LCA results for the Xperia™ T model. This model is considered to provide representative life cycle results also for other smartphones and tablets while for more advanced devices (such as PCs), the impact is likely to be underestimated.

14 Abbreviations

CML	Institute of Environmental Sciences
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CPE	Customer Premises Equipment
ERM	Environmental Resources Management
ETSI	European Telecommunications Standards Institute
GB	Gigabytes
GWP	Global Warming Potential
IC	Integrated Circuits
ICT	*Information and Communications Technology*
IP	Internet Protocol
IPCC	Intergovernmental Panel on Climate Change
ITU	International Telecommunication Union
kWh	Kilowatt hour
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCSEA Manual	Life Cycle Stressor-Effects Assessment, A Practitioner's Manual
MP	Megapixel
MSW	Municipal Solid Waste
PBA	Printed Board Assembly
PCB	Printed Circuit Board
PWB	Printed Wiring Board
RBS	Radio Base Station
SMS	Shot Message Service
UNEP	United Nations Environment Programme
2G	Second Generation
3G	Third Generation
4G	Fourth Generation

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17 References

ABI Research, 2007. *Handset Recycling and Refurbishment*, New York, USA [Online]
Available at: http://www.abiresearch.com/
[Accessed 09 February 2013]

Apple, 2012. Apple and Environment: Measuring performance, one product at a time. [Online]
Available at: http://www.apple.com/environment/reports/
[Accessed 17 May 2013]

Apple Inc., 2012. *iPhone 5 Environmental Report* [Online]
Available at:
http://images.apple.com/environment/reports/docs/iPhone5_product_environmental_report_sept2012.pdf
[Accessed 12 May 2013]

Baumann H. and Tillman A., 2004. *The Hitch Hiker's Guide to LCA*. Sweden: Studentlitteratur AB.

Battery University, 2010. *Is Lithium-ion the Ideal Battery?* [Online]
Available at: http://batteryuniversity.com/learn/article/is_lithium_ion_the_ideal_battery
[Accessed 09 February 2013]

Bergelin, F., 2008. *Life cycle assessment of a mobile phone - a model on manufacturing, using and recycling*. Master thesis at Ericsson Research with cooperation with Sony Ericsson. Uppsala University, Faculty of Science and Technology, Uppsala, Sweden.

Biber E., 2010. *The Problem of Environmental Monitoring* [Online] University of Colorado Law Review, Forthcoming; UC Berkeley Public Law Research Paper No. 1680000.
[Accessed 24 May 2013]

CEA, 2010. *Inspiring Change, CEA 2010 Sustainability Report* [Online]
Available at: http://www.ce.org/CorporateSite/media/Government-Media/Green/CEA-2010-Sustainability-Report.pdf
[Accessed 03 January 2013]

EMPA, 2009. *E-waste; What is E-waste – and why is it an issue?* [Online] EMPA, Switzerland.
Available at: www.itu.int/dms_pub/itu-t/oth/06/.../T065B0000280011PPTE.ppt
[Accessed 03 January 2013]

ETSI, 2011. *Environmental Engineering (EE); Life Cycle Assessment (LCA) of ICT equipment, networks and services; General methodology and common requirements* [Internet] France: ETSI
Available at: http://www.etsi.org/deliver/etsi_ts/103100_103199/103199/01.01.01_60/ts_103199v010101p.pdf
[Accessed 26 November 2012]

Fierce Wireless, 2012. *Analyzing the world's 11 biggest handset markets in Q2 2012* [Online] (Updated 22 August 2012)
Available at: http://www.fiercewireless.com/europe/special-reports/analyzing-worlds-11-biggest-handset-makers-q2-2012
[Accessed 06 March 2013]

Fisher , et al., 2006. *Battery Waste Management Life Cycle Assessment*, Environmental Resources Management, ERM. [pdf]
Available at: http://www.epbaeurope.net/090607_2006_Oct.pdf
[Accessed 12 February 2013]

Flipsen, et al., 2012. *Environmental sizing of smartphone batteries* [Online], Delft University of Technology, Delft, The Netherlands [e-journal]
Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=06360448
[Accessed 19 January 2013]

Gesi, 2013. *Global e-Sustainability Initiative* [Online],
Available at: http://gesi.org/
[Accessed 15 February 2013]

Goedkoop, et al., 2008. *SimaPro Database Manual Methods Library* [pdf] PRé Consultants, the Netherlands.
Available at: http://www.pre-sustainability.com/download/manuals/DatabaseManualMethods.pdf
[Accessed 03 May 2013]

Google Earth, 2013. Download the latest version of Google Earth for PC, Mac, or Linux
Available at: http://www.google.com/earth/index.html
[Accessed 19 January 2013]

G&P, 2006. The Complete Waste Battery Service- Recycle [Online]
Available at: http://www.g-pbatt.co.uk/recycle.html
[Accessed 19 January 2013]

GSMarena, 2000. *Sony Ericsson W890* [Online]
Available at: http://www.gsmarena.com/sony_ericsson_w890-2172.php
[Accessed 06 March 2013]

Guinée, et al., 2004 (final ed), *Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards.* Dordrecht: Kluwer Academic Publishers.

IER, 2009. *What Can the U.S. Learn from China's Energy Policy?* [Online]
http://www.instituteforenergyresearch.org/pdf/What%20Can%20the%20U.S.%20Learn%20from%20China%27s%20Energy%20Policy-FINAL.pdf
[Accessed 10 May 2013]

ISO, 2006a. *ISO 14040 Environmental management- Life Cycle Assessment- Principles and framework: Electronic documents*.
Geneva: ISO.

ISO, 2006b. *ISO 14044 Environmental management- Life Cycle Assessment- Requirements and Guidelines: Electronic documents*.
Geneva: ISO.

ITU, 2012. *L.1410: Methodology for environmental impact assessment of information and communication technologies (ICT) goods, networks and services*[Internet] UN:ITU (Published 03/2012)[Accessed 26 November 2012]

ITU, 2012. *Measuring the Information Society.* [Online] Switzerland, Geneva: International Telecommunication Union
Available at:
http://www.itu.int/ITU-D/ict/publications/idi/material/2012/MIS2012_without_Annex_4.pdf
[Accessed 02 January 2013]

ITU Statistics, 2013. *Global ICT Development [Online]*
Available at: http://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx
[Accessed 02 January 2013]

KO, 2012. *Bilen och Miljön.* [Online]
Available at:
http://www.konsumentverket.se/Vara-omraden/Bilar-och-fordon/Miljotips-for-bilagare/
[Accessed 20 May 2013]

Liew F.C., 2008. *Pyrometallurgy Versus Hydrometallurgy*, Engineering Department TES-AMM Singapore [pdf]
Available at: http://www.tes-amm.com.au/downloads/TES-AMM_analysis_pyrometallurgy_vs_hydrometallurgy_April_2008.pdf
[Accessed 19 January 2013]

Malmodin, et al., (submitted). *LCA of data transmission and IP core networks*

Mobithinking, 2012. *Global mobile statistics 2012 Home* Online] (Updated ?)
Available at: http://mobithinking.com/mobile-marketing-tools/latest-mobile-stats
[Accessed 10 May 2013]

NobelPrize.org, 2013. *The History of the Integrated Circuit* [Online]
Available at:
http://www.nobelprize.org/educational/physics/integrated_circuit/history/?downloadURL=true&loId=F16078C4-0FD7-4EFC-8286-C6FD990C79B5
[Accessed 20 April 2013]

Nokia, 2011. *Use of Life Cycle Assessments: Opportunities and Limitations* [Online]

Available at: http://i.nokia.com/blob/view/-/2330104/data/1/-/Use-of-Life-Cycle-Assessments-pdf.pdf
[Accessed 22 April 2013]

Nokia, 2012. *Each and every Nokia device is created with the environment in mind* [Online]
Available at: http://www.nokia.com/global/about-nokia/people-and-planet/sustainable-devices/sustainable-devices/
[Accessed 17 May 2013]

PE International, 2011. *GaBi paper clip tutorial, Part 1Introduction to LCA and modeling using GaBi* [Online] Leinfelden-Echterdingen, Germany
Available at: http://www.gabi-software.com/uploads/media/Paper_Clip_Tutorial_Handbook_Part1.pdf
[Accessed 06 January 2013]

Schakenda, et al., 2008. *CO2-emissions associated with different electricity mixes.* Agder Energy Production AS, ISBN:82-7520-621-9 Ostfold Research
[Accessed 22 April 2013]

Schepelmann, P. undated. *Life Cycle Assessment (LCA)* [Online]
Available at: http://www.ivm.vu.nl/en/Images/AT9_tcm53-161581.pdf
[Accessed 22 April 2013]

SGNL, 2006. SGNL ™by Sony:Gadgets & Gaming! *Putting our* Xperia™ *Tablet Z back together in 60 seconds* [Online] (Updated 26 March 2013)
Available at: http://www.youtube.com/user/sgnl/videos?query=sony+xperia+t
[Accessed 06 May 2013]

Sonymobile, 200-. *Xperia™ T* [Online]
Available at: http://www.sonymobile.com/global-en/products/phones/xperia-t/specifications/
[Accessed 06 March 2013].

Sonymobile, 2011. 2011 Sustainability Report [Online] Available at: http://blogs.sonymobile.com/wp-content/uploads/2012/09/SustainabilityReport2011.pdf
[Accessed 07 March 2013].

Souter, D., 2012. *ICTs, the Internet and Sustainability: A discussion paper* [Online] The international Institute for Sustainable Development (Published 2012)
[Accessed 01 May 2013].

Top ten reviews, 2013. *Best Smartphone Reviews and Comparisons* [Online]
Available at: http://cell-phones.toptenreviews.com/smartphones/
[Accessed 10 May 2013]

UNEP, 2011. LCA Training Kit (*A product-oriented method for sustainability analysis)* [Online]
(Updated 05 July 2010)

Available at: http://www.estis.net/sites/lcinit/default.asp?site=lcinit&page_id=56666AB6-E732-45F2-A89E-640951EA5F59
[Accessed 22 December 2012]

UNEP, 2012. *UNEP Year Book 2012: Emerging Issues in our Global Environment.* [Online]
Available at: http://www.unep.org/yearbook/2012/pdfs/UYB_2012_CH_1.pdf
[Accessed 22 December 2012]

UNEP, undated. *Resource Efficiency and Sustainable Consumption and Production* (Life Cycle Approaches and Indicators) [Online]
Available at:
http://www.unep.org/resourceefficiency/Assessment/LifeCycleApproachesandIndicators/tabid/55531/Default.aspx
[Accessed 22 December 2012]

18 Appendixes

18.1 Appendix A CML Impact Categories

Impact categories defined by the Institute of Environmental Sciences (CML) at the University of Leiden in the Netherlands as implemented in GaBi (Guinée, et al., 2004).

Impact Category	Unit
Global warming	kg CO_2 equiv.
Acidification	kg SO_2 equiv.
Eutrophication	kg Phosphate equiv.
Ecotoxicity Potential to freshwater, land and seawater	kg DBC- equiv.
Photochemical Ozone Creation Potential	kg Ethene- equiv.
Ozone Depletion Potential	kg R11- equiv.
Abiotic resource depletion	kg Sb- equiv./ MJ
Human Toxicity Potential	kg DBC- equiv.

Global warming

Climate change is defined as the impact on the atmospheres heat radiation absorption, having secondary impacts on the ecosystem and human health. Most of the emissions considered enhance the absorption of radiation causing a rise in the earth's surface temperature, referred to as the "greenhouse effect" and are called by the common name greenhouse gases (GHGs). The characterization model is defined by the Intergovernmental Panel on Climate Change (IPCC) and describes the global warming potential over 100 years. Any emission of a GHG to the air is measured by the carbon dioxide equivalency factor (kg CO_2e).

Acidification

Acidification arises from emissions of acidifying pollutants, mainly being sulphur dioxide (SO_2), nitrogen oxides (NO_X) and ammonia (NH_4). When the pollutants reach the atmosphere they react with water causing "acid rain" that affects living organisms, ecosystems and construction materials. Visible secondary effects include fish mortality, forest decline and crumbling of building materials. The acidification potential for every acidifying emission to the air is given the reference unit of kilogram sulphur dioxide equivalent (kg SO_2 eq.). The characterization model is based on the RAINS10 model for the deposition of acidifying substances developed at the International Institute for Applied Systems Analysis (IIASA).

Eutrophication

The eutrophication potential incorporates all discharge of nutrients, the most important being nitrogen (N) and phosphorus (P), which causes an undesirable shift in the ecosystem. Apparent effects are unacceptable nutrition concentrations in drinking waters or decreased oxygen levels in aquatic systems due to increased biomass production and decomposition. The eutrophication potential for all related emissions to air, water and soil is measured by a phosphate equivalent (kg PO_4 eq.)

Ecotoxicity Potential to freshwater, land and seawater

Ecotoxicity relates to emissions of toxic substances having a detrimental effect on ecosystems. The characterization model is adapted to LCA based on the USES 2.0 model which describes fate, exposure and effects of toxic substances. Freshwater aquatic ecotoxicity potential (FAETP) relates to the impact on freshwater aquatic ecosystems, marine aquatic ecotoxicity potential (MAETP) relates to marine aquatic ecosystems and terrestrial ecotoxicity potential (TETP) relates to land-based ecosystems. Emissions are related to the reference unit of kilograms of 1,4-dichlorobenzene equivalents (kg 1,4DCB eq.).

Photochemical Ozone Creation Potential

Photochemical ozone creation is the effect of emissions such as carbon monoxide (CO) and volatile organic compounds (VOCs) that cause ozone to be created in the presence of sunlight, commonly seen as summer smog. Winter smog, by contrast, is considered under human toxicity. Photochemical ozone creation potential (POCP) relates to the detrimental effects on human health and is modeled by the UNECE Trajectory model. Emission factors are measured against the reference unit of kilograms of ethylene equivalents (kg C2H4 eq.).

Ozone Depletion Potential

Stratospheric ozone depletion refers to the breakdown of ozone in the stratosphere resulting in a thinning of the ozone layer. This is caused by the anthropogenic emission of ozone-depleting gases to air. The ozone depletion potential (ODP) of different gases is modeled by the World Meteorological Organization (WMO) and relates to human health and ecosystem effects caused by ozone depletion. Emissions of gases are measured against the reference unit of kilograms of chloroflurocarbon-11 equivalents (kg R-11 eq.).

Human Toxicity Potential

Human toxicity relates to emissions of toxic substances having a detrimental effect on human health. The characterization model is adapted to LCA based on the USES 2.0 model which describes fate, exposure and effects of toxic substances. The human toxicity potential (HTP) of each toxic substance emitted to air, water and soil is measured against the reference unit of kilograms of 1,4-dichlorobenzene equivalents (kg 1,4 DCB eq.).

Abiotic resource depletion

Abiotic depletion potential of primary energy carriers (ADP fossil) and minerals (ADP element) is a measure of the use of non-living natural resources e.g. crude oil, minerals, etc. For ADP elements, the extraction rate and remaining reserves are considered and compared to the reference of Antimony metal depletion creating a reference unit of kilograms Antimony equivalent (kg Sb eq.). For ADP fossil the extraction of fossil fuels is measured in energy (MJ).

18.2 Appendix B Inventory Data

List of inventory data used in GaBi for the modeling process of the smart phone, including all materials and processes.

Process	Data Source	Year	Region
Materials			
Metals			
Aluminium ingot mix	PE_GaBi	2011-2014	Europé
Aluminium, production mix, wrought alloy, at plant	Ecoinvent	2002	Europé
Cast iron, at plant	Ecoinvent	2001-2002	Europé
Cobalt, at plant	Ecoinvent	2002	Global
Copper mix (99,999% from electrolysis)	PE_GaBi	2011-2014	Germany
Gold, primary, at refinery	Ecoinvent	2000-2004	Global
Lead, primary, at plant	Ecoinvent	2000-2005	Global
Manganese, at regional storage	Ecoinvent	2003	Europé
Nickel, 99.5%, at plant	Ecoinvent	1994-2003	Global
Palladium, at regional storage	Ecoinvent	2002	Europé
Silver, at regional storage	Ecoinvent	2000-2005	Global
Stainless steel cold roll (Version 2006)	PE_GaBi	2004-2012	Germany
Steel cold rolled coil	PE_GaBi	2011-2014	Germany
Tin plate	BUWAL	1996	Germany
Zinc, primary, at regional storage	Ecoinvent	1994-2003	Europé
Other Materials			
Acetic acid	Ecoinvent	2011-2014	Germany
Acetic acid	PE-GaBi	2011-2014	Germany
Adhesive for metals, at plant	Ecoinvent	1996-2003	Germany
Aluminum oxide (alumina)	BUWAL	1996	Europé
Barite, at plant	Ecoinvent	1978	Europé
Butyl acetate, at plant	Ecoinvent	1991-2006	Europé
Butyl acrylate, at plant	Ecoinvent	1995	Europé
Carbon black, at plant	Ecoinvent	2000	Global
Chromium, at regional storage	Ecoinvent	1994-2003	Europé
Chromium, at regional storage	Ecoinvent	1994-2003	Europé
Ethene (ethylene)	PlasticsEurope	2005-2012	Europé
Ethyl acetate, at plant	Ecoinvent	1991-2006	Europé
Ethylene glycol, at plant	Ecoinvent	1997-2000	Europé
Formaldehyde, production mix, at plant	Ecoinvent	1997-2000	Europé
Formaldehyde, production mix, at plant	Ecoinvent	1997-2000	Europé
Glass fibres	PE-GaBi	2011-2014	Germany

Glass wool mat, at plant	Ecoinvent	1993-2000	Switzerland
Magnesium oxide, at plant	Ecoinvent	2000	Europé
Manganese oxide (Mn2O3), at plant	Ecoinvent	2009-2010	Switzerland
Methanol, at plant	Ecoinvent	1994-2001	Global
Molybdenum, at regional storage	Ecoinvent	2000-2003	Europé
Phenolic resin, at plant	Ecoinvent	2000	Europé
Phosphorus, white, liquid, at plant	Ecoinvent	2000	Europé
Production of carton board boxes, gravure printing, at plant	Ecoinvent	1993	Switzerland
Propene (propylene)	PlasticsEurope	2005-2012	Europé
Silicon mix (99%)	PE-GaBi	2011-2014	Global
Sulphur (elemental) at refinery	PE-GaBi	2009-2014	EU-27
Sulphur (elemental) at refinery	PE-GaBi	2009-2014	EU-27
Titanium dioxide, production mix, at plant	Ecoinvent	1997-2000	Europé
Zinc oxide, at plant	Ecoinvent	2005-2007	Europé
Plastics			
adhesive for metals, at plant	Ecoinvent	1996-2003	Germany
Epoxy resin	PlasticsEurope	2005-2012	Europé
epoxy resin, liquid, disaggregated data, at plant	Ecoinvent	1994-1995	Europé
Nylon 6 granulate (PA 6)	ELCD/PlasticsEurope	1996-2006	Europé
Polycarbonate granulate (PC)	PlasticsEurope	2007-2020	EU-25
Polyester Resin unsaturated (UP)	PE-GaBi	2011-2014	Germany
Polyethylene granulate (PE)	BUWAL	1996	Europé
Polyethylene terephthalate (PET,sc.)	BUWAL	1996	Europé
polyethylene terephthalate, granulate, amorphous, at plant	PlasticsEurope	1999-2000	Europé
Polymethylmethacrylate-ball (PMMA)	ELCD/PlasticsEurope	1996-2006	Europé
Polypropylene film (PP)	PlasticsEurope	2005-2012	Europé
polystyrene foam slab, 100% recycled, at plant	Ecoinvent	2009	Switzerland
Polyurethane flexible foam (PU)	PlasticsEurope	2005-2012	Germany
Silica sand (Excavation and processing)	PE-GaBi	2011-2014	Germany
Silicon mix (99%)	PE-GaBi	2011-2014	Global
silicone product, at plant	Ecoinvent	1997-2001	Europé
Solder paste (Sn99.3Cu0.7)	PE-GaBi	2002	Germany
solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant	Ecoinvent	2005	Global
Styrene	BUWAL	1996	Europé
synthetic rubber, at plant	Ecoinvent	1995-2003	Europé

Process	Data Source	Year	Region
Manufacturing			
Battery Manufacturing	Primary Data	2012	Confidential
Camera Manufacturing	Primary Data	2011	Confidential
Charger Manufacturing	Primary Data	2012	Confidential
Handsfree Manufacturing	Primary Data	2012	Confidential
IC Manufacturing	Primary Data	2012	Confidential
Liquid Crystal Display (LCD), Panel Assembly LED TFT, mixed TN-IPS technology	PE GaBi 6.0	2010	Global
Mechanical Manufacturing	Previous study data	2008	Confidential
Mobile phone assembly	Primary Data	2011	Confidential
OP Mechanicals Manuf.	Average estimate	2012	Confidential
PBA Manufacturing	Previous study data	2008	Confidential
Packaging Manufacturing	Primary Data	2012	Confidential
PCB Manufacturing	Primary Data	2012	Confidential
Phone Shell Manufacturing	Primary Data	2012	Confidential
Standard Component Manufacturing	PE GaBi 6.0	2005-2012	Confidential
USB-Cable Manufacturing	Previous study data	2008	Confidential
Utilization			
Smartphone Usage GLO	Public Study	2013	Global
Smartphone Usage SWE	Public Study	2013	Sweden
Energy			
Electricity mix	Ecoinvent	2004	Sweden
Electricity mix GLO			Global
Electricity, production mix CN	Ecoinvent	2005	China
Heavy fuel oil at refinery (1.0wt.% S)	PE GaBi 6.0	2009-2014	EU-27
Light fuel oil at refinery	PE GaBi 6.0	2009-2014	EU-27
Natural gas mix	PE GaBi 6.0	2009-2014	EU-27
Process steam from hard coal 85%	PE GaBi 6.0	2009-2014	US
Transportation			
Lorry			
transport, lorry 7.5-16t, EURO3	Ecoinvent	2005	Europe
transport, lorry 16-32t, EURO3	Ecoinvent	2005	Europe
transport, lorry >32t, EURO3	Ecoinvent	2005	Europe
transport, lorry 7.5-16t, EURO4	Ecoinvent	2005	Europe
transport, lorry 16-32t, EURO4	Ecoinvent	2005	Europe
transport, lorry >32t, EURO4	Ecoinvent	2005	Europe
transport, lorry 7.5-16t, EURO5	Ecoinvent	2005	Europe
transport, lorry 16-32t, EURO5	Ecoinvent	2005	Europe
transport, lorry >32t, EURO5	Ecoinvent	2005	Europe
Aircraft			
transport, aircraft, freight	Ecoinvent	2000	Europe
transport, aircraft, freight, Europe	Ecoinvent	2000	Europe

transport, aircraft, freight, intercontinental	Ecoinvent	2000	Europe
End-of-Life Treatment			
Battery Hydrometallurgical Recycling	PE GaBi 6.0	2005	Global
Battery Pyrometallurgical Recycling	PE GaBi 6.0	2005	Global
Hazardous Waste Treat.	Previous study data	2008	Sweden
Landfill of municipal solid waste	PE GaBi 6.0	2011-2014	EU-27
Waste incineration	ELCD/CEWEP	2006-2010	EU-27
Waste incineration of paper	ELCD/CEWEP	2006-2010	EU-27
Waste incineration of plastics	ELCD/CEWEP	2006-2010	EU-27

18.3 Appendix C Battery Recycling

The following section describes the battery recycling model created in GaBi but not included in the smart phone LCA study. It has been decided to be included and is presented as additional material.

As the battery is built-into the mobile device, dismantling of the phone is required in order to access the battery which is why this area requires additional processing. The recycling process of the disposed batteries is assumed to follow a collection scenario involving container collection schemes from *Waste Electrical and Electronic Equipment* (WEEE) dismantler premises. Based on a study conducted by the Environmental Resources Management, (ERM) year 2006, a battery recycling model has been established for this LCA study (Fisher, et al., 2006).

The battery recycling model includes the following aspects associated with the process:

Collection; container materials, manufacturing and processing and battery transport requirements.

Sorting; energy requirements for the sorting process

Transportation; to central recycling plant

Recycling; process materials and energy requirements

As mentioned above, the collection route involves collection from retail stores and WEEE dismantlers. The containers assumed to be utilized in the collection process include polycarbonate tubes and polypropylene sacks. Inventory data for collection containers can be found in the table below. The collection process from the stores to larger storage sites are considered to be done by transit vans, through numerous collections over a period of time in the same area. After a certain amount has been reached, larger lorries transport the batteries to a central sorting plant. The average route from stores to storage sites is assumed to be at a distance of 160 km and the storage sites are at an average distance of 400 km from the central sorting plants. Table below presents the input and output data that is included in the battery sorting process.

Life cycle inventory data for collection containers

Container	Inventory data input	Quantity	Inventory data sources	Time coverage	Geographic coverage	Average Capacity (kg)
Large Tube	Polycarbonate granulate (PC)	0.95 kg	PlasticsEurope	2007-2020	Europé	40
	Extrusion, plastic pipes	0.90 kg	Ecoinvent	1993-1997	Europé	
	Steel, low	6.8 kg	Ecoinvent	2001	Europé	

	alloyed					
	Injection moulding	6.8 kg	Ecoinvent	1993-1997	Europé	
Sack	Polypropylene	0.3 kg	Ecoinvent	1992-1993	Europé	40
	Extrusion, plastic film	0.31 kg	Ecoinvent	1993-1997	Europé	

INPUTS	Inventory Data	Quantity	Units	OUTPUTS	Inventory Data	Quantity	Units
Input Product Mixed waste batteries	-	0.035	kg	*Output product* Sorted Batteries	-	1	ton
Container	See Appendix B	4.38E-5	kg*	*Container*	See Appendix B	4.38E-5	kg*
Water Consumption	Water (PE, Europe 2011)	1.65E-5	kg	*Solid Wastes*	-	Negligible <1%	-
Electricity consumption	Electricity (PE; Europe, 2005)	8,4E-5	kWh	*Water emissions*			
				Waste water	treatment, sewage, to wastewater treatment, class 1 (Ecoinvent	1.65E-5	kg

				1994)		
Fuel consumption				*Air emissions*		
	Diesel mix at refinery (PE, 2009)	5.95E-6	Liters	NOx	1.35E-7	kg
				PM10	8.75E-9	kg
				CO	8.4E-8	kg
				NMVOC	2.7E-8	kg
				SO_2	1.02E-8	kg
				CO_2	1.61E-5	kg
				Dioxins and Furans	negligible	

Recycling of lithium batteries, as well as rechargeable, can be done both through hydro-metallurgic and pyro-metallurgic processes. Rechargeable lithium ion batteries can be treated by both of these processes (Fisher, et al., 2006). While pyro-metallurgical treatment involves the thermal treatment of the battery in a furnace, hydro-metallurgical treatment involves chemical treatment of the battery to separate the materials in the battery (G&P, 2006). The hydro-metallurgical route is considered to have a higher material separation rate; to be more energy efficient and to release less emission in contrast to the pyro-metallurgical route. In this study both processes are modeled in the GaBi software using built-in Ecoinvent database models (Liew F.C., 2008).

Battery Transportation

The battery recycling model is not geographically bound to a certain location in this study and hence creates difficulties in determining the average transportation distances. For simplicity, an average scenario is created and an estimated value is used based on a study conducted by the Environmental Resources Management, (ERM) year 2006 (Fisher, et al., 2006). Table 8 presents the transportation data included in the GaBi model for the weight-distance relation. Generic GaBi data has been used to model the alternative transportation models for which inventory data can be found at Appendix B

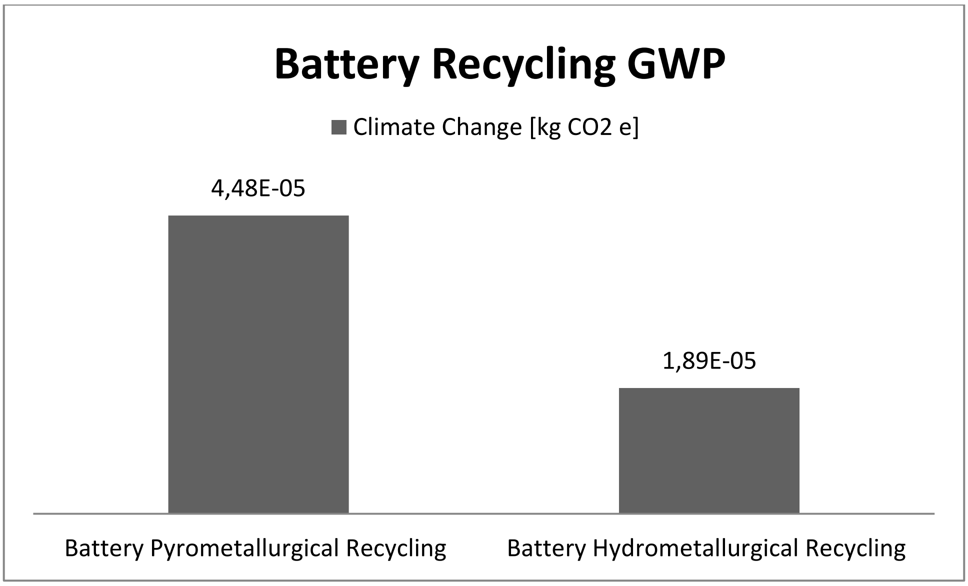
Table 19 Battery End-of-Life transportation in weight-distance relation.

Transportation type	LoadxDistance	Destination
Transit van	561 kgkm	Sorting plant
Articulated lorry	2500 tkm	Recycling Facility

End-of-life

2 percent of the total results have been estimated to account for the end-of-life stage for this smartphone. Two battery recycling models have been created in GaBi software; pyro-metallurgical recycling and hydrometallurgical recycling. These processes that have been investigated and compared, as can be seen in figure below, are still

included in the 2 percent end-of-life stage. The battery recycling results are calculated for a single unit of battery for both processes and as can be seen the pyro-metallurgical process results in a greater impact in contrast to hydrometallurgical recycling process.



As modeling for battery recycling was possible, the two alternative processes were included in the study to provide useful data for future studies for the end-of-life stage of the mobile device. Results showed that the hydrometallurgical treatment resulted in less climate change impact; this was expected as this treatment method was determined earlier to be more energy efficient.

18.4 Appendix D IC LCA Study

Due to confidentiality, this data has not been made public. If further information regarding this IC study is wanted, please contact Sony Mobile or Ericsson Research.

18.5 **Appendix E** Life Cycle Inventory Questionnaire

Below are the questions formulated and presented to Sony Mobile smart phone suppliers in order to collect production data for the phone components.

BACKGROUND DATA **A. Product/ product type for which the data is required:** Name of product: Location of production site:	
B. Company information - Time period when the data is relevant: - Company name and address: - Contact person (name, phone, e-mail):	
C. Plant process: Please attach: Technical description of the plant production	
D. Product information **D1. Constituents:** What are the constituents (e.g. specific electronic components or component types) that the product and packaging consist of? ***D2. Description of the product line*** Please attach: Technical description of the product line Flowchart of process steps for production of the studied product Also, give a brief description of the technology used in your processes	
D3. Previous LCA: Has an LCA been conducted for this product? If so, could you share any outcome plus description of the study?	

D4. Production volumes and transportation

Please provide data on production volumes (This information is needed for allocation of data)

Distance and Transportation method of the final product to Sony Mobile Communications

D5. General LCA related information on the product system

Please state any assumptions, limitations etc. related to the data given in paragraph E&F

Any applicable guidelines for allocation of data is also interesting for us

Note! Data needs to include not only the production plants and its buildings contribution to resource usage from offices and personnel in administration, marketing and R&D if applicable and significant.

**) All data in this questionnaire are requested as annual values (quantity/a)*

PRODUCT/PROCESS INFORMATION

E. Raw material, components and natural resource input

E1. Input of ancillary products

State here any input of materials and components *that is needed for the production process, but is not part of the produced goods*. Group the materials according to supplier.

Definition -Ancillary Products:

A range of Support Products cover various jobs in a production environment (for example PCB production) and are often critical for an efficient manufacturing. For Example Thinners and Retarding Agents as well as Cleaning Agents etc.

1) Total use means the total use of material needed in the production to manufacture the product.

Name of material,	Total use 1)		Supplier	

component or resource	(quantity/a)	Uncertainty (±%)	Company name (optional)	Manufacturing location (region/country)

E2. Energy input Group the energy types according to supplier. Express data as annual amounts used to manufacture the product alternatively data for the total factory Please state if data is given for product or total factory.		
Name of material, component or resource	Total use	
	(quantity/a)	Uncertainty (±%)
Light fuel oil Heavy fuel oil Biofuel (specify type) District heat (MWh/a) Electricity (MWh/a)		
Alternative Energy Sources (Please state if other energy sources are used then those above):		
Gas consumption Vehicle fuel		

E3. Energy Mix	
Which energy mix applies for your operation? According to regional conditions or specific (e.g. green certificates etc.).	
Do you have any information regarding the emission factor for the energy mix?	

F. Emissions

All emission data given should show emissions after control/emission reduction equipment.

Express data as annual amounts emitted in connection to the manufacturing of the product

F1. Emissions to air

Group according to nature of release (stack: height, diffuse/fugitive). Indicate whether emissions from energy use are included in the data.

Please state chemical formulas if applicable.

Name of emission:	Emission to air		Remarks
	(quantity/a)	Uncertainty (±%)	

F2. Emissions to water

Group according to nature of release (external purification plant or directly to recipient, define recipient).

Please state chemical formulas if applicable.

Name of emission:	Emission to water		Remarks
	(quantity/a)	Uncertainty (±%)	

F3. Emissions to soil

Group according to nature of release (describe the soil affected).

Pelase state chemical formulas if applicable.

Name of emission:	Emission to soil		Remarks
	(quantity/a)	(±%)	

F4. Water consumption			
	Quantity		Remarks
	(quantity/a)	Uncertainty (±%)	
Total Water Consumption: <u>Amount of water *that goes to production:*</u> public water provider other source(s) respectively?			
<u>For other water source(s) how much is:</u> Ocean water Fresh water Ground water or fresh surface water, respectively?			
<u>Amount of water *released from the production*</u>: to public water treatment/ or directly to nature respectively?			
<u>Amount of the water sent to public water treatment/to nature is:</u> Green water Chemically polluted water Thermally polluted water			
<u>If you have any thermal pollution of water:</u>			

How many degrees How much to fresh water Other water sheds respectively?	
F5. Waste generation and transport Group according to waste handling (To recycling: destination, to municipal dump, to hazardous waste treatment: plant, etc.).	

Name of material	**Waste Handling**	Waste		Remarks
		(quantity/a)	Uncertainty (±%)	

G. Metadata

To perform an LCA assessment according to standards we need to understand the following aspects related to the data:

1. Which year does the data represent?	
2. Do you have a quantified value related to the uncertainty of the data? What uncertainty factors have you considered?	
3. How representative is the data? **a.** How was the data collected (measured/ estimated)?	

b. In case you operate more than one site - does the data represent one or several sites? If one out of several sites – how large part of your production volume does that site represent?	
4. If you have made any allocation of data between different products or processes, describe how that was done.	
5. Are there any specific data gaps, i. e. relevant parts of the processes/ operation for which data is missing? Have you made any cut offs in your data collection?	

18.6 Appendix F Weight scaling of Smartphone Components

The amount of unknown weight in each smart phone component has been scaled up according to weight. The percentile amount that has been scaled up is presented in the table above.

Component	Scaled Material Content %
USB-Cable	0.3
Charger	24.9
Headset	0.2
Battery	45.7
Standard Components	48.7
Packaging	1.9
PCB	43.9
Camera	6.3
Shell	19.6
IC	NA

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