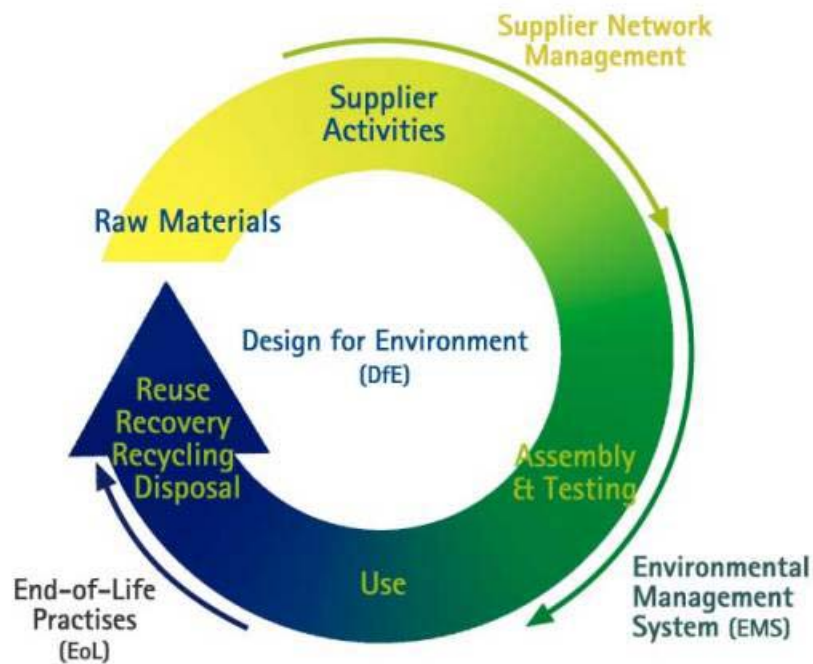


Integrated Product Policy Pilot Project

Stage I Report



NOKIA

Espoo, Finland, January 2005

Submit written comments to:

Pranshu Singhal

Project Manager, IPP

NOKIA CORPORATION

P.O.Box 407, FI-00045 NOKIA GROUP, Finland

Fax: +358 (0)7180 37128

Email: pranshu.singhal@nokia.com

Executive Summary

The IPP pilot project at Nokia was initiated as a part of the European Commission's approach to work together with stakeholders to develop the Integrated Product Policy (IPP). The objective of the EC's IPP approach is to, "reduce the environmental impacts from products throughout their life-cycle, harnessing, where possible, a market-driven approach, within which competitiveness concerns are integrated". The IPP pilot project aims to demonstrate how IPP can work in practice and shall be carried out in several stages in cooperation with the participating stakeholders. The focus of Nokia's IPP pilot project is on mobile phones.

This first report in the IPP pilot project serves as a guidance document on the environmental issues in the life cycle of a mobile phone and shares the findings of the assessments conducted by Nokia and the stakeholders for assessing the life cycle environmental impacts of mobile phones. The report also discusses Nokia's experiences with different environmental assessment tools, and its environmental initiatives.

A mobile phone¹ is a small personal two-way radio, which sends and receives radio signals, carrying voice and data in personal communications with other mobile phones, and telephones. Mobile phones have a very complicated structure and material composition. A typical mobile phone consists of 500 - 1000 components. Most of these components are made up of large variety of materials and substances.

The number of global mobile phone subscriptions is growing and is expected to touch the landmark of 2 billion in 2006. A total of 471 million mobile phones were sold globally in the year 2003 and it is estimated that in the year 2004 approximately 630 million mobile phones were sold.

The life cycle of a mobile phone is quite similar to that of other electronic products such as PCs. The main phases in the life cycle of a mobile phone are - extraction and processing of raw materials, components manufacture, transport of components to the phone assembly plant, phone assembly, transport of phones to the distribution network, use and end-of-life. The main findings of the environmental assessments of mobile phones conducted by Nokia and the stakeholders are:

- Regardless of the assessment method used, the use phase and components manufacture phase are the biggest contributors to the life cycle environmental impacts.
- In the use phase, the standby power consumption of the charger accounts for majority of the environmental impacts.
- In the components manufacture phase, the energy consumption of the manufacturing processes accounts for the major portion of environmental impacts.
- The most important environmental issue for a mobile phone in all the life cycle phases is energy consumption.
- The Printed Wiring Board (PWB), Integrated Circuits (ICs) and Liquid Crystal Display (LCD) are the components with the highest environmental impacts in the life of a mobile phone.

¹ The terms 'mobile phone', 'mobile terminal', 'cellular phone', and 'cell phone' refer to the same product

- In the transportation phase, the airfreight accounts for almost all the environmental impacts.
- The collection and proper management of the mobile phones (and accessories) at the end of their life is crucial to have positive environmental impacts from end-of-life (EoL) phase and to prevent any material and substance dispersions to the environment. The positive environmental impacts in the EoL phase arise from the recovery of metals, especially precious ones.
- From the perspective of a mobile system, the energy consumption of radio base stations during the use phase is most significant.

The total CO₂ emissions, which are closely linked to total energy consumption, from the life cycle of a 3G mobile phone are equivalent to the emissions from driving a car for 65–95 kms or to 4-6 lts of gasoline. The CO₂ emissions per subscriber and year for a 3G system² are equivalent to the emissions from driving a car for 250-380 kms or to 19-21 lts of gasoline.

A mobile phone contains small amounts of some materials that are of concern. These substances do not present any environmental or human health hazard when the phone is in ordinary use but they might be released into the environment from landfills, incinerators and recycling facilities if the end-of-life processes are not properly managed.

Nokia considers environmental impacts from a product life cycle perspective and has tried several approaches for conducting environmental assessments. As discussed in this report, full LCA, EFA and MIPS are today not appropriate for application in the product development cycles of mobile phones. Since the methodologies and available data for conducting these assessments are constantly developing, it is important for a company such as Nokia to be actively involved in methodology development and common industry efforts to collect and publish data where practicable. Nokia together with other companies is voluntarily working to develop suitable methods for environmental assessments of electronic products, an example of this being the KEPIs. KEPIs, a small number of product environmental performance indicators validated as representative of the most important environmental impacts of an electronic products life cycle, may provide a good and simple assessment tool for use in the electronics industry. A full LCA can be done after regular periods and the KEPIs revised based on the results obtained.

To address the environmental issues in all the life cycle phases of a mobile phone, it is imperative that everyone in the value chain takes full responsibility of the activities under their control. The stakeholders in the system also need to work in cooperations to manage environmental issues of common concern and share their experiences and best practices. Partnership initiatives like RosettaNet, and MPPI under Basel Convention are the steps in this direction.

To reduce the adverse environmental impacts throughout the product life cycle Nokia's environmental activities are focused on sound environmental management of own operations, systematic supplier network management, integration of design for environment into product and technology development, and sound end-of-life practices.

² The 3G system consists of 3G mobile phones, a radio network with radio base stations and radio network control equipment, and a core network with switches, routers, servers and workstations.

Since their introduction mobile phones have moved from being strict business products to being everyday convenience items. Over the years the consumer demands and technological innovations have led to the development of phones that are lighter, have longer operational times, and that can be used for multiple purposes. The energy consumption of the phone charger during the charging and standby modes has also reduced considerably. All these developments in the mobile phone industry have resulted in lowering of environmental load of a phone. The environmental improvements may continue to take place in the mobile phone industry in the future too as they are closely tied to the business critical issues and are in line with the technological development.

The next report in this IPP pilot project shall identify and document the improvement options that Nokia and the participating stakeholders can take to enhance the environmental performance of the mobile phones. The stakeholders can play a crucial role in almost all the life cycle phases and have responsibilities in the areas like disclosure of information on material contents of components, building environmental awareness among the consumers and other stakeholders, collection of used products and accessories, development of effective environmental legislation, industry cooperations and voluntary agreements, and identifying new roles for standardisation bodies.

The second report shall also provide an insight on the factors that affect the business decisions in the mobile phone industry. These factors may include customer requirements, technology development, legislative environment and other requirements that need to be considered in product development decisions.

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION	5
1.1 INTEGRATED PRODUCT POLICY (IPP) PILOT PROJECT	5
1.2 OBJECTIVES AND METHODOLOGY	5
1.3 SCOPE	6
1.4 DEVELOPMENT OF FIRST REPORT	6
2. A MOBILE PHONE	7
2.1 WHAT IS A MOBILE PHONE?	7
2.2 TRENDS IN THE MOBILE PHONE INDUSTRY	8
2.3 NOKIA PROFILE	11
2.4 LIFE CYCLE OF A MOBILE PHONE	12
2.4.1 Raw Material Extraction and Processing	13
2.4.2 Components Manufacture	13
2.4.3 Components Transport	13
2.4.4 Phone Manufacture (Assembly)	13
2.4.5 Phone Transport	13
2.4.6 Distributors	14
2.4.7 Phone Use	14
2.4.8 End-of-life (EoL)	14
3. ENVIRONMENTAL ISSUES IN THE LIFE CYCLE OF A MOBILE PHONE	16
3.1 LIFE CYCLE ASSESSMENT (LCA)	16
3.1.1 LCA of a Third Generation (3G) Mobile Phone by Nokia (2003)	16
3.1.2 Life Cycle Energy Analysis of a Mobile Phone by Nokia (1999)	19
3.1.3 LCA of a Third Generation (3G) System by Ericsson (2004)	21
3.1.4 Nokia's Experience with LCA	23
3.2 ECOLOGICAL FOOTPRINT ANALYSIS (EFA)	24
3.2.1 Nokia's Experience with EFA	26
3.3 MATERIAL INPUT PER SERVICE UNIT (MIPS)	27
3.3.1 Nokia's Experience with MIPS	27
3.4 KEY ENVIRONMENTAL PERFORMANCE INDICATORS (KEPIs)	28
3.4.1 Discussion on KEPIs	30
3.5 MATERIALS OF CONCERN IN A MOBILE PHONE	31
3.6 A BRIEF PROPORTIONALITY ANALYSIS OF IMPACTS OF A MOBILE PHONE	33
3.7 SUMMARY ON THE ENVIRONMENTAL HOT-SPOTS OF A MOBILE PHONE	34
4. NOKIA'S ENVIRONMENTAL ACTIVITIES	35
4.1 PROGRAMS AND PRACTICES	35
4.1.1 Design for Environment (DfE)	35
4.1.2 Substance Management	36
4.1.3 Supplier Network Management	37
4.1.4 Logistics Management	37
4.1.5 Environment Management at Nokia Sites	37
4.1.6 Environmentally Conscious Packaging	37
4.1.7 Communications	38
4.1.8 Information for Consumers	38
4.1.9 End-of-life	39
4.2 ACTIVITIES TO ELIMINATE MATERIALS OF CONCERN	39
4.3 INITIATIVES TO DEVELOP NEW ENVIRONMENTAL ASSESSMENT TOOLS	40

4.4	SECTORAL ENVIRONMENTAL INITIATIVES	40
4.4.1	<i>Mobile Phone Partnership Initiative (MPPI), Basel Convention, UNEP.....</i>	40
4.4.2	<i>Global e-Sustainability Initiative (GeSI), UNEP.....</i>	41
4.4.3	<i>RosettaNet</i>	41
4.5	OTHER ENVIRONMENTAL COOPERATIONS	42
4.5.1	<i>Cooperation with World Wide Fund for Nature.....</i>	42
4.5.2	<i>Universities and Research Institutions.....</i>	42
4.5.3	<i>Industry Associations.....</i>	42
5.	CONCLUSIONS AND OUTLOOK.....	44
	BIBLIOGRAPHY.....	46
	ABBREVIATIONS.....	48
	APPENDIX A: LIST OF STAKEHOLDERS PARTICIPATING IN NOKIA'S IPP PILOT PROJECT	50
	APPENDIX B: OVERVIEW OF COMPONENTS IN A MOBILE PHONE	51
	APPENDIX C: LIFE CYCLE ASSESSMENT OF A THIRD GENERATION (3G) MOBILE PHONE BY NOKIA (2003).....	53
	APPENDIX D: LCA OF A MOBILE PHONE BY NOKIA AND IKP (2001).....	67
	APPENDIX E: ECOLOGICAL FOOTPRINT ANALYSIS (EFA) OF A MOBILE PHONE (2002).....	69
	APPENDIX F: REFERENCES TO PUBLICLY AVAILABLE STUDIES/REPORTS/ARTICLES (IN WHICH NOKIA HAS PARTICIPATED).....	75

List of Figures

Figure 2-1: Material composition of a typical mobile phone.....	7
Figure 2-2: Global mobile phone subscriptions	8
Figure 2-3: Growth of mobile phone market	8
Figure 2-4: Reduction in weight of a mobile phone over the years.....	9
Figure 2-5: Changes in weight, talk and standby times during the development of phones	10
Figure 2-6: Evolution of accumulator chemistries.....	10
Figure 2-7: Sales of smart phones and camera phones	11
Figure 2-8: Life cycle of a mobile phone.....	12
Figure 3-1:Life cycle energy consumption of a third generation mobile phone.....	18
Figure 3-2: Life cycle energy analysis of a mobile phone.....	20
Figure 3-3:Amount of upstream waste of a mobile phone relative to one tonne of final waste	21
Figure 3-4: Carbon dioxide emissions per subscriber and year during different life cycle phases for a 3G system	22
Figure 3-5: Carbon dioxide emissions per subscriber and year for different equipments in a 3G system.....	23
Figure 4-1: Life cycle thinking approach at Nokia.....	35

List of Tables

Table 1-1: Stages in the IPP pilot project5

Table 3-1: User scenarios in the LCA17

Table 3-2: Benefits and Limitations of LCA23

Table 3-3: Limitations and benefits of using EFA27

Table 3-4: Limitations and benefits of MIPS28

Table 3-5: Key Environmental Performance Indicators (KEPIs) for a mobile phone30

Table 3-6: Limitations and benefits of KEPIs31

1. Introduction

1.1 Integrated Product Policy (IPP) Pilot Project

This IPP pilot project was initiated by the European Commission (EC) as part of their efforts to work together with stakeholders to develop Integrated Product Policy (IPP). The objective of the EC's IPP approach is to, "reduce the environmental impacts from products throughout their life-cycle, harnessing, where possible, a market-driven approach, within which competitiveness concerns are integrated". As part of the measures to implement it the EC has initiated two pilot projects. These pilots aim to show how IPP can work in practice. Nokia has been selected by the EC to work closely with it for the mobile phones product group. This will take a stakeholder-based approach.

1.2 Objectives and Methodology

The IPP pilot project aims to demonstrate how IPP can work in practice. The IPP project at Nokia shall be carried in several stages in cooperation with the participating stakeholders. The list of stakeholders participating in Nokia's IPP pilot project is provided in the appendix A. The stages in this project along with their objectives are mentioned in the following table.

Table 1-1: Stages in the IPP pilot project

Project Stages	Objectives
Stage I	Analysis of environmental impacts of a mobile phone during its life-cycle
Stage II	Identification of improvement options during different life cycle phases to reduce the environmental impacts
Stage III	Analysis of significant aspects affecting the development of mobile phones. Analysis of the potential environmental, social and economic effects (sustainability analysis) of improvement options identified in the stage II
Stage IV	Selection of final improvement options based on sustainability analysis conducted in the stage III & Agreement on plans for implementation by Nokia and participating stakeholders
Stage V	Implementation of the plans agreed, during the stage IV, by Nokia and the participating stakeholders
Follow-up	Monitoring of the IPP pilot project after a year of implementation of the commitments

During the course of Nokia IPP pilot project four reports shall be developed. This first report covers the stage I of the IPP project. It aims to lay a foundation for the later stages of the project by providing a basic understanding of a mobile phone, its composition, its life cycle, market trends, and the associated significant environmental issues. This report also discusses Nokia's experiences with different environmental assessment tools, and its environmental initiatives.

The second report shall identify and document the improvement options that Nokia and the participating stakeholders can take to enhance the environmental performance of the mobile phones. While identifying the improvement options in the stage II, the environmental initiatives of Nokia and the mobile phone industry will be considered.

The next report in this IPP pilot project shall also provide an insight on the factors that affect the business decisions in the mobile phone industry. These factors may include customer requirements, technology development, legislative environment and other requirements that need to be considered in product development decisions.

The third report shall document the analysis of environmental, economic and social impacts of the improvement options identified in stage II. Nokia and the participating stakeholders shall develop and agree on the implementation plans after considering the environmental, economic and social aspects of the improvement options mentioned in the third report.

The final report shall summarise the actions that the participating stakeholders committed to take in order to improve the environmental performance of the product.

1.3 Scope

The focus of Nokia's IPP pilot project is on mobile phones. This project will consider the environmental impacts and improvement options in the life cycle phases of a mobile phone. Only for the use phase, the environmental impacts and improvement options for network infrastructure will be considered.

1.4 Development of First Report

To document the significant environmental issues of a mobile phone few environmental assessments conducted by Nokia, Motorola, Panasonic and Ericsson are reviewed. Nokia has used tools like Life Cycle Assessment (LCA), Ecological Footprint Analysis (EFA) and Material Input per Service Unit (MIPS) to assess the life cycle environmental performance of a mobile phone.

2. A Mobile Phone

2.1 What is a Mobile Phone?

A mobile phone³ or mobile terminal is a small personal two-way radio. It sends and receives radio signals, carrying voice and data in personal communications with other mobile phones, and telephones. A mobile phone works by communicating with a network of base stations that are located throughout their area of coverage (or operation). A mobile phone sends and receives radio signals to and from the nearest base station. The strength of the signal depends on the distance of the phone to this base station. The base stations communicate with each other and transmit the voice and data between the mobile phones or between a mobile phone and a regular landline phone.

The sales package of a mobile phone generally contains a mobile phone, a charger, a battery, and sometimes accessories like a headset. The mobile phone consists of a plastic housing, a display, a keypad and sometimes an antenna when viewed externally. Internally the mobile phone mainly consists of a printed wiring board with active components like Integrated Circuits (ICs) and passive components like capacitors and resistors mounted on it, connectors and acoustics. The charger of the phone mainly consists of a transformer, a small printed wiring board with a few components, and a cable for connecting it to the phone.

Mobile phones have a very complicated structure and material composition. A mobile phone consists of 500 - 1000 components depending on its complexity. Most of these components are made up of large variety of materials and substances. In the phone, the mechanical components like housing are mostly made up of polymers, and the electrical and electronic components mainly of metals. The following figure shows the material composition of a typical mobile phone (Lindholm, 2003). More information on the components of a mobile phone is provided in the appendix B.

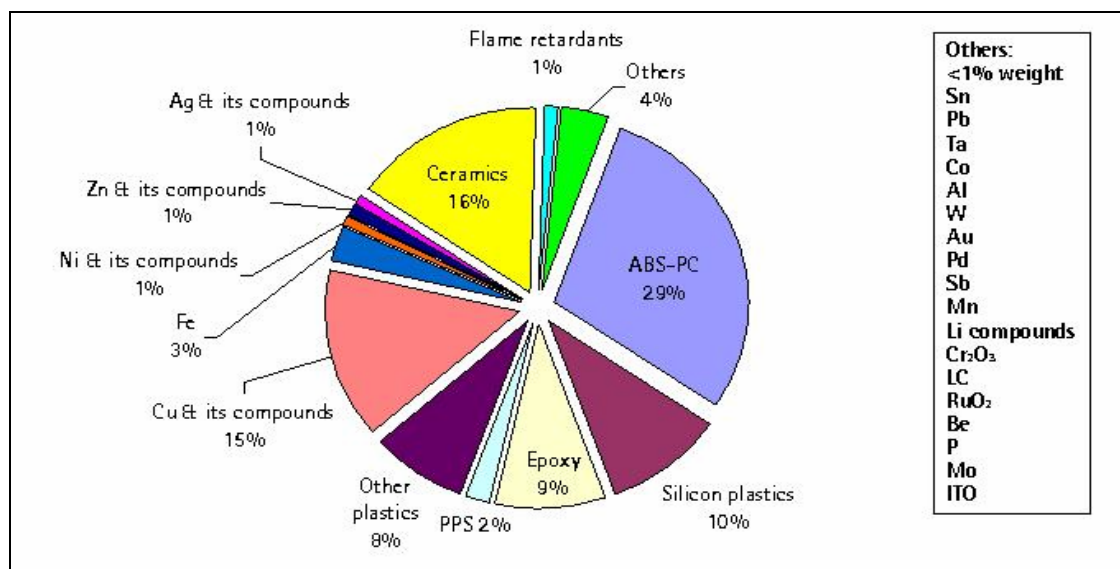


Figure 2-1: Material composition of a typical mobile phone

³ The terms 'mobile phone', 'mobile terminal', 'cellular phone', and 'cell phone' refer to the same product

2.2 Trends in the Mobile Phone Industry

The number of global mobile phone subscriptions is growing and is expected to touch the landmark of 2 billion in 2006. In several countries including a few developing countries the number of cellular subscribers outnumbers the fixed line connections. In many developing countries mobile telephony is now preferred over fixed line connections to avoid the need to lay massive and expensive cable networks.

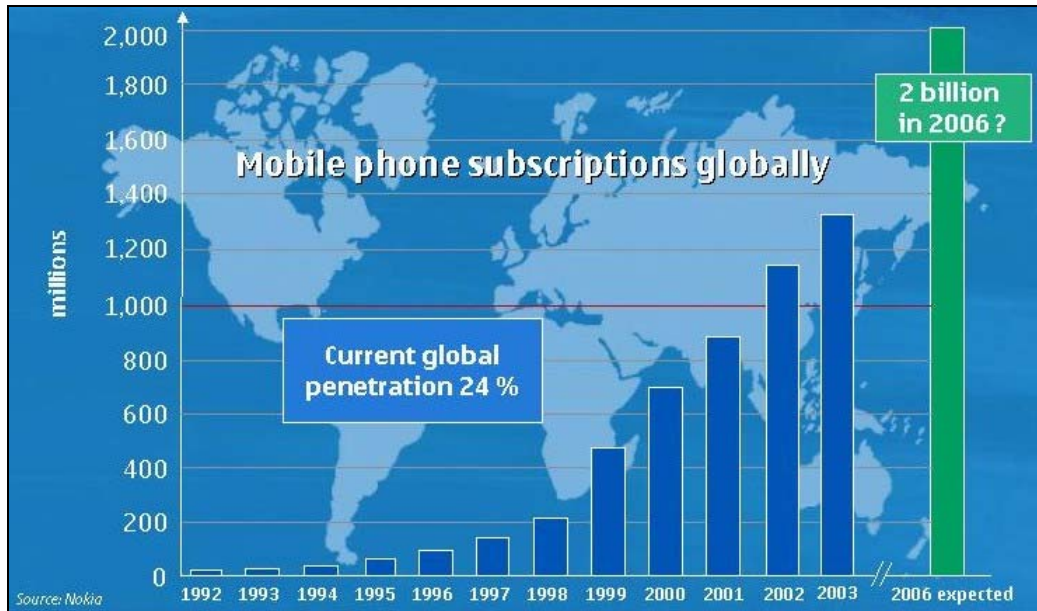


Figure 2-2: Global mobile phone subscriptions

Mobile phones have witnessed explosive growth since their introduction. The mobile phone market is one of the fastest growing consumer markets. A total of 471 million mobile phones were sold globally in the year 2003 and it is estimated that in the year 2004 approximately 630 million mobile phones were sold. One of the key drivers behind this expansion is the new growth in markets such as China, India, Brazil and Russia. The following figure shows the number of mobile phones sold every year since 2001.

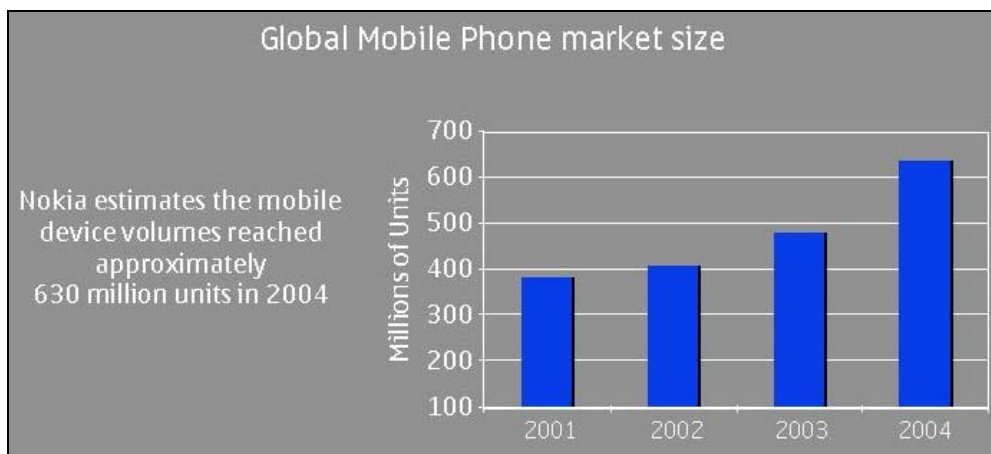


Figure 2-3: Growth of mobile phone market

A dominant feature of the mobile phone market is the very fast turnover of the products. The potential life span of a mobile phone (excluding batteries) is over ten years but due to the technological and fashion obsolescence most of the users upgrade their phones around four times during this period (Wright, 1999). This consumer behaviour has resulted in the present situation where replacement phones represent approximately 80% of the new mobile phone purchases (Antoine, 2003).

Mobile phones have moved from being strict business products to being everyday convenience items. Over the years the consumer demands and technological innovations have led to the development of phones that are lighter, have longer operational times, and that can be used for multiple purposes.

Since the mobile phones were introduced for the first time they have continued to get smaller and lighter. This trend has resulted in lower environmental load of a phone due to reduced amounts of materials and components. The size of the mobile phones has now reduced to a level where any further reductions may lead to consumers facing difficulty in using the keypad of the phones. The trend of the phones getting smaller is also showing some reverse signs due to the integration of multiple applications. The following figure shows the decrease in weight during the evolution of mobile phones. The percentages in the figure show the percentage weight reduction of the phone as compared to its predecessor.

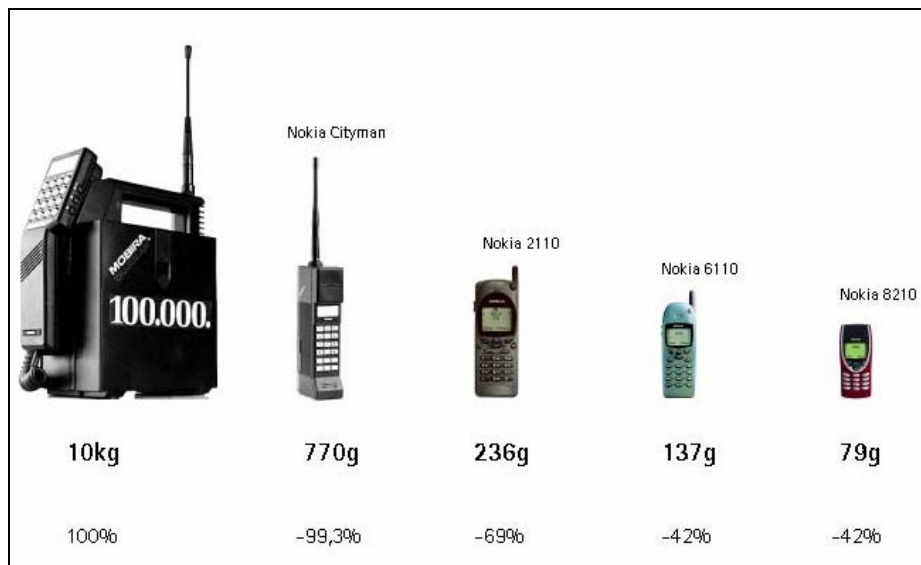


Figure 2-4: Reduction in weight of a mobile phone over the years

The evolution of the phones has also been marked by longer standby and talk times primarily driven by consumer demands and technological development. The longer standby and talk times of the phones are attributed to the significant improvements in the energy efficiency of different electrical and electronic components, reduction in the operating voltage and overall energy requirements of the circuits in the phone, software development and the changes in the chemistry of the batteries. The energy consumption of the phone charger during the charging and standby modes has also reduced considerably over the years.

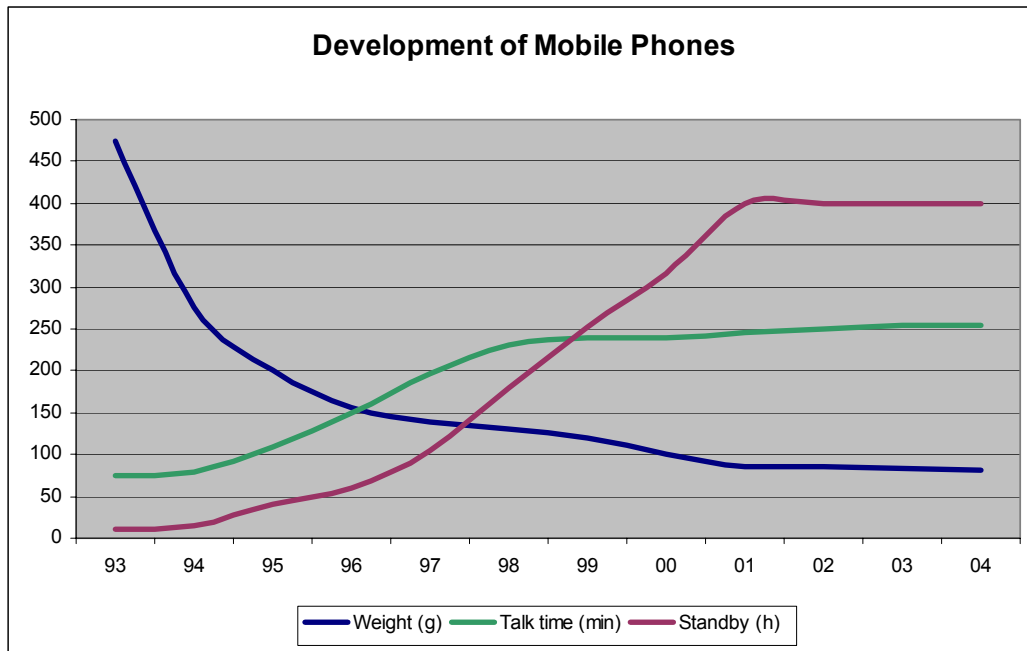


Figure 2-5: Changes in weight, talk and standby times during the development of phones

The chemistries of the batteries (accumulators) have greatly changed over the past years and are still changing. The change in the accumulator chemistry from lead to a nickel-cadmium took around 10 years, the transition from nickel-cadmium to nickel-metal-hydride around 5 years and since the last few years the lithium-ion and lithium-polymer batteries are replacing the nickel-metal hydride batteries in the mobile phones. These changes in the batteries have significantly reduced the energy consumption of the phones during the use phase and most importantly diminished the toxicity potential due to the phase out of lead and cadmium from the battery.

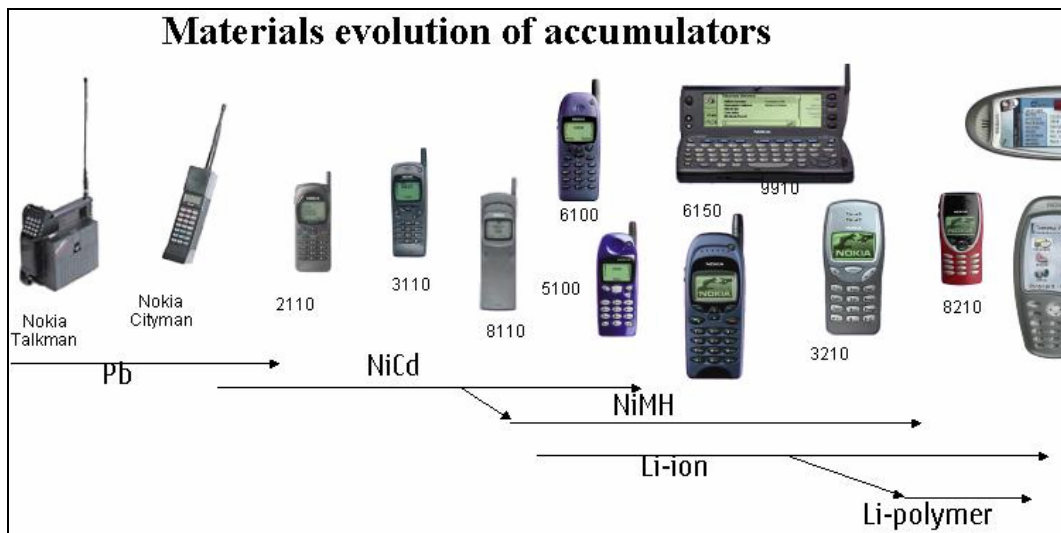


Figure 2-6: Evolution of accumulator chemistries

The convergence of the telecommunication, consumer electronics, Internet and wireless technologies has been leading to increase in the functionalities of a mobile phone. For the last few years the mobile phones have been (and continue to be) in a transition phase from ‘communication terminals’ to ‘multiple-use mobile terminals’. Some trends in line with this

transition include integration of functions like text messaging, alarm clock, games, internet, music player, radio, still and video camera, personal digital assistant (PDA), global positioning device, business application packages for creating and reading documents, video conferencing, and possibility to make payments at shops by phone. The development of multiple-use mobile terminals creates a substitution effect and has the potential for consumers to satisfy their needs by buying one, instead of many electronic devices.

Two specific examples of the multiple-use mobile terminals are ‘smartphones’ and ‘camera phones’. Smartphones provide, in addition to voice, features normally found in PDAs for example downloadable applications, e-mail, personal information management and synchronization to the PC. The camera phones highlight the convergence in mobile imaging. The current and the expected sales figures of the smartphones and mobile phones with integrated cameras are shown in the following figure. The sales of smart phones and camera phones are increasingly rapid, enabling further development of multiple-use mobile terminals.

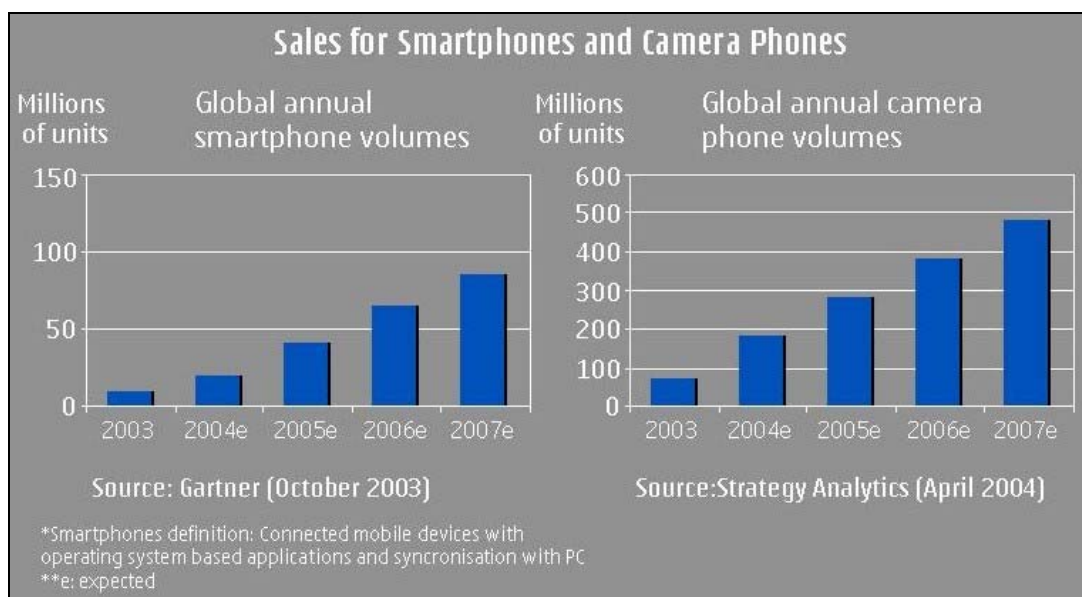


Figure 2-7: Sales of smart phones and camera phones

2.3 Nokia Profile

Nokia is the world's largest manufacturer of mobile phones since 1998 with a sales volume of 179 million units in the year 2003. Nokia manufactures products for all customer segments and mobile standards worldwide and employs over 50 000 employees from more than 120 countries. Nokia had net sales of € 29.5 billion and an operating profit of € 5.0 billions in the year 2003. Nokia sells its products in over 130 countries and there are approximately 500 to 600 million Nokia phones used globally (Nokia, 2004).

2.4 Life cycle of a Mobile Phone

This section provides an insight into the various life cycle phases of a mobile phone. The life cycle of a mobile phone is quite similar to that of other electronic products such as PCs. A simple illustration of the life cycle⁴ of a mobile phone is presented in the following figure.

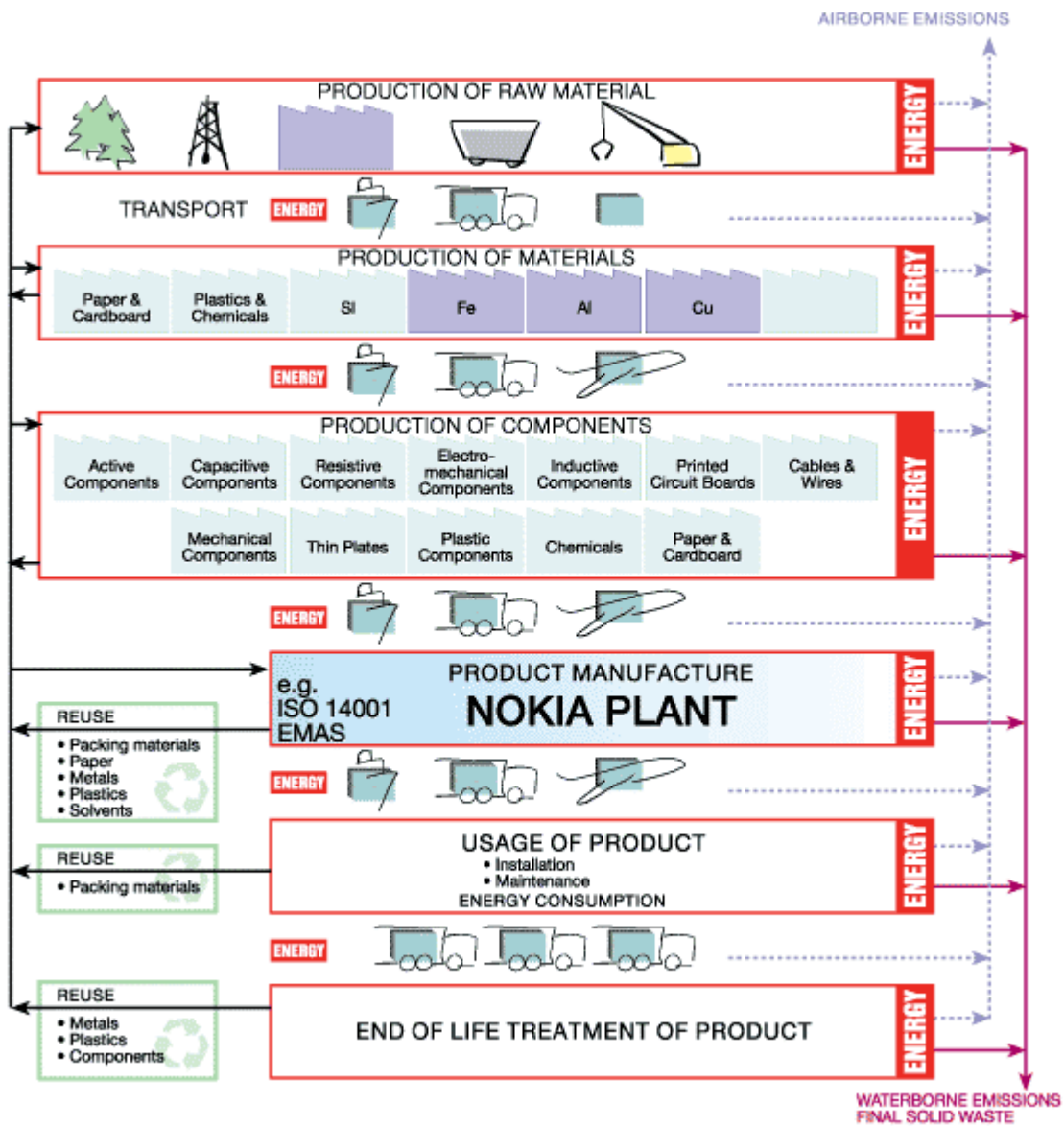


Figure 2-8: Life cycle of a mobile phone

The environmental aspects of a mobile phone are mainly linked to the materials and energy used during its life cycle. A brief description of the most important life cycle phases of a mobile phone is presented in the following sub-sections.

⁴ The terms 'installation' and 'maintenance' in the Usage of Product highlight the network infrastructure

2.4.1 Raw Material Extraction and Processing

The life cycle of a mobile phone starts with the extraction of the raw materials. An average mobile phone consists of 500-1000 components, which are made of a large variety of materials and substances⁵. This phase includes both the production of raw material and the use of these raw materials to produce other materials and substances. The environmental aspects and impacts from this phase arise from the mining operations, refining of ores, and manufacturing of materials and substances.

2.4.2 Components Manufacture

This phase covers the manufacturing of the components⁶ used in a mobile phone. The principal components in a mobile phone are PWB, semiconductors, LCD and housing. The components manufacture is characterised by several environmental aspects main among them being energy consumption and use of materials with hazardous properties. The role of component manufacturers is crucial to reduce the environmental impacts from this phase.

As a global company Nokia has component suppliers located all around the world. The main countries and regions for Nokia's contract manufacturing and supplier locations are: Austria, Brazil, China, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Israel, Japan, Korea, Malaysia, Mexico, Morocco, Netherlands, Philippines, Portugal, Singapore, Slovakia, Spain, Sweden, Switzerland, Taiwan, Thailand, UK and USA.

2.4.3 Components Transport

As mentioned earlier a mobile phone is comprised of hundreds of components, which are sourced from suppliers located in different parts of the world. Components are delivered to the assembly plant(s) both by surface and air transport. The environmental impacts in this phase mainly arise from the energy consumption of the carriers.

2.4.4 Phone Manufacture (Assembly)

This phase covers the assembly of the components to manufacture a phone. The main process in the phone assembly is components placement, attaching the components to the PWBs by soldering, assembling the mechanical parts, electromechanical parts and components, programming, testing, packaging main body together with the battery and charger, and then dispatching the phone in its sales package to the retailer. The main environmental aspect from this phase is the energy consumption of assembly line and overheads.

2.4.5 Phone Transport

This phase covers the transportation of the phone in its sales package from the assembly plant to the distributors. Energy consumption of the carriers is the main environmental aspect from this phase.

⁵ See figure 2.1 for material composition of a mobile phone

⁶ See appendix B for an overview of components in a mobile phone. The term 'components' stands for all mechanical parts, electromechanical parts and electronic components.

2.4.6 Distributors

The distribution structure of the mobile phone industry is quite unique. The network providers sell majority of the mobile phones to the end-users (consumers). The phone manufacturers are thus in little contact with the consumers. This unique distribution structure gives network providers the opportunity to cooperate and educate the customers on the takeback and recycling of the phones.

2.4.7 Phone Use

A network infrastructure which comprises of radio network with radio base stations and radio network control equipment, a core network with switches, routers, servers and workstations and transmission equipment is required for using mobile phones. The chief environmental impacts from this phase arise from the energy consumption of the network infrastructure and the energy consumption of the mobile phones.

The consumer uses the phone for a desired period of time. The sales packaging waste, the energy consumption during the charging of the phone battery, the standby energy consumption of the charger, the used unwanted phones and the unwanted accessories account for the environmental aspects from this phase.

2.4.8 End-of-life (EoL)

After buying a replacement phone consumers follow many different pathways to dispose off their replaced phone. The consumers either put the replaced phone aside for future use, give it to a relative, trade it in at a retailer/distributor/any shop, leave it at a charity collection point, or drop it at a service point/collection facility for waste handling. Some of these pathways can be classified as 'continued use'. Only a fraction of the replaced phones ends up in the waste treatment facilities⁷.

Manual and mechanical methods are used to separate the different material fractions of the phone during EoL treatment⁸. The manual separation involves the separation of the battery and other phone accessories from the main body of the phone. In a few cases the housing of the phone is also removed during manual separation. The mechanical separation methods include shredding, crushing and size reduction of the main body of the phone followed by the use of various material separation techniques like magnetic separation, heavy media and density separation, air classification and eddy current separation. These techniques separate the materials into different material streams.

Plastics and metals are the two main material streams. The precious metal stream, which consists of the populated PWB⁹ of the phone, is recycled in a copper smelter. The present end-of-life treatment methods are optimised to recover metals especially precious ones like gold, palladium, platinum, silver as is it leads to both economic and environmental benefits. The beneficial environmental impacts from recycling the metals far exceed that of any other materials (including plastics) in the phone (Stevens, 2003; Huisman, 2004; Singhal et al., 2004). Plastics are the largest single category, by weight and volume, of mobile phones. Presently the

⁷ This situation is mainly attributed to the consumer perception that a mobile phone is too valuable to give up for recycling (MPPI, 2004).

⁸ For additional information on EoL issues, see mobile industry initiative on EoL issues at <http://www.basel.int/industry/>

⁹ A populated PWB means a PWB with the active and passive components mounted on it.

plastic stream is incinerated and energy is recovered. The recovery of plastics from mobile phones for material recovery and recycling is not widely practiced due to lack of viable techniques for recovering plastic fractions of marketable quality. A relatively higher percentage of the plastics in the phone must now be recycled to meet the requirements of WEEE Directive¹⁰. Nokia has participated in several studies on the end-of-life phase of a mobile phone. References to many of these studies are included in the appendix F.

The environmental aspects and impacts from the end-of-life phase of a mobile phone depend on how the phone is managed in the end-of-life. If the phone is properly managed then this phase results in positive environmental impacts due to metal recovery but if it is mismanaged then it may cause negative environmental impacts like landing contamination, water pollution, and air pollution due to leaching of metals.

The European Commission (EC) estimates that the Waste from Electrical and Electronic Equipments (WEEE) constitutes about 4% of the municipal waste. Further an analysis of WEEE data, by SWICO Environmental and Energy Commission, collected in Switzerland indicates that mobile phones constitute just 0.12% of the collected WEEE. In the case of Finland, the data from year 2000 shows that the mobile phones represent 0.06% by weight of the collected WEEE (MPPI, 2004).

¹⁰ The WEEE Directive requires that the component, material and substance reuse and recycling shall be increased to a minimum of 65 % by an average weight per appliance for IT and telecommunications equipment.

3. Environmental Issues in the Life Cycle of a Mobile Phone

This chapter documents the significant environmental issues associated with the various life cycle phases of a mobile phone. Nokia considers environmental impacts from a product life cycle perspective and has tried several approaches for conducting environmental assessments.

This chapter highlights the results from Life Cycle Assessments (LCAs) of mobile phones by Nokia, a LCA of a 3G system by Ericsson, and Ecological Footprint Analysis (EFA) and Material Input per Service Unit (MIPS) studies in which Nokia had participated. A new assessment approach called Key Environmental Performance Indicators (KEPIs), and Nokia's experiences and recommendations for various assessment methods are also discussed in this chapter. Finally, a summary of the environmental hot spots of a mobile phone is presented.

3.1 Life Cycle Assessment (LCA)

The ISO 14040 standard defines LCA as the “compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle”. According to the Society of Environmental Toxicology and Chemistry (SETAC) “LCA provides a framework, an approach, and methods for identifying and evaluating environmental burdens associated with the life cycles of materials and services, from cradle-to-grave (or, as preferred by some, ‘cradle-to-cradle’, which captures the recyclability of materials) (Todd & Curran, 1999).

Nokia has been involved with LCAs since mid 1990s and has conducted many LCAs for its products. In this section the main results from two LCAs of mobile phones conducted by Nokia (in 2003 and 1999) and a LCA of a 3G system conducted by Ericsson (Malmodin, 2004) are presented. In addition results from another LCA (conducted in 2001 by Nokia in collaboration with IKP) are mentioned in appendix D.

3.1.1 LCA of a Third Generation (3G) Mobile Phone by Nokia (2003)

This recent assessment at Nokia was conducted in line with the guidelines set in ISO 14040 series (Mclaren & Piukkula, 2004; Piukkula, 2003). In this section only a brief summary and results for the aspect indicator on Primary Energy Consumption (PEC) are discussed. For a detailed summary and results on impact indicators on Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Acidification Potential (AP), Human Toxicity Potential (HTP) and Photochemical Oxidant Creation Potential (POCP) refer to appendix C of this report.

3.1.1.1 Goal and Scope

The main objective of this assessment was to identify the key environmental impacts of a Nokia 3G mobile phone during its life cycle. The functional unit in this assessment was the use of a Nokia 3G mobile phone, its battery and charger, with an average life time (2 years) and average daily use time. This study considered the energy consumed by the phone and the charger during its use phase. The phone has many of the latest features like Bluetooth module and a camera and provides functionalities like text and multimedia messaging, games, music and video playing. The solder paste used in the phone is lead-free and the battery is a lithium ion battery (Mclaren & Piukkula, 2004; Piukkula, 2003).

This assessment accounted the environmental aspects from the raw material extraction and processing, components manufacture, components transport from the first tier to assembly plants, phone assembly, transport of phone to the first customer and the use of the phone. The end of life phase was left out of the scope of this assessment due to the paucity of data. Components sales packaging, network infrastructure and operations of the mobile retailers were also left out of the scope of this assessment. No cut-off rules were applied and all the parts and over 99% of materials were included. In this study it was assumed that the phone is assembled at Nokia's production site in Salo, Finland and used and charged in Europe. The transport steps that have been included are based on reasonable assumptions of freight origins and destinations. This study used the German LCA tool GaBi v3.0 and GaBi Life Cycle Inventory (LCI) data to model all material and electronic components. The LCA was modelled by using two different user profiles (Mclaren & Piukkula, 2004; Piukkula, 2003). The differences between these user profiles are shown in the following table.

Table 3-1: User scenarios in the LCA

Light User Scenario	Heavy User Scenario
Moderate use of several phone features	Heavy use of all phone features
Battery discharge 95%	Battery discharge 100%
Minimal charging of 1.5 hrs in every 48 hrs	Charging of 10 hrs in every 24 hrs
Charger left on even after the completion of charging	Charger left on even after the completion of charging

3.1.1.2 Inventory Analysis

The phone consisted of approximately 500 components that were categorised into three groups namely electronics, electro-mechanics and mechanics, and accessories¹¹. The GaBi LCI consisted of data on materials and energy inputs and outputs for the electronics and mechanics groups. For electro-mechanics, data regarding component raw material composition was collected from the material declaration forms that are used by Nokia for collecting information on the material contents of the components. Reasonable assumptions were made for the components and materials for which no data was available. The production processes were excluded for battery, LCD, camera, acoustic parts and the painting process. There were uncertainties associated with the integrated circuits (ICs) and engine assembly as the LCI database had information only for older technology ICs. The PWB data was only available for a six-layered PWB, which had lesser number of layers than the actual PWB in the phone. The process data mainly excluded the plastic and metal processing. Only the materials that had a concentration greater than 0.7 g were modeled for electro-mechanics and mechanics, and accessories (Mclaren & Piukkula, 2004; Piukkula, 2003).

3.1.1.3 Impact Assessment and Interpretation

Several environmental indicators namely PEC, GWP, ODP, AP, HTP and POCP were analysed in this assessment. This section only delineates the results for the indicator on primary energy consumption (PEC). The LCA results on other indicators are mentioned in appendix C.

¹¹ See Appendix C for more information on component categories. The term 'accessories' in this particular LCA accounts the battery and the charger.

The total primary energy consumption includes the energy consumption from both renewable and non-renewable sources in mega-joules (MJ) during the life of a mobile phone. The following figure¹² illustrates the life cycle energy consumption of the mobile phone (McLaren & Piukkula, 2004; Piukkula, 2003).

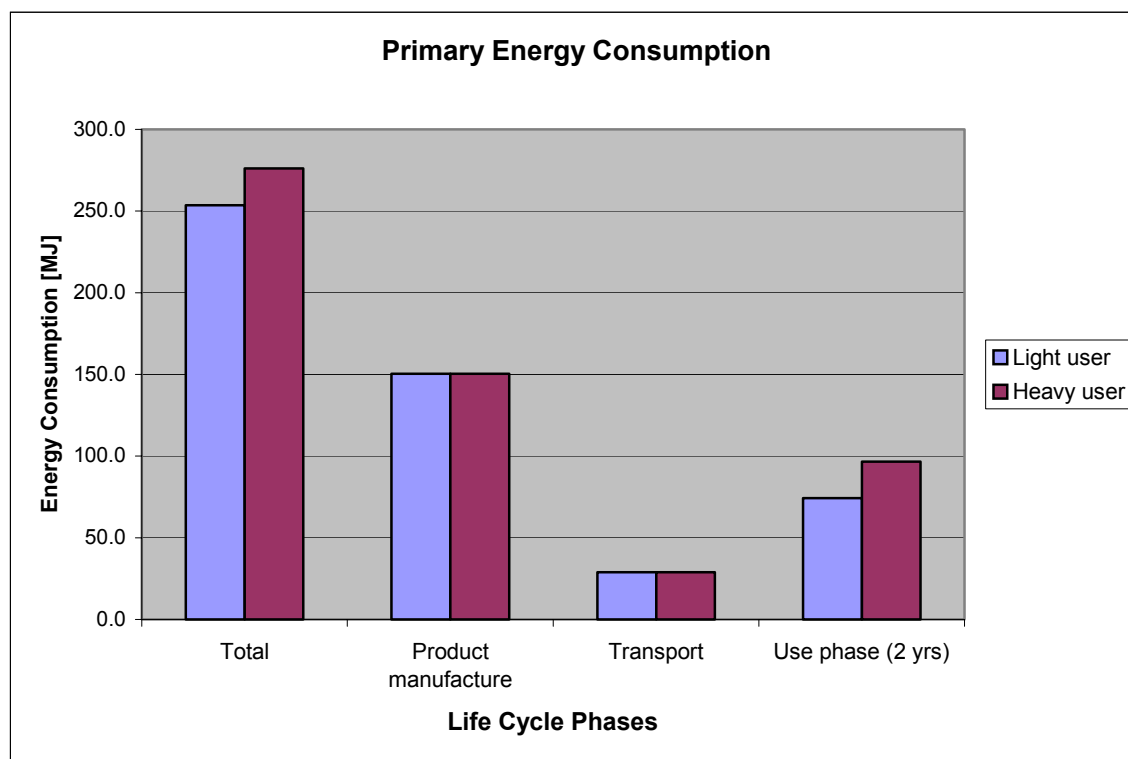


Figure 3-1: Life cycle energy consumption of a third generation mobile phone

For the indicator on primary energy consumption, the LCA identifies:

- The product manufacture phase accounts for approximately 60% of the total energy consumption in the case of light user scenario and about 54% in the case of heavy user scenario.
- The use phase accounts for approximately 29% of the total energy consumption in the case of light user scenario and approximately 35% in the case of heavy user scenario. During the use phase the most important contributor is the standby energy consumption of the charger.
- The transportation of the components from the first tier suppliers to the assembly plant accounts for approximately 6% of the energy consumption whereas the energy consumption for the transportation of the phone to the first customer accounts for 5% of life cycle energy consumption.
- PWBs are the most energy intensive components in the phone. The raw material acquisition¹³ and manufacture of the PWBs accounts for approximately 40% of the total

¹² In the figure, the term 'product manufacture' includes raw material extraction and processing, component manufacture and assembly of the phone. The term 'transport' includes transportation of components from the first tier supplier to the assembly plant, and the phone transport from the assembly plant to the first customer.

¹³ 'Raw material extraction and processing' is also referred as 'raw material acquisition'

energy consumption. The raw material acquisition and manufacturing of ICs is also significant in terms of energy consumption.

3.1.2 Life Cycle Energy Analysis of a Mobile Phone by Nokia (1999)

3.1.2.1 Goal and Scope

This study at Nokia was a ‘cradle to grave’ life cycle energy analysis of an average mobile phone. The functional unit was the use of one phone for an average lifetime of 2.5 years. The life cycle phases that were included were: raw material extraction and processing, components manufacturing, transport of phones to assembly plant, assembly of mobile phone, transport of phone to first customer, use, and end-of-life (Wright, 1999).

The study considered two types of phones: **type B** was an average of four products released in the market between 1992-1994 and its weight was 160 g, and phone **type C** was an average of three products that were released in the market between 1995-1996 and its weight was 130 g. The study evaluated the mobile phones without considering batteries, chargers and accessories. An exception to this was the inclusion of standby power consumption of the charger in the use phase (Wright, 1999).

3.1.2.2 Inventory Analysis

In the raw material extraction and processing phase the focus of the study was on plastics and metals. All metals over 10ppm in the phone were included in the analysis. The raw materials not assessed in the study accounted for around 30% of weight (mainly glass, epoxy resin in printed circuit boards, ceramic, and LCD). Components manufacture included printed circuit board production, printed circuit board laminate production, packaging and production of semiconductors.

The components were categorized into three types: active components, passive components and other mechanical parts. Plastics injection moulding was included when passive component production was estimated. The transport of components considered only the airfreight. The assembly of the mobile phone included only the energy consumption of the production line and not overheads like space heating and lighting. The use phase included energy used to charge up the phone battery based upon an average daily use (phone used 1700 minutes per year for calling and receiving phone calls) and average lifetime (2.5 years) and the energy consumed by the charger. The energy consumption of the network infrastructure was not included in this study. The battery was assumed to be charged for one hour every three days, and therefore the charger would be used for 122 hours/year and left plugged in for the rest of the year. The standby power consumption of the charger was 1.3 watts. In end-of-life phase four options were considered: landfill, collection and metals recovery in the UK, collection and metals recovery in Sweden, and collection and component reuse, and plastic recycling in the UK. Several tools – such as TEAM and GaBi – and methods were used during the study, and it included quite an amount of assumptions and estimations (Wright, 1999).

3.1.2.3 Impact Assessment and Interpretation

The energy consumption and the environmental rucksack for the various life cycle phases of a mobile phone were calculated in this study. Following are the results from the energy analysis of the phone (Wright, 1999).

- The overall energy balance for product type B was about 327 MJ and for product type C it was about 307 MJ when landfill was used as an end-of-life option.
- For both mobile phone types the components manufacture phase accounted for the biggest part with energy consumption of 126-130 MJ. The energy consumption for IC production in case C was calculated to be 61 MJ. Resistors and capacitors accounted for 0.24 MJ, coils and beads 0.015 MJ, printed wiring board 11 MJ, and other SMD components 53 MJ.
- The use phase energy consumption was calculated to be total 116 MJ of which charger standby was 101 MJ.
- The contribution of the transport was about 10% (if the transport of components to assembly plant and transportation of phones to first customer are added).
- The raw material extraction and processing accounted for 25-40 MJ depending on the product type.
- The assembly line contribution to the environmental impact was 11 MJ and landfill's only 0.005-0.007 MJ. The other end-of-life management options would have reduced the total energy balance of product type B between 17-54 MJ and for product type C between 3-49 MJ. The take back and recycling of mobile phones had beneficial effects on the environment.

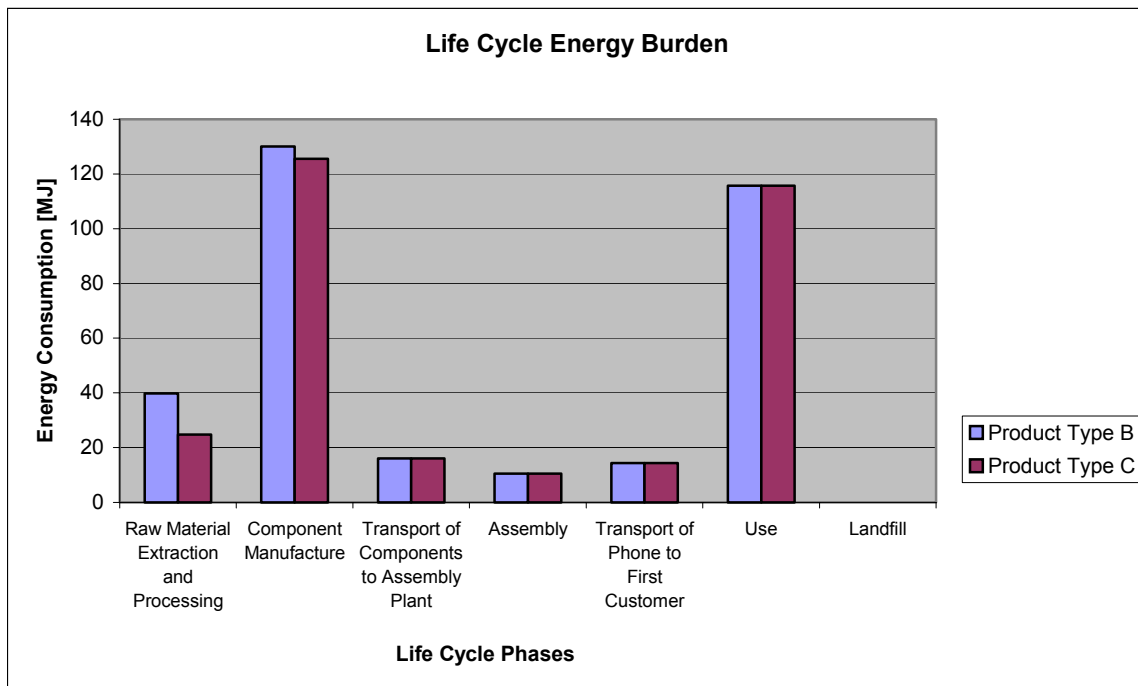


Figure 3-2: Life cycle energy analysis of a mobile phone

Besides energy life cycle analysis, the study included also an environmental rucksack analysis for a mobile phone. The rucksack calculation accounted for waste created from raw material extraction and processing for silver, copper, gold, zinc and lead. The rucksack calculation for this phase did not include all the materials in the product due to data paucity. The waste

generated from the manufacture of ICs and PWBs was included in manufacture. The following figure illustrates the results of this rucksack analysis (Wright, 1999).

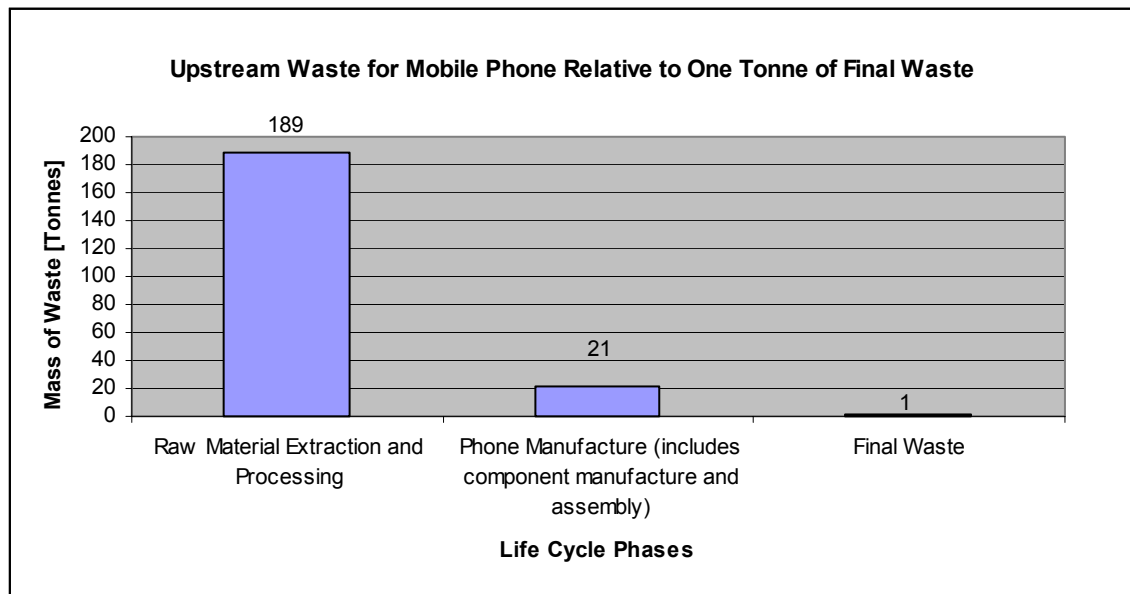


Figure 3-3: Amount of upstream waste of a mobile phone relative to one tonne of final waste

3.1.3 LCA of a Third Generation (3G) System by Ericsson (2004)

Ericsson recently conducted a life cycle assessment for assessing the environmental impacts of a 3G system. The LCA was conducted in line with the requirements of ISO 14040. In this LCA, a pilot UMTS system for 1.5 million subscribers was studied (Malmodin, 2004).

The 3G system consists of 3G mobile phones, a radio network with radio base stations and radio network control equipment, and a core network with switches, routers, servers and workstations. Transmission equipment like feeders and cables, and various site materials like antennas, climate control equipment and site housing were also included. The study did not include application networks (mainly servers) (Malmodin, 2004).

Several environmental indicators were assessed within this study. The results for the impact indicator on climate change, which is closely linked to energy consumption, are as follows (Malmodin, 2004):

- The operational (use) phase was found to be the most important in 3G pilot system's life cycle. The operational phase accounted for 78% of the total environmental impacts for the indicator on climate change.
- The operation (use) of telecom equipment¹⁴ accounted for 60% and the operator's office activities accounted for 18% of the of the total environmental impacts for the indicator on climate change.
- The manufacturing phase, which includes raw material acquisition, manufacture of components and products, transports and Ericsson's office activities account for the

¹⁴ The term telecom equipment includes mobile terminals, radio base stations and other network equipment like routers, switches, and servers.

remaining 22% the total environmental impacts. The mobile phones are the biggest contributor to the impacts from the manufacturing phase of a 3G system. The environmental impacts of a mobile phone are very low in comparison to a base station but as each and every subscriber requires a mobile phone their combined impact accounts for the largest portion in the manufacturing phase.

- The EoL phase accounted for -0.8% of the total environmental impacts. The negative figure means that the EoL has a net positive impact on the environment due to recycling.

The following figures illustrate the results of the LCA for the indicator on climate change (Malmodin, 2004).

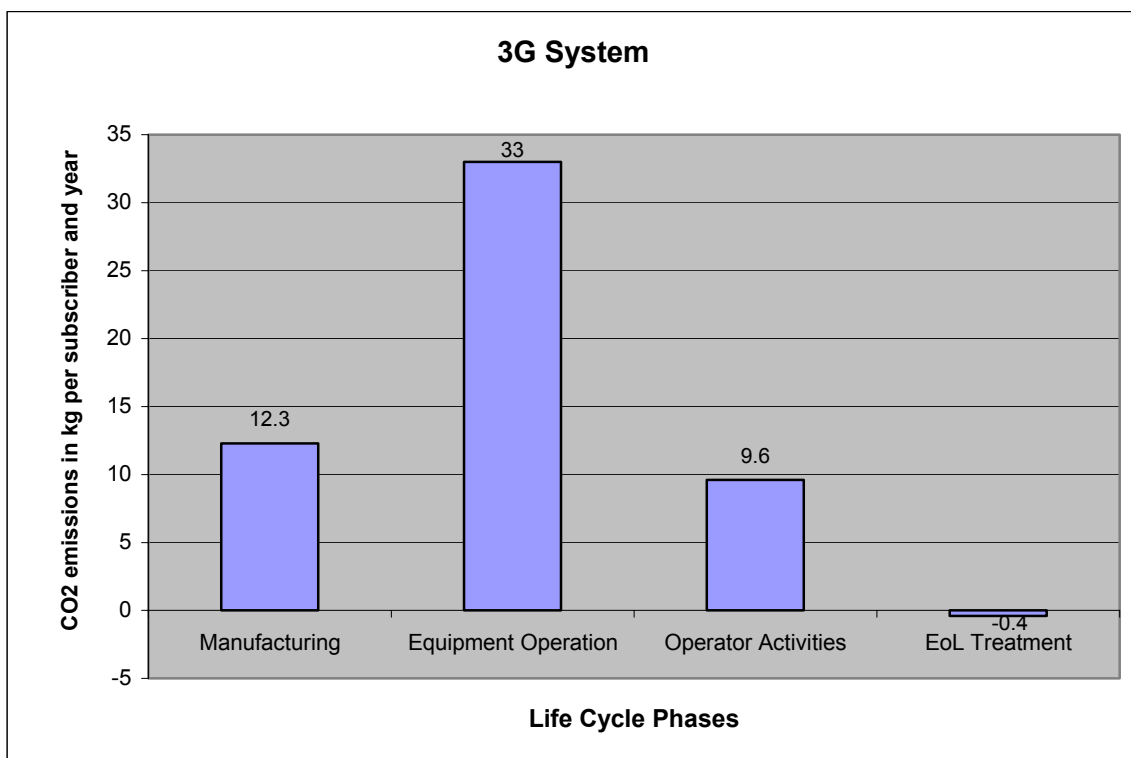


Figure 3-4: Carbon dioxide emissions per subscriber and year during different life cycle phases for a 3G system

The term network equipment in the next figure refers to the equipments like routers, switches and servers.

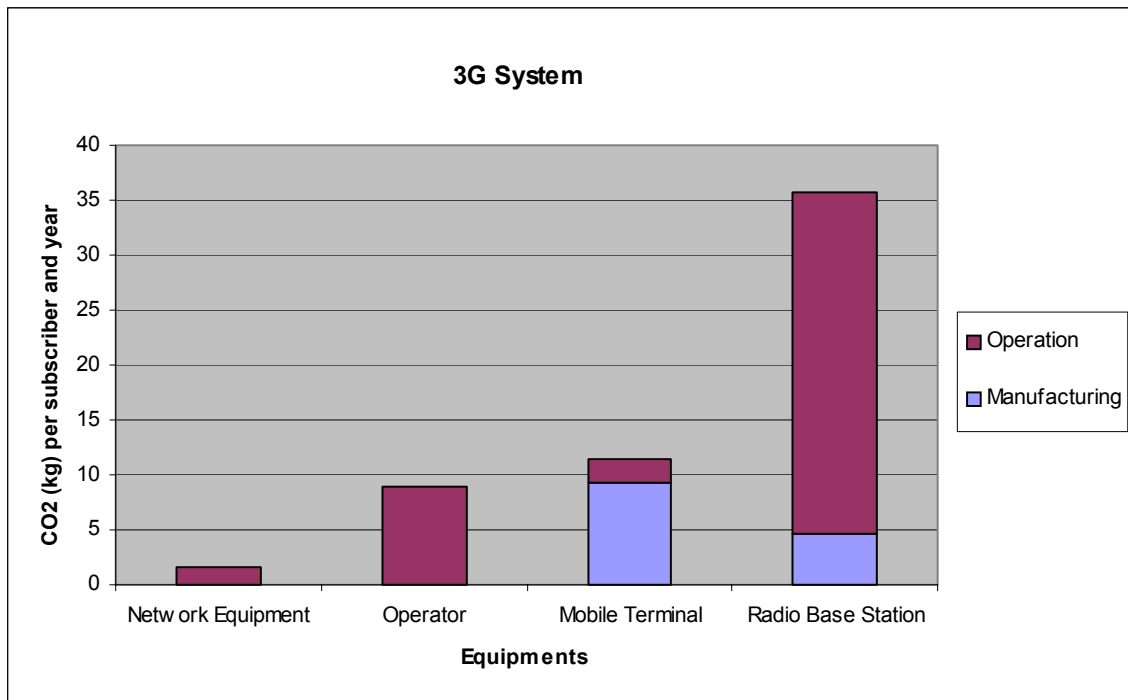


Figure 3-5: Carbon dioxide emissions per subscriber and year for different equipments in a 3G system

3.1.4 Nokia’s Experience with LCA

Nokia supports life cycle thinking and considers environmental impacts from total product life cycle perspective. At the moment, however, Nokia does not consider LCA to be a fully reliable method for definition of the environmental impact of complicated electronic devices like mobile phones. Nokia will continue to contribute to the development of processes and tools suitable for electronics by cooperating with researchers and specialists in recognized initiatives. The table below discusses Nokia’s experiences with LCAs.

Table 3-2: Benefits and Limitations of LCA

Limitations of LCA	Benefits of LCA
<ul style="list-style-type: none"> – A full LCA is not well equipped for making comparisons over different products within short product development and innovation timescales in the mobile phone industry. – Due to the complex nature of many electronics products including mobile phones, the potential scope of the data that has to be collected to conduct a life cycle inventory is immense. – A major issue inhibiting the use of LCA is the current lack of available process and environmental data for many substances and components in mobile phones. For example, data is only just becoming available for many of the materials used e.g. precious metals such as gold and silver. Information on any substances that are not in widespread use, including rare earth metals and rare substances, are not usually available at all. In particular there is a lack of data on the toxicity issues related to the end-of-life phase. 	<ul style="list-style-type: none"> – If the challenges can be overcome then LCA is suitable, for example, for: <ul style="list-style-type: none"> ○ Strategic environmental assessment of new technology or business model, i.e. new type of component, material, product or service provision. ○ Developing other simple environmental indicators to implement life cycle thinking in business decision-making. ○ Research purposes in identifying the most significant environmental impacts of a product life cycle.

<ul style="list-style-type: none"> – LCA has not proven to be a good method to assess the differences between two mobile phones, as the differences are so small that they easily get buried in the assumptions that need to be made for conducting LCA. – It is not easy for non-experts to interpret the LCA results. – The impact assessment phase is in LCA inevitably contentious because of the complexity of environmental problems and also because it involves value judgements in weighting the significance of different environmental impacts. 	
---	--

Some general observations from the LCAs conducted by Nokia are:

- All the LCAs conducted at Nokia since mid 1990s have yielded similar results.
- The results from LCAs of mobile phones do not deviate much from the results from other simple environmental analyses (or assessments).
- Although LCA is accepted as a concept its practical application for complex products, in particular as a tool for environmental improvement in product design, has proved very difficult.
- The technology & related materials and processes have been changing too fast to make any meaningful & detailed process comparisons by using LCAs.

Recommendations for using LCAs:

- The main value of detailed and effort intensive LCA studies lie in providing scientific input to the strategic decisions. LCA may be a useful methodology to scientifically assess the environmental costs/benefits of politically driven technology changes by using scenario modeling.
- For conducting LCA the best available inventory data for materials, components, processes and choice of impact assessment categories should be used. To successfully conduct LCAs, it is imperative to develop the life cycle information on the relevant materials and processes.
- Type of LCA study should be chosen with regard to question in hand and business decision context. Different tools are required to assess different questions so applicability of the tool to question is critical.
- Data gaps, and uncertainties should be transparent and possible effects on the final results understood. Expert peer review is agreed ISO approach for study validation.

3.2 Ecological Footprint Analysis (EFA)

Nokia participated in this EFA study carried by Sibyllne D. Frey as a part of her doctoral thesis as it uses natural capital accounting. This section provides a brief summary of the final

results achieved in this study. More details on the methodology and the results of this study are provided in appendix E.

The ecological footprint for a particular population, as defined by Rees and Wackernagel, is “The total area of productive land and water ecosystems required to produce the resources that the population consumes, and assimilate the wastes that the population produces, wherever on earth that land and water may be located using prevailing technology.” The EF assumes that all the categories of energy and material consumption and waste generation requires the productive or absorptive capacity of a finite area of land or water (Rees & Wackernagel, 1996).

The ecological footprint extends farther than LCA and converts the impacts identified from LCA into bio-productive areas required which can be further aggregated into a single score and compared to the ecological bottom line. To measure the ecological footprint of a mobile phone a life cycle approach was used in this study with a focus on total primary energy and carbon dioxide (CO₂) emissions. The CO₂ emissions were used as a first order approximation of waste flows in subsequent EFA (Frey, 2002).

The functional unit in this study was the use of one mobile phone during its life cycle with an average lifetime (2.5 years) and an average amount of daily talk time. The study accounted for the charger’s energy consumption in standby mode, but not for the environmental impacts associated with the charger itself, phone battery, or any other accessories or network infrastructure needed for using the phone (Frey, 2002).

The study focused on a specific Nokia phone model, which weighed 90 grams and contained more than 100 different materials and 90 different types of components. Besides total primary energy, CO₂ emissions were calculated for various life cycle phases. The LCA by Wright in 1999 was used as a basis for this study but major changes were included in raw material extraction and manufacturing energy. Data from other LCA studies conducted by Nokia was also utilised. This ‘cradle to grave’ study took into consideration raw materials production including extraction data where possible (TEAM 3.0 software tool was used for this life cycle stage), components manufacture and phone assembly (accounting only for materials remaining within the phone and not for the process materials), use and EoL phase.

An overall estimation of the energy value was used for the manufacture so that **case A** used older manufacturing energy data and **case B** newly updated energy data. The use phase was modeled in the same way as by Wright in 1999 LCA, and in end-of-life 95% of precious metals were assumed to be recycled (granulated, smelted and recovered) and the remainder to be landfilled. A so-called ‘avoided energy approach’ was used, i.e. avoided energy by recycling a metal is equal to the energy that would have been required to mine and produce same quantity of a metal. Transport was the only excluded life cycle phase from the energy analysis (Frey, 2002).

This study resulted in much higher figures for total primary energy consumption than any other studies at Nokia. The results for the total primary energy consumption are summarised below (Frey, 2002):

- The most significant life cycle phase of the mobile phone was the use phase, coming before the components manufacture and assembly by a small margin.
- For case A, both use of the phone and manufacture of its components contributed about half to the total primary energy. For case B, the use phase had the biggest

environmental impact contribution of 54% with components manufacture and phone assembly coming second with 45%.

- The production of raw materials had the lowest impact of approximately three percent in terms of energy consumption.

For the indicator on CO₂ emissions, the study identifies (Frey, 2002):

- The components manufacture and phone assembly was the dominating life cycle phase followed by the use phase.
- The CO₂ emissions for the overall phone life cycle were about 39 kg of CO₂ for case A and about 36 kg for case B.

In both impact categories, the significance of raw material production was fairly insignificant compared to other life cycle phases. The impact of end-of-life was positive due to the recycling of metals.

To apply the EF concept the methodology was split into the estimation of Direct Land Use (DLU) from mining activities and the estimation of indirect land use from CO₂ sequestration by land and sea. To find the DLU value for a mobile phone, raw material flows were multiplied by their respective land use values, DLU (m²kg⁻¹). Due to the non-availability of data not all resource flows could be included. The CO₂ emissions from the life cycle of a phone were converted to fossil energy land. The fossil energy land is the land to be reserved for CO₂ absorption and refers to the spatial impact of fossil fuel use.

The DLU result for case A was 2.23 m² and for case B it was 2.09 m². The fossil energy land for the case A was 60 m² and for the case B it was 55 m². For the cases A and B, the DLU areas and the fossil energy land were scaled with equivalent factors to calculate the global areas of bioproductive space. These areas were aggregated to get the EF for case A and case B (Frey, 2002).

The ecological footprint of a mobile phone varied from 104 to 115 (m² phone⁻¹ yr) that is 7000 to 8000 times greater than its actual size. 94% of the EF was caused by carbon emissions of which 5-6% were attributed to transport. The remaining 6% were caused by direct land use mainly due to mining operations (Frey, 2002).

With regard to **the fair Earth share, the case A had a share on 0.60% and case B a share of 0.55%**. A fair Earth share is the amount of land each person would get if all the ecologically productive land on Earth were divided evenly among the present world population. In both the cases, a mobile phone requires less than 1% of available bioproductive capacity per capita. The fair Earth share was calculated by dividing the ecological footprint with the existing global bioproductive capacity of 1.89 ha/ca (Frey, 2002).

3.2.1 Nokia's Experience with EFA

Nokia has participated in the only ecological footprint studies of mobile phones in the industry. At present EFA does not provide a good method for use in the electronics industry. The experiences of Nokia with EFA are mentioned in the following table:

Table 3-3: Limitations and benefits of using EFA

Limitations of EFA	Benefits of EFA
<ul style="list-style-type: none"> - As EFA extends further to an LCA and converts impact categories to bioproductive areas, all the limitations of LCA are applicable to it. - The time and assumptions required to conduct an EFA is even more than an LCA. - Effects of pollutants on bioproductivity are not very well understood. - EFA is a relatively new tool that has not been used by the electronics industry. The only EFA study in this field is (Frey, 2002). Thus, the results of EFA cannot be verified. - The main risk in using an undeveloped tool like EFA is that it can lead to significant misinterpretations (external peer review could be the best way to counter this). 	<ul style="list-style-type: none"> - The ecological footprint is a new indicator which looks at the impacts from a different perspective based on available productive 'earth space'. - The indicator is easy to visualise for a non-expert, (although non-experts still need to understand the basic methodology behind the EFA concept and the units of expression used).

3.3 Material Input per Service Unit (MIPS)

“To estimate the input orientated impact on the environment caused by the manufacture or services of a product, MIPS indicate the quantity of resources used for this product or service. MIPS calculates the use of resources from the point of their extraction from nature: all data corresponds to the amount of moved tons in nature, thus to the categories of biotic or renewable raw material, abiotic or non renewable raw material, water, air and earth movement in agriculture and silviculture (incl. erosion). All material consumption during manufacture, use and recycling or disposal is calculated back to resource consumption” (Riffhoff, Rohn, & Liedtke, 2002).

As a part of Nokia’s effort to find a suitable method for assessing the environmental impacts of its products, Nokia participated in the Factor X project in addition to several other companies. In this project MIPS method was used to assess life cycle environmental performance of several different products like balconies made of stainless steel and shirts made of polyester and cotton. The Nokia case was a mobile phone for which the material composition data was available. The Material Input (MI) indicators required for the MIPS evaluation only existed for about one fifth of the materials in the mobile phone. Thus the assessment could not be carried out in a reliable manner. If only a few of the needed MI indicators were missing some approximations could have been made, but in the case of a mobile phone there were far too many data gaps (Autio & Lettenmeier, 2002).

3.3.1 Nokia’s Experience with MIPS

Nokia has tried MIPS for assessing the environmental performance of a mobile phone as well as a base station. Due to the limitations mentioned in the following table it is currently difficult to use MIPS in this sector.

Table 3-4: Limitations and benefits of MIPS

Limitations of MIPS	Benefits of MIPS
<ul style="list-style-type: none"> – MIPS database did not have any data for approximately 80% of the materials used in a mobile phone. – If the data is not available in the MIPS database then it is virtually impossible to identify the hidden material flows of different materials and components in the phone. – The conceptual problem with MIPS is that it gives an equal weightage to all the materials and does not differentiate them on their properties like toxicity. – Calculating MIPS is a time-consuming process and the method cannot be used within the product development timeframe. 	<ul style="list-style-type: none"> – MIPS provides a simple indicator to assess the environmental performance of products if all data on material inputs is available.

3.4 Key Environmental Performance Indicators (KEPIs)

KEPIs are a small number of product environmental performance indicators validated as representative of the most important environmental impacts of an electronic product's life cycle. The KEPIs study was jointly commissioned by Motorola, Nokia, Panasonic and Philips and carried by Pranshu Singhal. This section provides a brief summary of the results from this study.

The main objective of this study was to develop a new simple method for assessing life cycle environmental performance of the electronic products and in particular mobile phones considering the limitations¹⁵ of using LCAs. KEPIs, developed in this study, account the physical and chemical characteristics of the components of product and are based on the results of life cycle assessments conducted by participating mobile phone manufacturers (Singhal et al., 2004). KEPIs are easy to use, and require little time and data. This method significantly reduces the reliance on the supply chain for data on material flows and allows the manufacturers to easily assess the relative environmental performance of their products.

The approach followed for developing KEPIs included detailed analyses of LCAs conducted by the participating companies in order to identify the components and materials that account for most of the environmental impacts. The LCA indicators on primary energy consumption, global warming potential, acidification potential, ozone depletion potential, photochemical oxidant creation potential, human toxicity potential, resource depletion potential and air pollution were analysed. GDA tool¹⁶ of Motorola was used to identify the materials that account for the embedded toxicity of the phone. The main assumption in development approach was that though the LCAs may not give accurate results, they rightly point out where the majority of impacts emerge from (Singhal et al., 2004).

The main results from the analyses of LCA indicators were:

¹⁵ For limitations on using LCA for mobile phones see section 3.1.4

¹⁶ For more information on GDA tool of Motorola see <http://www.motorola.com/EHS/environment/products/>

- The production¹⁷ and the use phase are the most important phases in the life of a mobile phone.
- In the use phase, the standby power consumption of the charger accounts for a major portion of the environmental impacts.
- The recovery of metals, especially precious, is crucial to have positive environmental impacts from EoL phase. The recovery of plastics contributes very little to the positive environmental impacts from EoL phase.
- The environmentally relevant components in the phone, arranged in the order of relevance, are PWBs, ICs and LCD. Solder paste was also highlighted as important in one of the impact categories.
- Bromine compounds are responsible for most of the embedded toxicity of the phone and were followed by lead compounds.
- The air transport of components to the assembly plant accounts for most of impacts from the transportation phase.

The LCAs of PWBs, ICs, LCD and Solder paste were then analysed to identify the significant phases in the life cycle of these components. At the same time research was carried to link the environmental impacts of these components to their physical and chemical characteristics. Following are the results obtained from this work:

Printed Wiring Board (PWB):

- The raw material acquisition and manufacturing are the most significant phases in the life cycle of a PWB. The presence of gold in the finishes of PWB accounts for most of the impacts from the raw material acquisition phase. The energy consumption of the manufacturing processes accounts for most of the impacts from the manufacturing phase.
- The life cycle environmental impacts of a PWB are proportional to its surface area, number of layers, and amount of gold.

Integrated Circuit (IC):

- The raw material acquisition and manufacturing are the most significant phases in the life cycle of an IC. The presence of gold in the wires and substrate of the packaging accounts for most of the impacts from the raw material acquisition phase. The energy intensive wafer fabrication processes account for significant portion of impacts from the manufacturing phase.
- The life cycle environmental impacts of an IC are proportional to the area of fabricated die in the IC, the number of mask steps during the fabrication of the die and the amount of gold.

¹⁷ The raw material acquisition, component manufacture and product assembly were covered in the production phase.

Liquid Crystal Display (LCD):

- The manufacturing phase accounts for almost all the life cycle impacts of a LCD. The energy consumption during the manufacturing processes of LCD, accounts for most of the environmental impacts from this phase.
- The life cycle environmental impacts of LCD are proportional to its surface area.

Solder Paste:

- The raw material acquisition is the most important phase in the life cycle of a solder. The presence of metals like silver in the solder pastes accounts for most of the impacts from this phase.
- The life cycle environmental impacts of the solder paste are proportional to its quantity (by weight).

Based on these results, following indicators were proposed for assessment of a mobile phone (Singhal et al., 2004):

Table 3-5: Key Environmental Performance Indicators (KEPIs) for a mobile phone

Production Phase	Transportation Phase	Use Phase
<ul style="list-style-type: none"> - Amount of gold in a phone - Total area of PWB (Surface Area x No. of Layers) - Total areas of fabricated dies (with same number of mask steps) in ICs - Amount of bromine in the phone - Amount of solder paste in the phone - Area of the LCD - Amount of copper used in charger and its cables 	<ul style="list-style-type: none"> - Number of components in the phone 	<ul style="list-style-type: none"> - Standby power consumption of the charger

3.4.1 Discussion on KEPIs

KEPIs are a small number of product environmental performance indicators validated as representative of the most important environmental impacts of an electronic products life cycle. They provide a good and simple assessment tool for use in the electronics industry. A full blown LCA can be done after regular periods and the KEPIs revised based on the results obtained.

KEPIs could possibly be used for simple assessment in product design phase, but may be more usefully applied in component purchase decision-making. The scope for improving the KEPI results may be very limited in some areas because product is technically optimized according to market defined characteristics (e.g. size of LCD, type of ICs needed).

KEPIs, which have been very recently developed, have yet not been put in practical application at Nokia. Some of the limitations and benefits of KEPIs are mentioned in the following table.

Table 3-6: Limitations and benefits of KEPIs

Limitations of KEPIs	Benefits of KEPIs
<ul style="list-style-type: none"> – The weaknesses of LCAs are inherent in KEPIs. – KEPIs do not always replace detailed studies, in particular if detail assessments are required for new technology or new process. – Peer review body and agreed timescale for periodic re-validation of KEPIs is required. 	<ul style="list-style-type: none"> – KEPIs provide a simple approach for conducting environmental assessments. – They are easy to communicate internally in a company. – They are easy to use by non-experts and are easily understood by product designers. – The KEPIs can be used to compare different mobile phones and their components. – They can be used during product development time scale.

3.5 Materials of Concern in a Mobile Phone

This section of the report addresses the material environmental, health and safety concerns that are associated with the various life cycle phases of a mobile phone. A mobile phone contains small amounts of some materials that are of concern. These materials do not present environmental or human health hazards during the intended use phase but they might be released in the environment from landfills, incinerators and recycling facilities if the EoL treatment is not carried out properly. As the materials health and safety concerns are mostly related to the improper management during EoL they are of special concern in countries that lack proper recycling infrastructure and where there is little awareness on EoL management. Following are the materials of concern in the case of a mobile phone:

- **Antimony:** Antimony trioxide is used as a flame-retardant in PWB and mouldings of some components of mobile phones.
- **Arsenic:** Arsenic is used in the manufacture of gallium arsenide semiconductors, as a dopant in silicon wafers, and to manufacture arsine gas used to make integrated circuits. A mobile phone may contain a minute amount of gallium arsenide in transistors and chips. The total amount of gallium arsenide is less than 1 mg in a mobile phone (MPPI, 2004).
- **Beryllium:** A mobile phone may contain beryllium in an alloy with copper or other metals. A copper-beryllium alloy is generally used in the connectors of a phone. A mobile phone contains approximately 3 mg of beryllium or about 40 parts per million (ppm). Beryllium may be released as fine particulate matter during the smelting process for the recovery of metals in EoL. The Beryllium dust exposure of workers may be controlled by proper containment and Local Exhaust Ventilation (LEV) in combination with strict administrative control measures. Some smelters have also established an incoming feedstock beryllium limit of 200 ppm (for solids) and 50 ppm for (pre)crushed feedstock, which is higher than the amounts of Beryllium in typical mobile phones (MPPI, 2004).

- **Brominated and Chlorinated Flame-retardants:** Brominated and chlorinated flame-retardants are used in the epoxy resins of PWB and component mouldings in mobile phones. The brominated and chlorinated flame-retardants are of concern in the manufacturing and EoL phases. In the EoL process there is a possibility of formation of dioxins and furans during the smelting process in the recycling plants or during uncontrolled incineration.
- **Cadmium:** Cadmium was earlier used in the nickel-cadmium batteries for mobile phones, and in small quantities in some electrical components. Nickel-cadmium batteries are no longer used in mobile phones though some old phones may still have these batteries. Cadmium is one of the six substances restricted from use, in new Electrical and Electronic Equipment (EEE) put on the market from 1 July 2006, by the EU's RoHS directive.
- **Hexavalent Chromium:** The chromic passivation process of magnesium and aluminium parts, as well as electrolytic zinc layers, is based on chromic acid, which contains hexavalent chromium. In the process, chromic acid reacts with the base material to create a protective/conductive layer of different kind of oxides and other chromium compounds. Very small amounts of hexavalent form of chromium ion may remain in between the lattices of the final plating structure. During the product life cycle, even this small amount of hexavalent chromium turns into chromic oxide and thus there is practically no hexavalent chromium left in the phone at its EoL.
- **Lead:** Main use of lead is in the tin-lead solder paste that is used to make the solid, conductive bonds between the components and the PWB in a mobile phone. The RoHS Directive restricts the use of lead in EEE. Most of the mobile phone manufacturers have already phased out the use of lead-containing solder in mobile phones.
- **Mercury:** A small amount of mercury is used in fluorescent tubes that may be used to illuminate displays of mobile devices.
- **Nickel:** Nickel is a common alloying element of steel used in mobile phones. A mobile phone may also contain nickel if it has a nickel-cadmium or a nickel-metal hydride battery. In addition, nickel plating may be used both on metal and plastic parts. The main property of concern with nickel is its sensitization potential when the metal is in direct and prolonged skin contact. Also nickel dust generated during the smelting process in the recycling plants may cause exposure to nickel unless properly controlled.
- **Poly Vinyl Chloride (PVC):** PVC is a synthetic polymer material with chlorine content of 57% w/w in the homopolymer. Homopolymeric PVC a rigid inflexible material, which is not used in mobile phones. The properties of PVC are modified by adding stabilisers (e.g. Cd, Pb) and other additives (phthalates, brominated and chlorinated compounds), which make it soft, flexible and improve its flame retardancy. PVC is used mainly in cables of mobile accessories and chargers. There are health hazards, caused by possible exposure to Vinyl Chloride Monomer (VCM), associated with PVC production and environmental issues at EoL, where dioxin and furan emissions can be generated from uncontrolled incineration. Stabilizers and additives may leach from PVC in landfills if the EoL treatment is not managed properly.

- **Polycyclic Aromatic Hydrocarbon (PAH):** The displays of mobile phones contain liquid crystals, which are a solid form of PAH. Parts of the PAHs may be released during uncontrolled incineration of the Liquid Crystal Display (LCD).

These materials do not pose major environmental threats because of their reasonably low concentration values in a mobile phone. Moreover, many of these substances have either been phased out or are in the phase out process.

3.6 A Brief Proportionality Analysis of Impacts of A Mobile Phone

In this section, the total environmental impacts of a 3G mobile phone and a 3G system¹⁸ are compared to environmental impacts from use of some other products to provide readers with a relative idea. The results from LCA of a 3G mobile phone by Nokia¹⁹ and a LCA of 3G System by Ericsson²⁰ are used to make the comparisons.

According to the LCA of the 3G phone, the total carbon dioxide (CO₂) emissions from the life cycle of a mobile phone are 13.2 kg in the case of light user scenario and 14.18 kg in the case of heavy user scenario. This study considers a lifetime of 2 years for a phone. The LCA of the 3G System reports 55 kg of CO₂ emissions per subscriber and year.

Comparison with car kilometers (kms) and amount of gasoline in litres (lts): The calculations are made using a reasonable range of emissions - 145–220 g of CO₂ / km of car driven and total CO₂ emissions of 2.7kg/lt of gasoline (Fortum, 2002).

- The total CO₂ emissions from the life cycle of a 3G mobile phone are equivalent to the emissions from **driving a car for 65–95 kms** or to **4-6 lts of gasoline**.
- The emissions of 55 kg of CO₂ per subscriber and year for a 3G system are equivalent to the emissions from **driving a car for 250-380 kms** or to **19-21 lts of gasoline**.

Comparison with a 750 gm food packet of cheese cream potato gratin: The total carbon emissions from all the life cycle phases of a food packet of cheese cream potato gratin, including cooking it in oven for an hour before eating, are estimated at 2.9 kg of CO₂ /packet (Katajajuuri, 2003).

- The emissions from the life cycle of a 3G mobile phone are equivalent to the emissions from **5 packets of cheese cream potato gratin**.
- The emissions of 55 kg of CO₂ per subscriber and year for a 3G system are equivalent to the emissions from **19 packets of cheese cream potato gratin**.

¹⁸ The 3G system consists of 3G mobile phones, a radio network with radio base stations and radio network control equipment, and a core network with switches, routers, servers and workstations.

¹⁹ See section 3.1.1 and appendix C for details of this LCA by Nokia.

²⁰ See section 3.1.3 for details of this LCA by Ericsson. The details of this LCA are also available at www.ericsson.com/sustainability/pdf/Ericsson_3G_LCA_study.pdf

3.7 Summary on the Environmental Hot-Spots of a Mobile Phone

This section provides a summary of the environmental hotspots of a mobile phone. The summary is based on the findings of different assessments conducted by Nokia and the stakeholders.

- Regardless of the method used, the use phase and components manufacture phase are the biggest contributors to the life cycle environmental impacts.
- The most important environmental issue for a mobile phone is energy consumption during various life cycle phases.
- In the use phase the standby power consumption of the charger accounts for majority of the environmental impacts.
- In the components manufacture phase, the energy consumption of the manufacturing processes accounts for the major portion of environmental impacts.
- The PWB, ICs and LCD are the components with the highest environmental impacts in the life of a mobile phone.
- In the transportation phase the airfreight accounts for almost all the environmental impacts.
- Collection and proper management of the mobile phones at the end of their life is crucial to have positive environmental impacts from EoL phase and to prevent any material and substance dispersions to the environment. The positive environmental impacts in the EoL phase arise from the recovery of metals, especially precious ones.
- From the perspective of a mobile system, the energy consumption of radio base stations during the use phase is most significant.

To improve the environmental performance of the whole system it is required that everyone in the value chain takes full responsibility of the activities in the life cycle phases that are under their control. The stakeholders in the system also need to work in cooperations to manage environmental issues of common concern like development of simple tools for environmental assessments and share their experiences and best practices.

4. Nokia's Environmental Activities

The chapter highlights the main environmental practices and programs of Nokia to provide the stakeholders with a basic understanding of Nokia's environmental work. This information may be useful for the stakeholders in the Stage II of this IPP pilot project when they suggest improvement options.

4.1 Programs and Practices

Nokia's environmental work is based on life cycle thinking. The goal is to reduce adverse environmental effects throughout the value chain (product life cycle) by environmental management of own operations, systematic supplier management, integration of design for environment into product and technology development, and sound end-of-life practices.

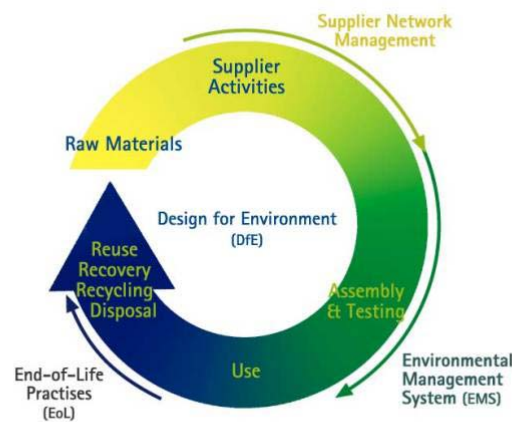


Figure 4-1: Life cycle thinking approach at Nokia

A life cycle approach highlights the main areas of environmental impact, which may have previously been hidden upstream in the supply chain or downstream at product use or disposal.

4.1.1 Design for Environment (DfE)

Nokia puts a great emphasis on the product development phase, as it tends to have the greatest possibilities for reducing the life cycle environmental impacts. For Nokia DfE means integrating environmental considerations systematically into the development of all products, processes and services. Nokia's DfE activities are firmly based on life-cycle thinking and aim at satisfying the requirements of customers and other stakeholders in ways that have less environmental impacts. DfE involves design procedures that minimize material and energy consumption while maximizing the possibility for reuse and recycling. By knowing exactly what materials are used in the products any dispersion of potentially hazardous substances can also be avoided. Nokia's work in DfE is currently focused in the following areas:

- **Increasing the energy efficiency of products.** Nokia is continuously working to reduce the energy consumption of its products. In this regard, Nokia has also signed the **European Union's voluntary Code of Conduct on Efficiency of External Power Supplies** (European Commission, 2004) and is committed to achieving a significant reduction in the non-load power supplies over the next few years.

- **Clarifying the content of products, including the quantity and type of materials used:** A detailed knowledge of the component composition is helpful in designing products and manufacturing processes and in handling the manufacturing waste and used products at the end-of-life. Most components, for example, are inert and perfectly harmless in normal use, but some may have to be given special consideration to enable proper EoL treatment.

Nokia is making continuous efforts to identify all the materials in the components of its phone and is working with its worldwide suppliers in this regard. The information on material contents helps Nokia to act proactively and systematically phase out materials that are identified to have adverse effects. Nokia is also working to standardise the process of materials declaration and is the main sponsor for the industry's joint initiative 'RosettaNet'²¹ to develop e-business tools for exchange of product information between producers and suppliers. Rosettanet will result in the integration of information about the material contents of the products with the business-related information.

- **Designing the products for efficient use, re-use, and recycling:** Nokia targets for efficient material use during the development of its products. Recyclability assessments are carried to evaluate the product material recyclability during the development phase. These assessments provide insights on how to change the design of the products during the initial development stages so that they are easily recyclable. Research is carried to identify suitable alternatives for the materials that have a significant adverse impact on the recycling of the products.
- **Preparing environmentally relevant information about Nokia products (see 4.1.8)**

4.1.2 Substance Management

The objective of substance management program at Nokia is to ensure substance and material safety of products and processes. Nokia has compiled a Nokia Substance List²² (NSL) based on regulatory requirements and reasonable facts. The list consists of substances that are banned, restricted or targeted for reduction. The Nokia substance list is divided into two categories:

1. **Restricted substances:** Substances that are banned or their use limited to certain applications in Nokia's products and packaging.
2. **Monitored substances:** Substances that Nokia expects to be reduced and phased out, either totally or in certain applications at some stage in the future. Suppliers using substances on the monitored list are strongly advised to investigate alternative solutions.

²¹ For more information on Rosettanet initiative see section 4.4.3 and <http://www.rosettanet.org>

²² See Nokia substance list at <http://www.nokia.com/nokia/0,6771,27566,00.html>

4.1.3 Supplier Network Management

The supply chain of Nokia represents a large part of the environmental and social impacts associated with the life cycle of products and services. The main objective of supplier network management program at Nokia is to ensure good environmental and ethical performance of the suppliers. Nokia requires its suppliers to be highly committed to improving environmental performance, ethical conduct and full compliance of applicable legislation, and is actively promoting the good practices among them.

Nokia has a common set of global Nokia supplier requirements²³, which are applicable to all Nokia suppliers, direct and indirect. These requirements include environmental requirements and ethical considerations for labour conditions. The Nokia requirements are communicated to the suppliers through personal contact and if required through training. Nokia's suppliers are also able to see all supplier requirements and their latest updates through a Nokia-Supplier web-based tool. Nokia assists the supplier in meeting its requirements by providing training and advice if required by the supplier. The suppliers are audited by Nokia to ensure that they have an in-depth understanding of Nokia's environmental requirements and also to assess their compliance levels with these requirements.

Nokia is also working to improve dialogue with suppliers and other stakeholders regarding environmental and social responsibility issues. Recently a workshop on corporate responsibility issues and the supply chain was conducted with the aim of bringing together different tiers of the supply chain and discuss the main ingredients and challenges to achieving good performance in issues such as labour conditions, throughout the value chain.

4.1.4 Logistics Management

The Nokia supplier requirements are applicable to its logistics service providers. Nokia is working with its logistics providers to establish reliable and comparable data on emissions associated with the logistics. These providers have communicated to Nokia that they are monitoring and reducing their emissions on a continuous basis. It is a normal business practice at Nokia to transport the phones to their markets from the nearest assembly plants.

4.1.5 Environment Management at Nokia Sites

To manage the environmental impacts arising from its own operations, Nokia has implemented certified EMS in accordance with ISO 14001 at all its production sites. Nokia's main goals in an EMS are decreasing energy consumption and improving waste management, combined with employee training to raise the general awareness level and gain employee involvement. To facilitate the communication of good practices the production facilities are practicing internal environmental performance benchmarking. The EMS approach at Nokia has also been extended to cover large offices and other non-production facilities.

4.1.6 Environmentally Conscious Packaging

Transportation of components from suppliers to assembly sites: Nokia cooperates with its suppliers to develop the incoming component transport packaging. The development focuses on reuse, material use and packing density to ensure eco-efficient component transport packaging.

²³ See Nokia Supplier Requirements at <http://www.nokia.com/nokia/0,6771,27570,00.html>

Fibre based packages that are lighter in weight and have low raw-material consumption have been taken into use for selected enhancement components. These packages are mainly made of recycled paperboard and are disposable into the recycling stream. Nokia is working on re-designing mechanical component packaging trays so that the components can be packed even more dense and the sizing is modular to fit standardised pallet sizes in international transportation. The component packaging trays used for transporting the components are reused between the suppliers and Nokia.

Transportation of phones from assembly plants to retailers: Nokia uses recyclable materials, mainly fibre-based or plastics, in its product packages. In the design phase of packaging much emphasis is put on material selection. The amount of recycled fibres used in packages varies from region to region based on the availability of materials and the market demand. In certain markets there is a demand for plastic packaging as the product becomes visible and appears attractive to the customer. To meet this demand, Nokia has been carrying out a pilot on use of biopolymers that have aesthetic properties of plastics but are biodegradable. Nokia has also developed alternative packaging designs and technologies along with its customers enabling PVC-free alternatives in package materials.

4.1.7 Communications

Nokia has a communications program to manage its relations with internal and external stakeholders. Continuous communications and consultations are an integral part of this program.

Internal Communications: Nokia communicates with its employees on environmental issues mainly through its intranet. Two global events, and several regional events for sharing information and promoting discussions between employees on environmental issues are organized annually. The environmental issues are also discussed in the global in-house magazine, global environmental e-magazine, monthly newsletters and several other internal publications.

External Communications: Nokia reports its environmental activities to its stakeholders mainly through its Internet site and Corporate Environmental Reports²⁴ (CERs). The CERs are developed every second year and are available online. Nokia's environmental activities are also highlighted in its Corporate Social Responsibility (CSR) report²⁵. Nokia also disseminates environmental information by participating in seminars and workshops, and giving presentations and interviews to its stakeholders.

4.1.8 Information for Consumers

Nokia is committed to providing consumers with the information they need to make informed and environmentally responsible choices.

Eco-Declarations: Nokia provides environmental information about its products through eco-declarations²⁶ on its website. Eco-declarations provide information on energy consumption, material use, packaging and documentation, battery and chargers, and

²⁴ See Nokia Environmental Reports at <http://www.nokia.com/nokia/0,6771,27464,00.html>

²⁵ See Nokia CSR report at <http://www.nokia.com/aboutnokia/downloads/archive/pdf/eng/CRR2003EN.pdf>

²⁶ See Eco-declarations for Nokia's products at <http://www.nokia.com/nokia/0,8764,49988,00.html>

disassembly and recycling issues. Nokia mobile phones' eco-declarations are based on the most widely accepted international ECMA-TR/70 standard template.

Mobile Phone Take-back: Nokia has established Mobile Phone Take-Back programs for the collection of mobile phones at the end of their service life, so that materials and energy can be recovered and harmful substances properly disposed of. Nokia assists the consumers with up-to-date, local information about where to return used phone and accessories when it is time to trade it in for a newer model. A recycling map²⁷ that suggests the nearest sites where the consumers can dispose their old phones is available on Nokia's website.

4.1.9 End-of-life

Nokia's aim is to provide an environmentally sustainable solution for end-of-life handling of its obsolete products. The EoL practices at Nokia are aimed at collection of equipment at the end of service life with the view of recovering their material and energy content and ensuring safe treatment of substances that may cause harm to environment or people if incorrectly treated or disposed of. The EoL work includes:

- Maximizing the recyclability of products through DfE and actively reducing the use of substances of concern in the products during the design phase.
- Supporting separate collection of WEEE and monitoring, comparing, and developing take-back and recycling systems in cooperation with recyclers and other stakeholders to ensure proper treatment of harmful substances
- Encouraging consumers to share the responsibility
- Ensuring responsible handling and maximum recycling

At Nokia's website consumers can find information on the nearest Nokia collection point for disposing their used Nokia product so that it can be treated and recycled properly. The consumers can also return their unwanted Nokia products at all the Nokia concept stores and service points, industry schemes take back points, and municipal collection points. In the phone manuals provided in the sales package, there are instructions on how to use mobile phone batteries economically, as well as information on recycling. To ensure the proper treatment of the materials in the phone Nokia has formulated a criterion for its approved EoL service providers.

4.2 Activities to Eliminate Materials of concern

Nokia aims to eliminate the use of materials of concern from its products. Nokia is working on phase out of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls²⁸ and polybrominated diphenylethers²⁹ from its products. Studies are also being carried at Nokia to phase out PVC and phthalates, and the use of all Bromine (Br), Chlorine (Cl) and Antimony Trioxide (Sb₂O₃) based flame-retardants.

²⁷ See Nokia Recycling Map at <http://www.nokia.com/nokia/0,8764,49675,00.html>

²⁸ Polybrominated biphenyls have already been phased out from Nokia products.

²⁹ Polybrominated diphenylethers have already been phased out from Nokia products.

4.3 Initiatives to Develop New Environmental Assessment Tools

Nokia is partnering with other companies and research institutes in different cooperation projects to ensure that all the limitations mentioned earlier are taken into consideration and the current environmental assessment procedures improved. Nokia has been actively looking for assessment methods by which it can gain a better understanding of the life cycle environmental impacts. Nokia had recently convened a workshop with eminent LCA experts in this regard. A brief description of the main co-operations in which Nokia is presently involved to develop assessment tools follows:

1. **ImPACT:** Nokia is carrying an initiative with the University of Helsinki for developing ImPACT method, which could serve as an alternative to MIPS and plug the gaps present in MIPS. Nokia is planning on participating in the study, and has actively contributed in the development of the project plan, but the actual project is yet to start. The idea is to develop some new indicators that could be used to evaluate the environmental importance of different phases in the life cycles of the products in question.
2. **NorLCA:** Nokia is actively participating the founding and development of Nordic Life Cycle Association which has the purpose of acting as a non-profit multidisciplinary organisation furthering use and, when needed development and improvement of the life cycle disciplines. In this context life cycle disciplines comprise concepts and tools like life cycle thinking, life cycle design, life cycle costs, life cycle assessment, product oriented management, integrated product policy etc. The overall and long-term goal is to support and push the life cycle disciplines on all levels into the authority, education and enterprise culture within the Nordic countries.

4.4 Sectoral Environmental Initiatives

4.4.1 Mobile Phone Partnership Initiative (MPPI), Basel Convention, UNEP

Nokia is cooperating with other phone manufacturers and stakeholders in the MPPI under the aegis of the UN Basel Convention. The initiative³⁰ requires cooperation between the phone manufacturers, UN bodies, network providers, operators and recyclers. The aim of the MPPI is to promote the objectives of the Basel Convention in the area of environmentally sound management of end-of-life mobile phones. Under the MPPI a Mobile Phone Working Group (MPWG) was established which is working on four specific projects (MPPI, 2004):

Project 1: Reuse of Used Mobile Phones.

Project 2: Collection and Transboundary Movement of Used Mobile Phones.

Project 3: Recovery and Recycling of End-Of-Life Mobile Phones.

Project 4: Awareness Raising and Training.

³⁰ For more information on Mobile Phone Partnership Initiative see <http://www.basel.int/industry/index.html>.

4.4.2 Global e-Sustainability Initiative (GeSI), UNEP

Nokia has joined the Supply Chain Working Group (SCWG) under the Global e-Sustainability Initiative (GeSI) of UNEP. “The GeSI supply chain working group explores ways in which ICT sector companies can work more closely together to more effectively manage social and environmental risks in their supply chains. The initial focus is to align the various Codes and Policies already used by member companies to manage their supply chain issue” (GeSI, 2004).

4.4.3 RosettaNet

It is a challenging task for the electronics industry to gather data on the material composition of products/components. This task, driven by legislation, increasing customer and market requirements and a company’s own will to achieve design improvements, practically means heavy and unnecessary burden for the suppliers. It is crucial to find solutions that allow the industry to standardise data gathering on certain materials and substances that are present in electrical and electronic equipment at greatly reduced costs, whilst substantially reducing the reporting burden on suppliers.

Nokia together with a number of ICT companies³¹ initiated Material Composition program in RosettaNet organization in order to develop a standardized approach for information exchange. RosettaNet, a subsidiary of the Uniform Code Council Inc., is a consortium of more than 400 leading Electronic Components (EC), Information Technology (IT) and Semiconductor Manufacturing (SM) companies.

The goal of RosettaNet is to develop a solution (or more precisely RosettaNet PIP – specifications) for material composition exchange and make information exchange as an integral part of normal information delivery between business partners. This will be realised through a common structured materials declaration solution to support the supply chain. The key advantages of RosettaNet approach compared to traditional methods (e.g. Microsoft Excel-sheets, papers) are (Mäkirintala, 2003):

- **Integrated approach:** Companies have a clear opportunity to integrate material composition to normal business processes. For example Nokia’s goal is to get material composition as a part of component (product) technical information and related business processes. This information can then be stored in Nokia’s backend systems in a way similar to other product information. All relevant persons in Nokia can then utilize this information when making e.g. design or purchasing decisions.
- **Speed:** Traditional excel-based solutions, let alone paper-based solutions, are inefficient in terms of speed and needed related efforts. Furthermore, if these efforts are not standardized then any kind of automation is very difficult to implement. RosettaNet solution provides standardized interface. A company needs to develop a link between RosettaNet gateway and backend system. Then all message creation can be done automatically and human effort can be directed to actual material composition problem instead of tool problems.
- **Standardization:** RosettaNet is currently the most recognized e-business process standard using also standard Internet protocols. It provides an excellent framework for a sophisticated material composition solution.

³¹ List of participating companies can be found from www.rosettanel.org

Furthermore, it is also hoped that the development of such a standard will benefit both producers and suppliers who adopt a common protocol, which is accepted by major players in the electrical and electronic goods industry. It is envisaged that it will greatly reduce duplication of effort and facilitate the flow of information both up and down the supply chain. Nokia has taken an active role to drive the adoption of RosettaNet as a defacto standard in electronics and telecom industry supply chain integration³² (Mäkirintala, 2003).

4.5 Other Environmental Cooperations

4.5.1 Cooperation with World Wide Fund for Nature

Nokia and WWF have signed a three-year global cooperation agreement. Under this agreement Nokia and WWF are working on a 'Learning Initiative' to increase environmental awareness among Nokia's employees and promote dialogue with shared external stakeholders.

Employee engagement activities include an innovative and interactive environmental intranet site as well as a series of internal workshops and seminars. Stakeholder engagement activities to date have involved NGOs, the academic world, customers and authorities through seminars, and web based programs to facilitate active dialogue and exchange on general environmental issues as well as those more specifically related to Nokia's business.

4.5.2 Universities and Research Institutions

Nokia has conducted several research projects with Universities/Institutions for identifying ways by which it can enhance its environmental performance. Some of these projects are:

- Behavioural research into the impact of the mobile phone communications on society.
- “ADSM - Active disassembly using smart materials ” EU 5th framework project led by Brunel University.
- Nokia Research Center and Tomra Systems together with the Helsinki University of technology and the University of Art and Design in Helsinki developed a prototype machine to collect and pre-separate the end-of-life phones to enhance collection rates during end-of-life phase.
- Nokia Research Centre, the Helsinki University of Technology, the Finnish School of Watchmaking and the University of Art and Design Helsinki have developed prototypes for the disassembly of mobile phones by means of heat-activated and magnet activated mechanism involving no contact.

4.5.3 Industry Associations

4.5.3.1 European Industry Association for Information Systems, Communications and Consumer Electronics (EICTA)

Nokia is cooperating together with other mobile phone manufacturers in EICTA³³. EICTA has one of its four policy groups dedicated to environmental policy, and teams dedicated to

³² For more information on Rosettanet initiative see <http://www.rosettanet.org>

³³ For more information see <http://www.eicta.org>

eco-design, waste and chemicals under its sub-groups. EICTA closely follows EU legislation and policy making.

4.5.3.2 Electronics Industry Alliance (EIA), USA

The EIA is a national trade organization that includes the full spectrum of U.S. electronics manufacturers. The EIA comprises more than 2 500 member companies whose products and services range from the smallest electronic components to the most complex systems used by defense, space and industry, including the full range of consumer electronic products. The Environmental Issues Council (EIC) leads the electronics industry in addressing national and international environmental policies surrounding electronic products. Nokia participates in the EIC.

4.5.3.3 Cellular Telecommunications Industry Association (CTIA), USA

CTIA is an U.S. trade association for mobile operators and manufacturers. Nokia is actively involved in the Environmental Working Group of CTIA, which drafted the CTIA Environmental Principles and guidelines on end-of-life treatment of cell phones³⁴. CTIA tends to be more focused on state and Federal U.S. legislative and regulatory issues, but is getting increasingly involved in international issues.

4.5.3.4 National Electronics Product Stewardship Initiative (NEPSI), USA

The NEPSI group's main goal for the dialogue is the "development of a system, which includes a viable financing mechanism, to maximize the collection, reuse, and recycling of used electronics, while considering appropriate incentives to design products that facilitate source reduction, reuse and recycling; reduce toxicity; and increase recycled content". Nokia is one of the participating stakeholders in the NEPSI dialogue.

³⁴For more information see <http://www.recyclewirelessphones.org>

5. Conclusions and Outlook

This report serves as a guidance document on the environmental issues in the life cycle of a mobile phone and shares the findings of the assessments conducted by Nokia and the stakeholders for assessing the life cycle environmental impacts of a mobile phone. It also discusses Nokia's experiences with different environmental assessment tools, and its environmental initiatives.

The life cycle of a mobile phone is quite similar to that of other electronic products such as PCs. Based on the results of several studies conducted by Nokia and the stakeholders, components manufacture phase and use phase are the most significant in life cycle of a mobile phone. The most important life cycle issue for a mobile phone is energy consumption. In the use phase, the standby power consumption of the charger accounts for a major portion of energy consumption. In the components manufacture phase, the energy consumption of the manufacturing processes accounts for the major portion of environmental impacts. The PWB, ICs and LCD are the components with the highest environmental impacts in the life of a mobile phone.

The collection and proper management of mobile phones (and accessories) and recovery of precious metals during waste treatment is crucial to have positive environmental impacts from end-of-life phase and also to prevent any material and substance dispersions to the environment. If the whole mobile system is considered, then the environmental impacts from the energy consumption of the radio base stations during the use phase is most significant.

The total CO₂ emissions, which are closely linked to total energy consumption, from the life cycle of a 3G mobile phone are equivalent to the emissions from driving a car for 65–95 kms or to 4-6 lts of gasoline. The CO₂ emissions per subscriber and year for a 3G system³⁵ are equivalent to the emissions from driving a car for 250-380 kms or to 19-21 lts of gasoline.

Nokia considers environmental impacts from a product life cycle perspective and has tried several approaches for conducting environmental assessments. As discussed in this report, full LCA, EFA and MIPS are today not appropriate for application in the product development cycles of mobile phones. Since the methodologies and available data for conducting these assessments are constantly developing, it is important for a company such as Nokia to be actively involved in methodology development and common industry efforts to collect and publish data where practicable. Nokia together with other companies is voluntarily working to develop suitable methods for environmental assessments of electronic products, an example of this being the KEPIs. KEPIs, a small number of product environmental performance indicators validated as representative of the most important environmental impacts of an electronic products life cycle, may provide a good and simple assessment tool for use in the electronics industry. A full LCA can be done after regular periods and the KEPIs revised based on the results obtained.

To address the environmental issues in all the life cycle phases of a mobile phone, it is imperative that everyone in the value chain takes full responsibility of the activities under their control. The stakeholders in the system also need to work in cooperations to manage environmental issues of common concern and share experiences and best practices.

³⁵ The 3G system consists of 3G mobile phones, a radio network with radio base stations and radio network control equipment, and a core network with switches, routers, servers and workstations.

Partnership initiatives like RosettaNet, and MPPI under Basel Convention are the steps in this direction.

Since their introduction mobile phones have moved from being strict business products to being everyday convenience items. Over the years the consumer demands and technological innovations have led to the development of phones that are lighter, have longer operational times, and that can be used for multiple purposes. The energy consumption of the phone charger during the charging and standby modes has also reduced considerably. All these developments in the mobile phone industry have resulted in lowering of environmental load of a phone. The environmental improvements may continue to take place in the mobile phone industry in the future too as they are closely tied to the business critical issues and are in line with the technological development.

The next report in this IPP pilot project shall identify and document the improvement options that Nokia and the participating stakeholders can take to enhance the environmental performance of the mobile phones. The stakeholders can play a crucial role in almost all the life cycle phases and have responsibilities in the areas like disclosure of information on material contents of components, building environmental awareness among the consumers and other stakeholders, collection of used products and accessories, development of effective environmental legislation, industry cooperations and voluntary agreements, and identifying new roles for standardisation bodies.

The second report shall also provide an insight on the factors that affect the business decisions in the mobile phone industry. These factors may include customer requirements, technology development, legislative environment and other requirements that need to be considered in product development decisions.

Bibliography

- Antoine, P. (2003). Understanding the Mobile Phone Markets. *Alcatel Telecommunications Review - 4th Quarter 2003*.
- Autio, S., & Lettenmeier, M. (2002). *Ekotekokkuus - Business as Future*. Espoo: Yrityksen ekoteho-opas.
- European Commission. (2004). *Code of Conduct on Energy Efficiency of External Power Supplies - Version 2*.
- Fortum Oil & Gas. (2002). Ekotasetiedote (1.3.2002). eurobenssiini
- Frey, S. (2002). *Development of New Ecological Footprint Techniques Applicable to Consumer Electronics*. Brunel University, Middlesex.
- GaBi 3. (1998). *The Software System for Life Cycle Engineering*. Dettingen/Teck: IKP University of Stuttgart and PE Product Engineering GmbH.
- GeSI. (2004). *Supply Chain*. Retrieved 3 December, 2004, from <http://www.gesi.org/activ/representing.htm>
- Huisman, J. (2004). *QWERTY and Eco-Efficiency analysis on cellular phone treatment in Sweden*. Delft: Delft University of Technology.
- Katajajuuri, J.-M., Voutiainen, P., Tuhkanen, H.-R., Honkasalo, N. (2003). *Environmental Impacts of Kesäpöytä Cheese-Cream Potato Gratin and Pirkka Potato Flour*. Retrieved 11 January, 2005, from <http://www.mtt.fi/met/pdf/met34.pdf>
- Lindholm, M. E. (2003). *Towards Environmentally Conscious Product Design - a Comprehensive DfE Implementation in New Generation Cellular Phones*. IEEE, 251 - 254.
- Malmodin, J. (2004). *Summary of the study "Life Cycle Assessment of a Third Generation (3G) System at Ericsson"*. Retrieved 27 December, 2004, from www.ericsson.com/sustainability/pdf/Ericsson_3G_LCA_study.pdf
- Mäkirintala, O-P. (2003). *The New Challenge for the Industry: Material composition - integrated approach using Rosettanet*. Paper presented at the Recycling Electrical and Electronic Equipment 6, Leatherhead.
- Mclaren, J., & Piukkula, N. (2004). *Life Cycle Assessment of a 3rd Generation Nokia Handset*. Paper presented at the Electronics Goes Green 2004+, Berlin.
- MPPI. (2004). *Mobile Phone Partnership Initiative, project 3.1: Recovery and recycling of end-of-life mobile phones*. Retrieved 20 December, 2004, from www.basel.int/industry/
- Nokia. (2004). *About Nokia*. Retrieved 29 November, 2004, from www.nokia.com/nokia
- Piukkula, N. (2003). *Life Cycle Assessment of a Third Generation Imaging Mobile Phone*. Unpublished Master's, Tampere University of Technology, Tampere.

- Rees, W., & Wackernagel, M. (1996). Urban ecological footprints: Why cities cannot be sustainable - and why they are a key to sustainability. *Environmental Impact Assessment Review*, 223-248.
- Riffhoff, M., Rohn, H., & Liedtke, C. (2002). *Calculating MIPS - Resource productivity of products and services*. Retrieved 28 December, 2004, from http://www.wupperinst.org/Publikationen/Wuppertal_Spezial/ws27e.pdf
- Singhal, P., Ahonen, S., Rice, G., Stutz, M., Terho, M., & Wel, H. v. d. (2004). *Key Environmental Performance Indicators (KEPIs): A new approach to environmental assessment*. Paper presented at the Electronics Goes Green 2004+, Berlin.
- Stevens, A. (2003). *Is the WEEE Directive EcoEfficient?* Paper presented at the IEEE Symposium on Electronics and the Environment, Boston.
- Stutz, M., Emmenegger, M. F., Guggisberg, M., Witschi, R., & Otto, T. (2003). *Life Cycle Assessment of the Mobile Communication System UMTS: Towards Eco-Efficient Systems*.
- Todd, J. A., & Curran, M. A. (1999). *Streamlined Life Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup*. Retrieved 27 December, 2004, from <http://www.setac.org/files/lca.pdf>
- Wright, L. (1999). *Product Life Cycle Management, EngD Thesis*. University of Surrey, Guildford.

Abbreviations

AP	Acidification potential
CO ₂	Carbon Dioxide
CER	Corporate Environmental Report
CSR	Corporate Social Responsibility
CTIA	Cellular Telecommunications Industry Association
DfE	Design for Environment
DLU	Direct Land Use
EC	European Commission
EEE	Electrical and Electronic Equipment
EF	Ecological Footprint
EFA	Ecological Footprint Analysis
EIA	Electronics Industry Alliance
EICTA	European Industry Association for Information Systems, Communications and Consumer Electronics
EMS	Environmental Management System
EoL	End-of-Life
EU	European Union
GDA	Green Design Advisor
GeSI	Global e-Sustainability Initiative
GSM	Global System for Mobile Communications
GWP	Global Warming Potential
HTP	Human Toxicity Potential
ICs	Integrated Circuits
IT	Information Technology
IPCC	Intergovernmental Panel on Climate Change
IPP	Integrated Product Policy

ISO	International Organisation for Standardisation
KEPIs	Key Environmental Performance Indicators
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCI	Life Cycle Inventory
MI	Material Inputs
MIPS	Material Input Per Service Unit
MPPI	Mobile Phone Partnership Initiative
MPWG	Mobile Phone Working Group
NEPSI	National Electronics Product Stewardship Initiative
NSL	Nokia Substance List
NGOs	Non Governmental Organisations
ODP	Ozone Depleting Potential
PDA	Personal Digital Assistant
POCP	Photochemical Oxidation Creation Potential
PVC	Poly Vinyl Chloride
PWB	Printed Wiring Board
RoHS	EU directive on Restriction of Hazardous Substances
UMTS	Universal Mobile Telecommunications System
UNEP	United Nations Environment Programme
VCM	Vinyl Chloride Monomer
VOC	Volatile Organic Compound
WEEE	Waste Electrical and Electronic Equipment
WWF	World Wide Fund for Nature
3G	Third Generation

Appendix A: List of Stakeholders Participating in Nokia's IPP Pilot Project

Phone Manufacturers

- Motorola
- Panasonic

Components Manufacturers

- AMD
- Epson
- Intel

Network Operators

- France Telecom
- TeliaSonera
- Vodafone

Research and Policy Institution

- Finnish Environment Institute (SYKE), Finland

Government

- Department of Environment, Food and Rural Affairs (DEFRA), UK

NGO

- World Wide Fund for Nature (WWF)

Appendix B: Overview of Components in a Mobile Phone

A typical mobile phone consists of a variety of components. To give an idea about the complexity of the material balance, materials in some mechanical, electromechanical and electrical components are discussed below.

B.1 Mechanical parts

The main mechanical parts in a mobile phone are the covers. They are often made of polymeric material, ABS-PC blend (Acrylonitrile Butadiene Styrene- PolyCarbonate).

B.2 Electromechanical parts

B.2.1 Connectors

A mobile phone might include one to ten connectors of various types. The surface material at the connection part has often been Wolfram, Copper, Silver or Platinum. The typical connectors can consist of plastic housing with a Gold coated contact part of an alloy metal, such as Beryllium-Copper, Brass, Phosphorus-Bronze, etc.

B.2.2 Microphones and speakers

Microphones and loudspeakers are electromagnetic components. With a microphone, sound waves are transformed to electrical signals. Loudspeakers, on the other hand, transform electrical signals to sound waves. Both microphones and speakers contain electronic components like varistors and resistors in a plastic case. Materials are much alike the electronic component materials, but in addition there are also some magnetic materials.

B.2.3 LCD

Liquid crystal displays are among the most complex parts of the mobile phone. The liquid crystal material is a trade secret of the LCD producers and is not publicly disclosed. The main fractions in displays are the cover glass and metals. These two fractions make up about 50 percent of the total mass, of course, depending on display construction.

B.3 Electronic components

B.3.1 Passives

Passive components like resistors, capacitors, ferrites and coil inductors constitute more than a half of the components used in mobile phones. Passive components are used for transforming signals in electrical circuits. With resistors the current can be limited to needed level or electrical potential can be split at different ration. Conductors are used for storing electrical energy. Resistors often made on a ceramic core of e.g. Aluminum trioxide (Al_2O_3), the resistive material is either rounded around the core in a form of resistive thread or evaporated as a lacquer on the core, depending on the technology used. Capacitors consist of metal plates, which are separated from each other with an insulating material. This insulation material can be a plastic (polyester, polycarbonate, Teflon) or a ceramic material. Coils are often listed as the only types of real inductors. However, also other types of components may have inductive character. The basic coil construction is a core, usually made of a ferro-metallic material like Iron, Nickel, or Cobalt on which a copper coil is wounded.

B.3.2 Semiconductors

Semiconductors is a collective name for a large group of electronic components including diodes, transistors and integrated circuits, which are based on a semi-conducting material technology. A semiconductor is a material, which is neither a good a conductor nor a good insulator. The conductivity of semi-conducting materials is in practice enhanced by doping them with other materials.

The most important semiconductor materials in electronics are Silicon and Gallium Arsenide. Another semiconducting material is Germanium, but its use has decreased for the benefit of Silicon. Doping can be made with n-type materials, such as Antimony, Arsenic, Phosphorus or with p-type materials like Boron, Gallium or Indium.

Appendix C: Life Cycle Assessment of a Third Generation (3G) Mobile Phone by Nokia (2003)

This LCA study was conducted by Jake McLaren of Nokia and Niina Piukkula a student at Department of Environmental Technology, Tampere University of Technology in 2003. This recent assessment at Nokia was conducted in line with the guidelines set in ISO 14040 series.

C.1 Goal and Scope

C.1.1 Goal

The main objective of this assessment was to identify the key environmental impacts of a Nokia third generation mobile phone during its life cycle. The LCA was carried to identify the relevant life cycle stages, environmentally relevant materials and components in a 3G mobile phone.

C.1.2 Scope

C.1.2.1 Functional unit

The functional unit in this assessment was the use of a Nokia's third generation mobile phone, its battery and charger, with an average life time and average daily use time. This study considered the energy consumed by the phone and the charger during its use phase. The use phase of the phone had been taken as two years considering the current market trends. The phone has many of the latest features like bluetooth module and a camera and provides functionalities like SMS and MMS messaging, games, music and video playing. The solder paste used in the phone is lead-free and the battery is a lithium ion battery.

C.1.2.2 System boundaries

This assessment accounted the environmental aspects from the raw material extraction and processing, components manufacture, components transport from the first tier to assembly plants, phone assembly, transport of phone to the first customer and the use of the phone. The end-of-life phase was left out of the scope of this assessment due to the paucity of data. Moreover, previous LCA studies also show that the end-of-life phase is not as significant as other life cycle phases³⁶ (Stutz, Emmenegger, Guggisberg, Witschi, & Otto, 2003; Wright, 1999)

Component sales packaging, network infrastructure, operations of the mobile retailers were also left out of the scope of this assessment. No cut-off rules were applied and all the parts and materials were included. In this study it was assumed that the phone is assembled at Nokia's production site in Salo, Finland and used and charged in Europe. The transport steps before and to the first tier suppliers were not included unless they were in the GaBi Life Cycle Inventory (LCI). The transport steps that have been included are based on reasonable assumptions of freight origins and destinations. . This study used the German LCA tool GaBi v3.0 and GaBi LCI data to model all materials and electronic components.

³⁶ This statement holds true for all indicators other than human toxicity potential.

The LCA was modeled by using two different user profiles. The differences between these user profiles are shown in the following table. The average European electricity mix was used for the energy calculations.

Table C.1: User scenarios in the LCA

Light User Scenario	Heavy User Scenario
Moderate use of several phone features	Heavy use of all phone features
Battery discharge 95%	Battery discharge 100%
Minimal charging of 1.5 hrs in every 48 hrs	Charging of 10 hrs in every 24 hrs
Charger left on even after the completion of charging	Charger left on even after the completion of charging

C.2 Inventory Analysis

The phone consisted of approximately 500 components that were categorised into three groups namely electronics, electro-mechanics and mechanics, and accessories.

Table C.2: Categories of components

Main Groups	Categories of similar components in these groups
Electronics	Printed Wiring Boards (PWBs)
	Bluetooth Module
	Passive components (resistors, capacitors, inductors)
	ICs
	Other SMD components
Electro-Mechanics and Mechanics	Liquid Crystal display (LCD)
	Camera Module
	Acoustics (vibrator, microphone, earpiece and speaker)
	Antennas (GSM & WCDMA)
	Connectors
	Engine Shield Assembly
	Other Plastic Parts
	Paint
	Others (e.g. screws)
Components in addition to the Main body	Battery
	Charger

GaBi LCI consisted of data on materials and energy inputs and outputs for the electronics group. For the other groups data was collected from the material declaration forms that are used by Nokia for collecting information on the material contents of the components. Reasonable assumptions were made for the components and materials for which no data was available. The main inventory related issues were:

- The production processes were excluded for battery, LCD, camera, acoustic parts and the painting process.

- There were uncertainties associated with the integrated circuits (ICs) and engine assembly as the database had information only for older technology ICs.
- The PWB data was only available for a six-layered PWB, which had lesser number of layers than the actual PWB in the phone.
- The process data mainly excluded the plastic and metal processing.
- Only the materials that had a concentration greater than 0.7 g in electro-mechanics and mechanics, and accessories were modeled.

C.3 Impact Assessment and Interpretation

The environmental impacts of the phone were classified into aspects and impacts related categories. The aspects related category consisted of Primary Energy Consumption (PEC) and the impacts related category consisted of Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Acidification Potential (AP), Human Toxicity Potential (HTP) and Photochemical Oxidant Creation Potential (POCP).

C.3.1 Primary Energy Consumption (PEC)

The total primary energy consumption includes the energy consumption from both renewable and non-renewable sources in mega-joules (MJ) during the life of a mobile phone. The following figure³⁷ illustrates the life cycle energy consumption of the mobile phone.

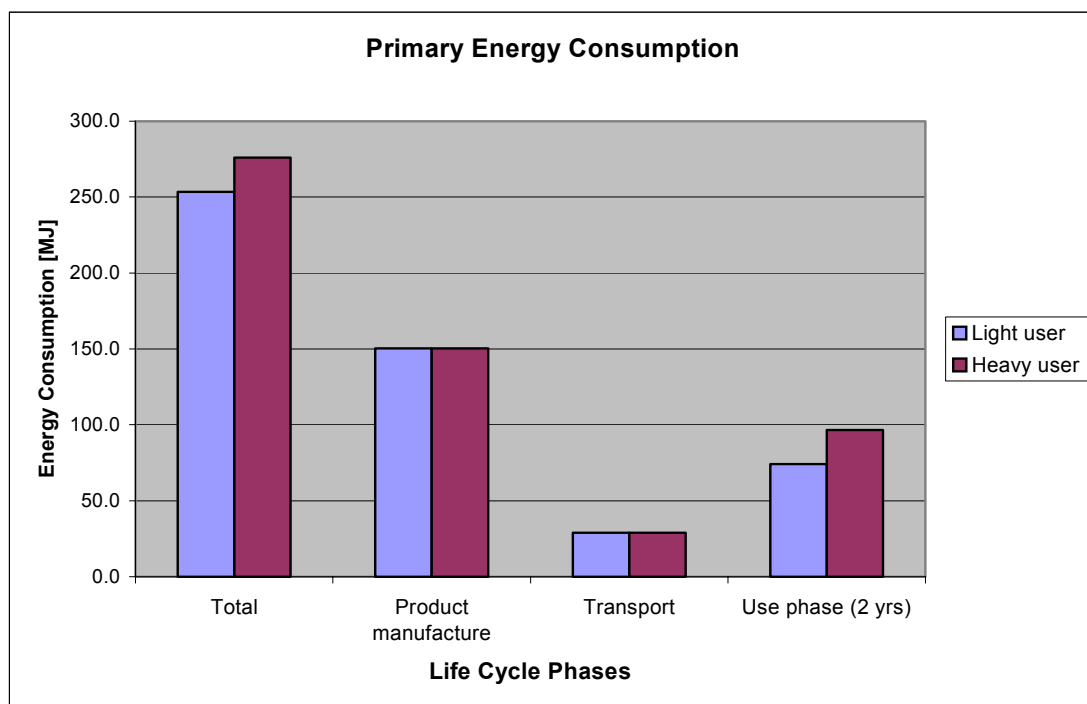


Figure C.1: Life cycle energy consumption of a third generation mobile phone

³⁷ In the figure, the term ‘product manufacture’ includes raw material extraction and processing, component and parts manufacture and assembly of the phone. The term ‘transport’ includes transportation of components from the first tier supplier to the assembly plant, and the phone transport from the assembly plant to the first customer.

For the PEC indicator, the LCA identifies:

- The raw material extraction and processing phase along with the components manufacture accounts for approximately 60% of the primary energy consumption during the life of a mobile phone in the case of light user scenario and about 54% in the case heavy user scenario.
- The use phase follows the production phase and accounts for approximately 29% of the total energy consumption in the case of light user scenario and approximately 35% in the case of heavy user scenario.
- The transportation of the components from the first tier suppliers to the assembly plant accounts for approximately 6% of the energy consumption whereas the energy consumption for the transportation of the phone to the first customer accounts for 5% of life cycle energy consumption.
- PWBs are the most energy intensive components in the phone. The raw material acquisition and manufacture of the PWBs accounts for approximately 40% of the energy consumption. The presence of gold in the finishing of PWBs and their energy intensive manufacturing process causes these high impacts. The raw material acquisition and manufacturing of ICs is also significant in terms of energy consumption.
- During the use phase the most important contributor is the standby energy consumption of the charger.

The contribution of the various life cycle phases and the different components to the life cycle primary energy consumption of the assessed mobile phone (for light user scenario) is illustrated in the following figure.

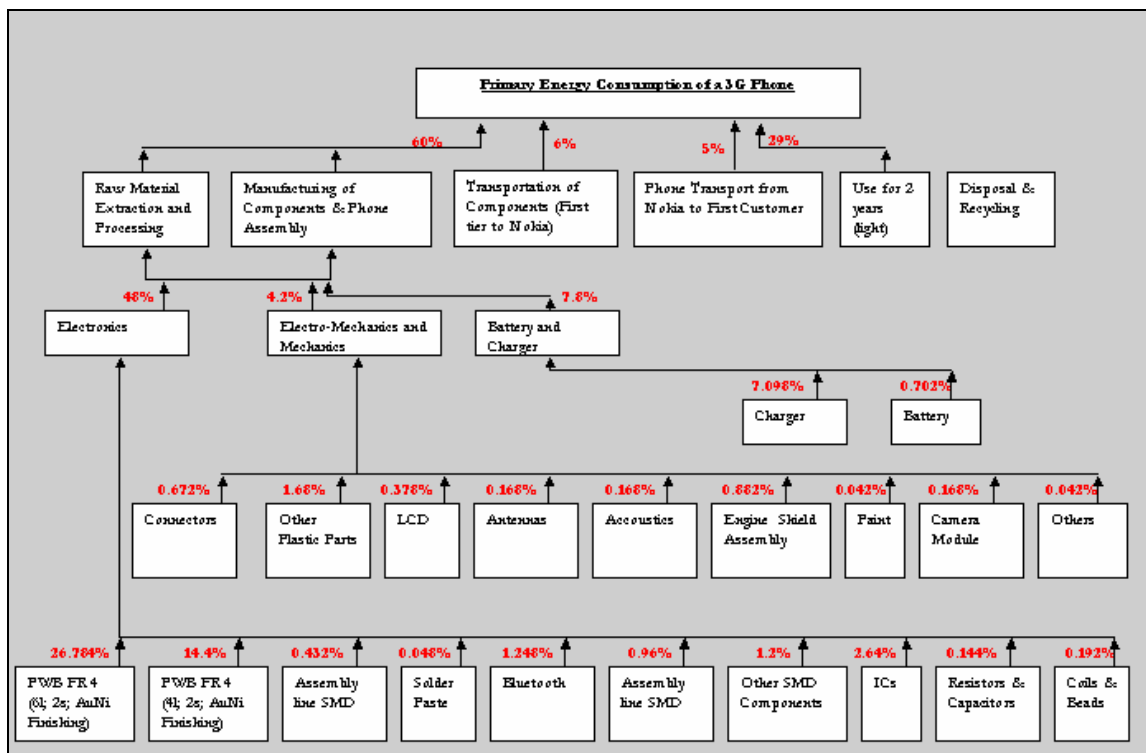


Figure C.2: Contribution of life cycle phases and components to the total PEC

C.3.2 Global Warming Potential (GWP)

GWP data in GaBi are based on the internationally accepted values of the Intergovernmental Panel of Climatic Change (IPCC) for different emissions and for three different integration times. The GWPs are expressed in kg CO₂ equivalents per kilogram of a certain global warming gas. The most commonly used integration time is 100 years and those values were used in this study. The modeling of the global warming contains many uncertainties, such as assumptions of atmospheric lifetime and heat radiation absorption of different gases, and the IPCC assumes an uncertainty of about +/-35% for its CO₂ equivalents. GWP is often linked to the primary energy consumption (GaBi, 1998).

The following figure illustrates the GWP of the assessed 3G mobile phone for its life cycle.

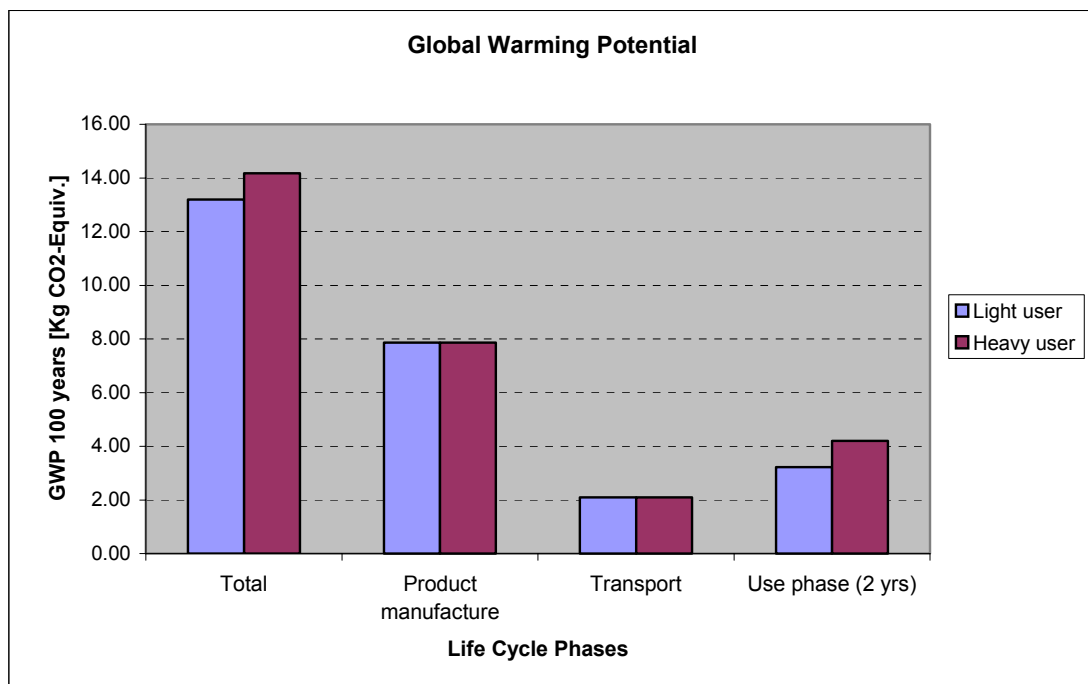


Figure C.3: Global warming potential of a third generation mobile phone

For the GWP indicator, the LCA identifies:

- The raw material extraction and components manufacture phases as the most important contributors to the global warming potential. These phases jointly account for approximately 60% of GWP of the phone.
- The next most significant contributor is the use phase, which accounts for 25% of the energy consumption in the case of light user scenario. In the case of heavy user this contribution goes upto 30%. The standby power consumption of the charger accounts for more than 50% of the GWP from the use phase.
- The PWBs account for approximately 68% of GWP from the production phase. PWBs are followed by ICs. The contribution of LCD comes out to be almost negligible, as their manufacturing process was not included in this study due to the lack of data.

- The transport of the components accounts for approximately 11% of the GWP whereas the transportation of the phones to the consumer causes approximately 5% of the GWP. The airfreight accounts for most of the GWP impacts from transportation.

The following figure illustrates the contribution of the different life cycle phases and components to the GWP of the phone in the case of light user scenario.

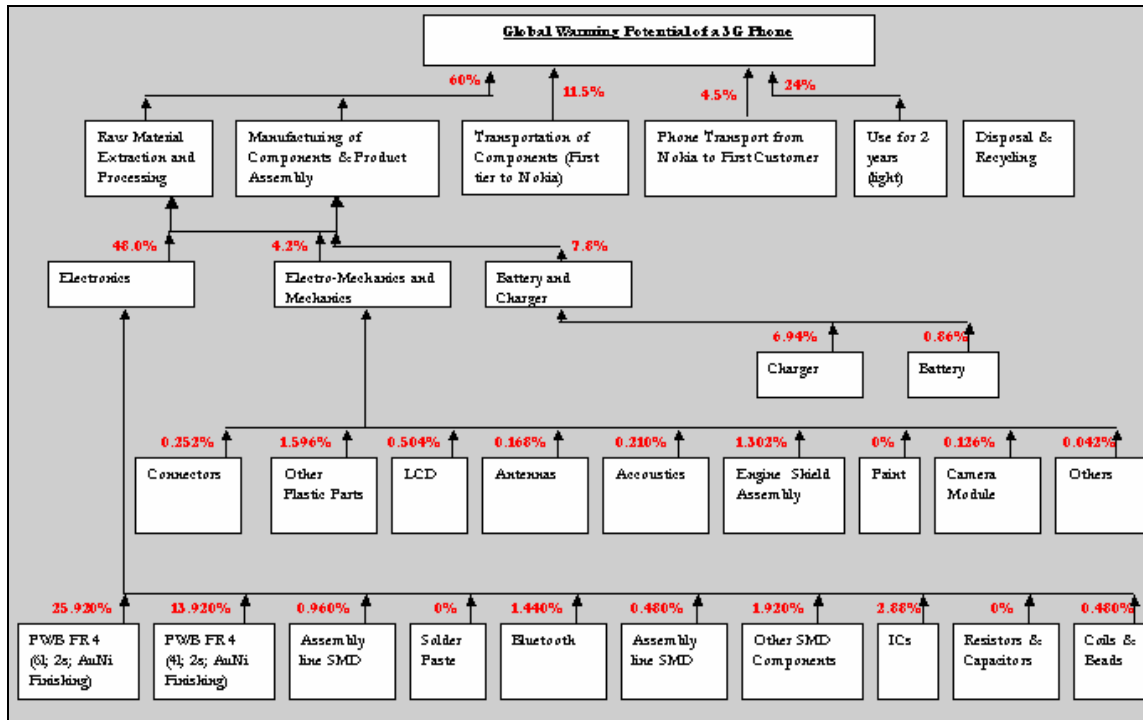


Figure C.4: Contribution of life cycle phases and components to the total GWP

C.3.3 Ozone Depletion Potential (ODP)

The ozone depletion is a very complex mechanism and it varies for example with the geographical latitude. The model used in GaBi takes into account only emissions that produce halogen oxides (such as ClO and BrO) in the stratosphere because they work as catalysts for the depletion, even though nitrous oxides ideally should be also characterised. Ozone depletion potentials (ODP) are defined for the halogen hydrocarbons (such as VOCs) using CFC-11 as a reference substance. Decisive parameters for an ODP are for example an atmospheric lifetime of a substance and the amount of its halogen atoms (GaBi, 1998).

The following figure shows the ODP from the emissions during various life cycle phases.

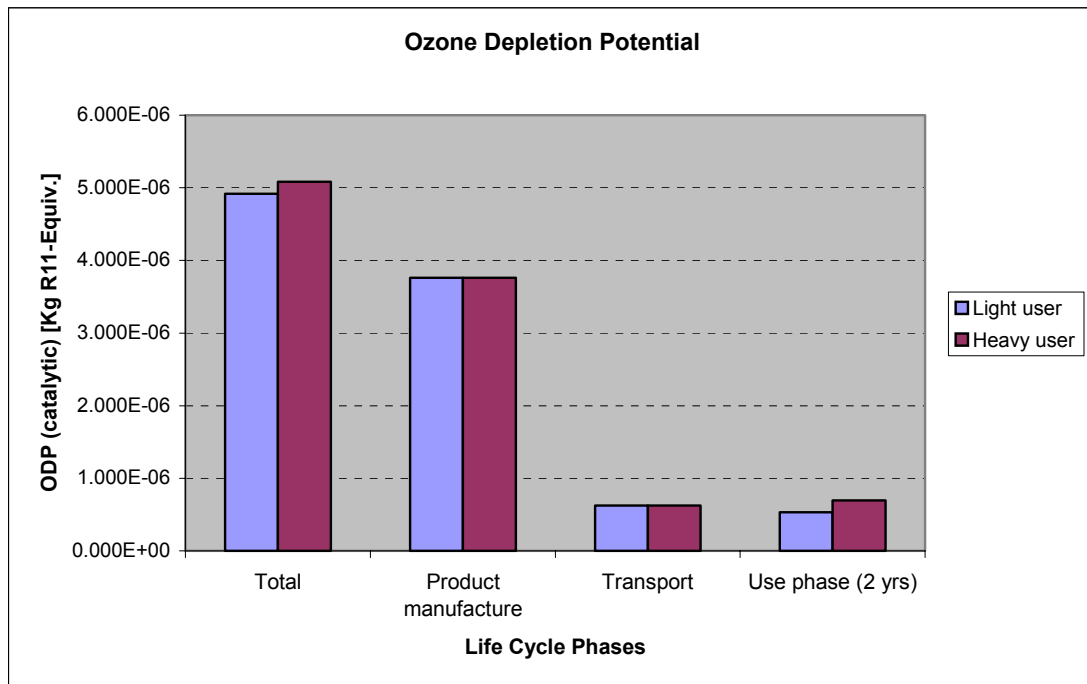


Figure C.5: Ozone depletion potential of a mobile phone

For the ODP indicator, the LCA identifies:

- The raw material acquisition and components manufacture phases contribute approximately 76% of the total ODP. The use phase contributes approximately 11% to the ODP in the case of light user scenario and approximately 14% in the case of heavy user scenario.
- The transportation phase accounts for approximately 14% of the ODP. In this 14%, the components transport to the assembly contributes approximately 9% and the phone transport to the first customer contributes approximately 5%. For the transportation phase, the airfreight is the most crucial whereas for the use period most of the potential arises from the standby power consumption.
- The solder paste accounts for over 40% of the total ODP. Two types of solder pastes were evaluated in this study, the first paste consisted of tin and silver, and the second paste consisted of tin, silver, copper and antimony.
- PWBs contribute approximately 25% of the total ODP.

The following figure illustrates the results of Nokia's LCA in the case of light user scenario.

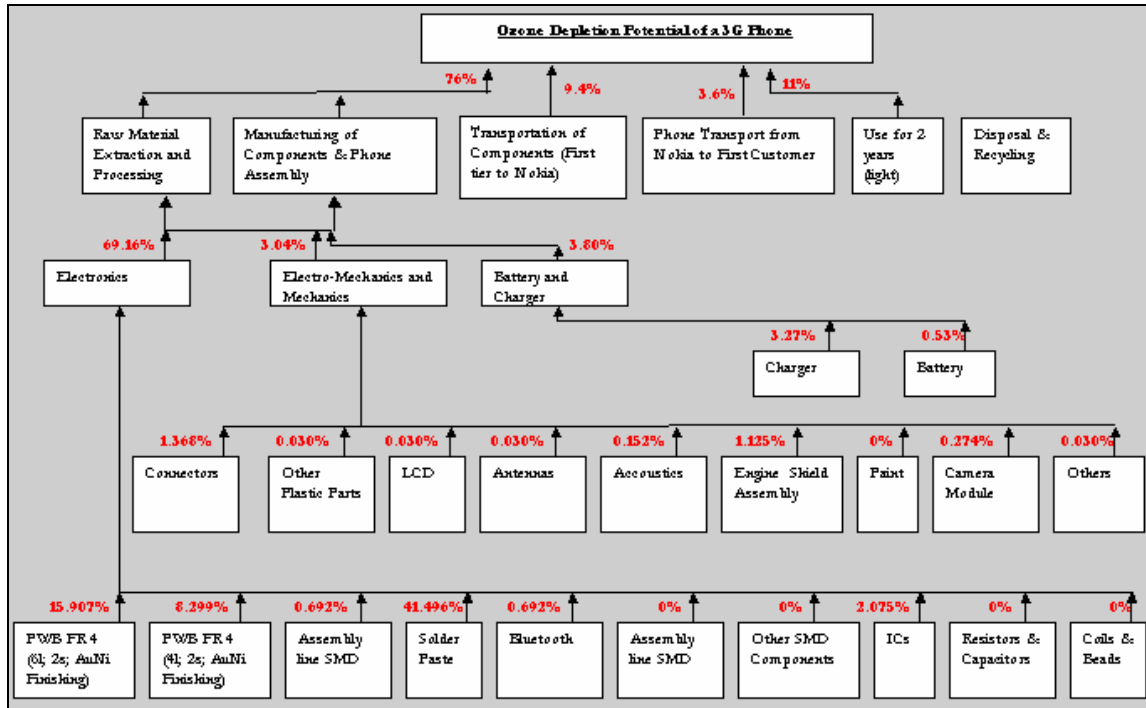


Figure C.6: Contribution of life cycle phases and components to the total ODP

C.3.4 Acidification Potential (AP)

Acidification is one of the most serious factors for environmental pollution. It is mainly caused by emissions containing nitrogen oxides (NO_x) and sulphur dioxide (SO₂) from combustion processes of industry, power plants, households, and traffic. The effects of these emissions depend on the geographical location. APs are calculated for substances as SO₂-equivalents by relating the existing S, N and halogen atoms in the substance to its molecular weight (GaBi, 1998).

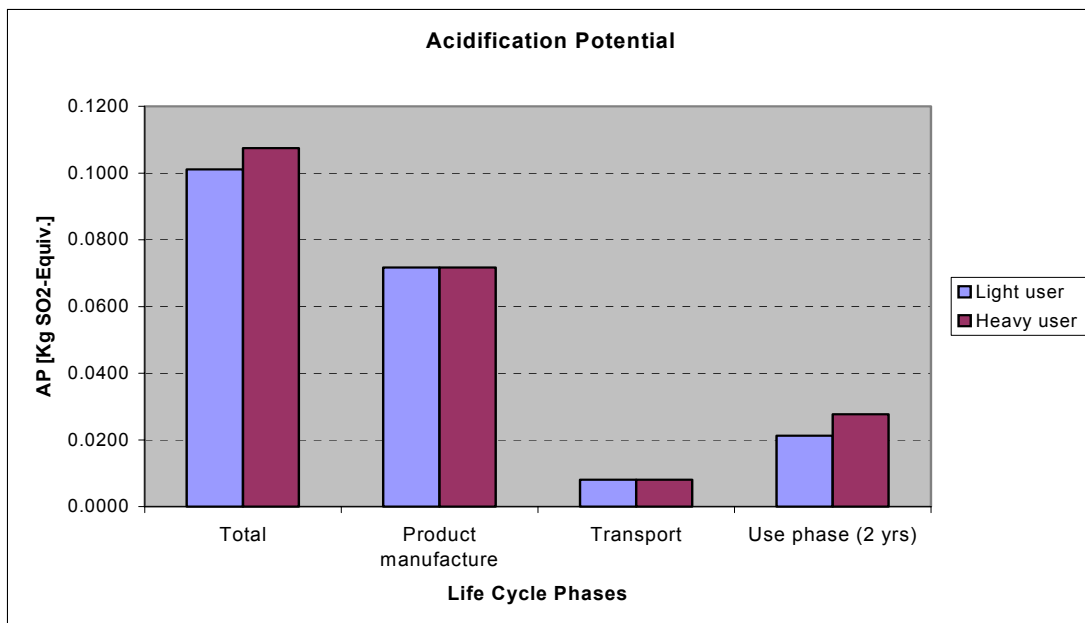


Figure C.7: Acidification potential of a third generation mobile phone

For the AP indicator, this LCA identifies:

- The raw material acquisition and components manufacture phase account for over 71% of the AP from the life cycle of a mobile phone in the case of light user scenario and 66% in the case of heavy user scenario.
- The transport of the components to assembly accounts for approximately 6% and the transportation of the phone accounts for approximately 2% of total AP in both the scenarios. In the transportation phase, the airfreight accounts for most of the acidification potential.
- The use phase accounts for approximately 21% of the acidification potential from the life cycle of the mobile phone in the case of light user scenario and around 26% in the case of heavy user scenario.
- The production of the PWBs accounts for over 30% of the total acidification potential in the case of light user scenario and it is the most significant component. The ICs account for approximately 4% of the total acidification potential. The Engine Shield Assembly accounts for approximately 5% of the total acidification potential. The silver mix in the Engine Shield Assembly is responsible for 99% of this acidification potential related to it.

The following figure illustrates the contribution of the various life cycle phases and components to the total acidification potential in the case of light user scenario.

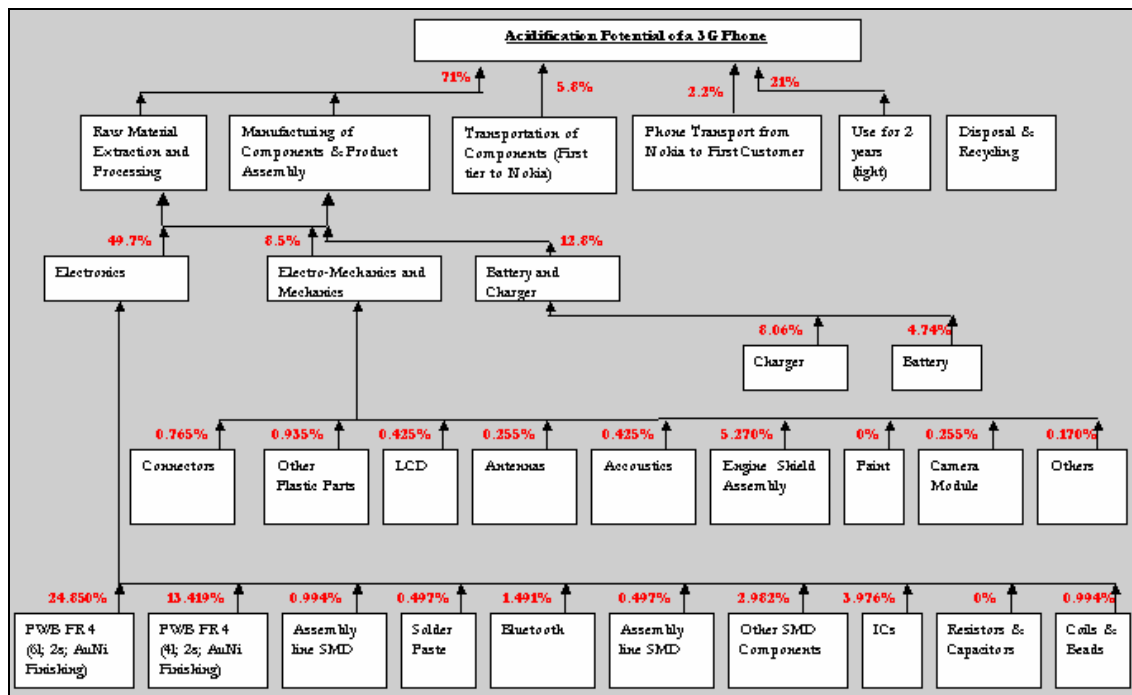


Figure C.8: Contribution of life cycle phases and components to the total AP

C.3.5 Human Toxicity Potential (HTP)

Human toxicity is one of the three toxicity types in GaBi database, the others being aquatic and terrestrial toxicity. To define HTP for a substance, three different figures were calculated

by dividing a Margin of Safety (MOS)³⁸ value of a reference substance 1,4-dichlorobenzene (DCB) in air by MOS values of the substance under evaluation. HTP is mainly caused by heavy metal (such as chromium III+ and VI+, arsenic, lead, cadmium, mercury, and thallium) and chlorinated hydrocarbon emissions (GaBi, 1998).

It should be noted that this LCA did not include the end-of-life phase due to the non-availability of data. A mobile consists of a few materials of concern, which may disperse in the environment due to the mismanagement of the phone in end-of-life phase.

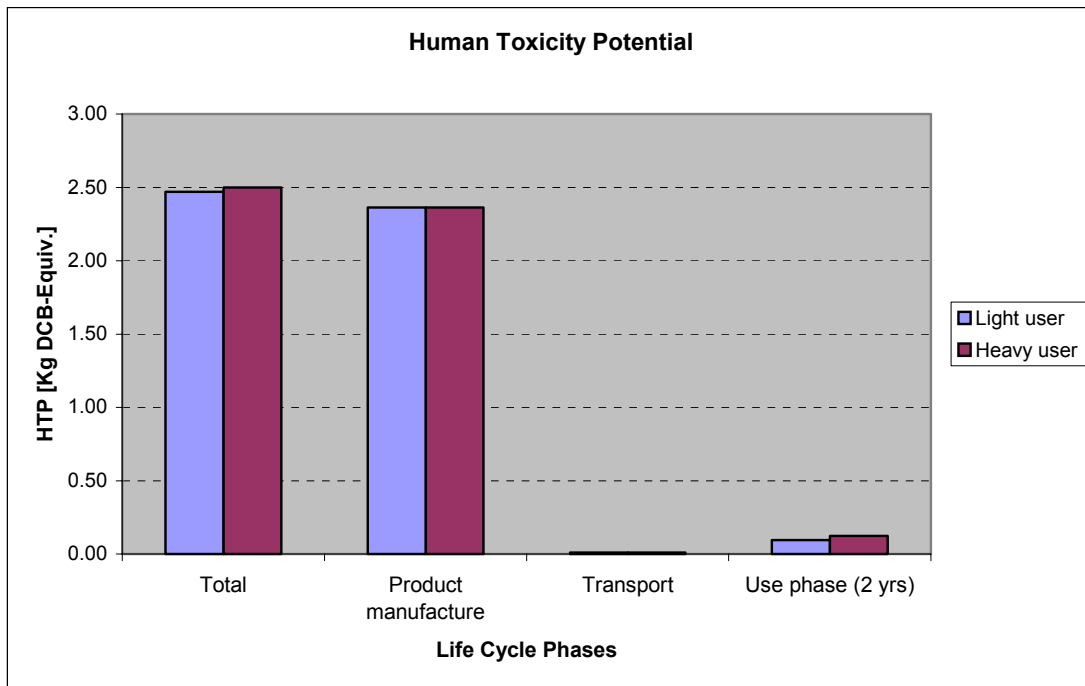


Figure C.9: Human toxicity potential of a third generation mobile phone

For the HTP indicator, the LCA identifies:

- The raw material acquisition and components manufacture phase jointly account for approximately 95% of the total HTP for both the scenarios.
- The PWBs are most relevant component and account for approximately 75% of the HTP. PWBs are followed by ICs, which contribute 9%, and other SMDs (surface mount devices such as transistors, diodes, capacitors, oscillators), which contribute over 10% of the HTP for the light user scenario.
- Under the category of electro-mechanic components, the connectors and the engine shield assembly account for over 80% of the HTP. Gold, present in the connectors, takes up to 98% of the HTP due to electro-mechanic components. In the case of engine shield assembly, 99% of its HTP is due to the presence of silver.
- The use phase accounts for approximately 4% of the total HTP in the light user scenario and 5% in the case of heavy user scenario.

³⁸ MOS is defined as the ratio of Accepted Daily Intake (ADI) to Predicted Daily Intake (PDI)

The following figure illustrates the HTP resulting from the various life cycle phases in the case of a light user scenario.

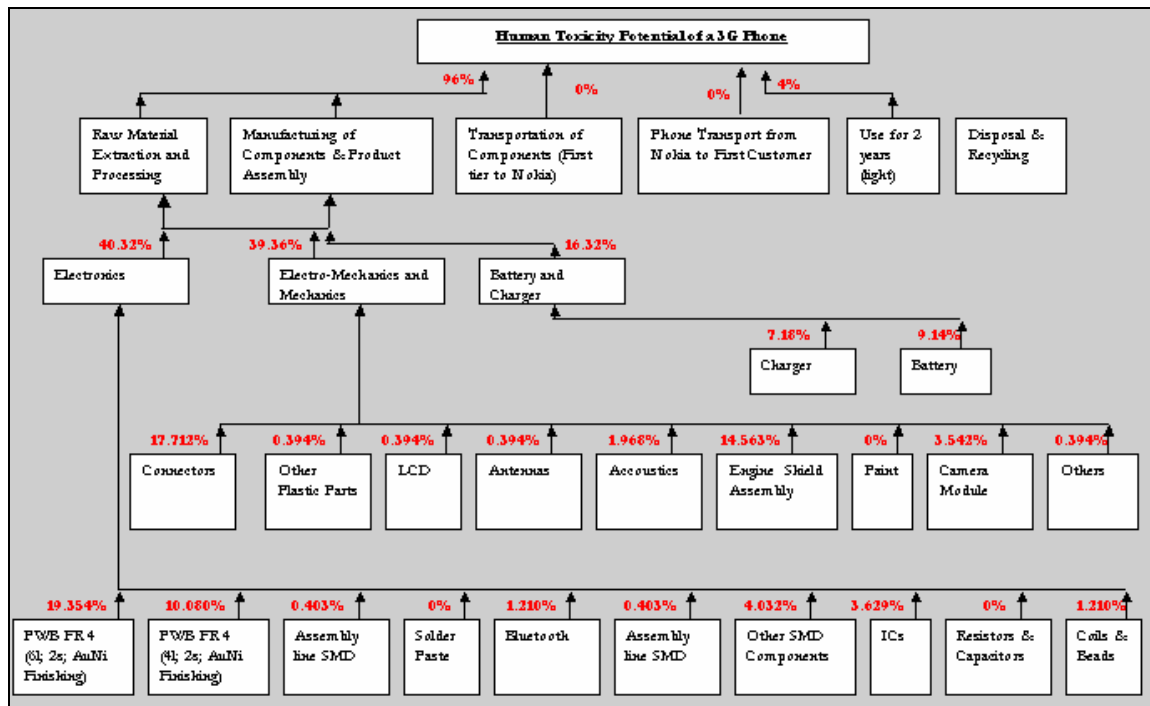


Figure C.10: Contribution of life cycle phases and components to the total HTP

C.3.6 Photochemical Oxidant Creation Potential (POCP)

Ozone acts as a noxious tracer gas in the troposphere being toxic for all organisms. The exact chemical process leading to the formation or reduction of active oxygen in the lower atmosphere is extremely complex. The active oxygen concentration depends for example on NO₂/NO concentration ratio, weather and effective light intensity (sunlight influencing in a negative way), although without emissions of hydrocarbons the concentration would not get very high. Hydrocarbons and nitrogen oxides arise mostly from vehicular pollution. POCP of substances accounts their ability to affect the ozone formation in the troposphere, a development known as ‘summer smog’. In order to use the different photo-oxidants as a reference against each other, POCP values are stated as ethylene equivalents (GaBi, 1998).

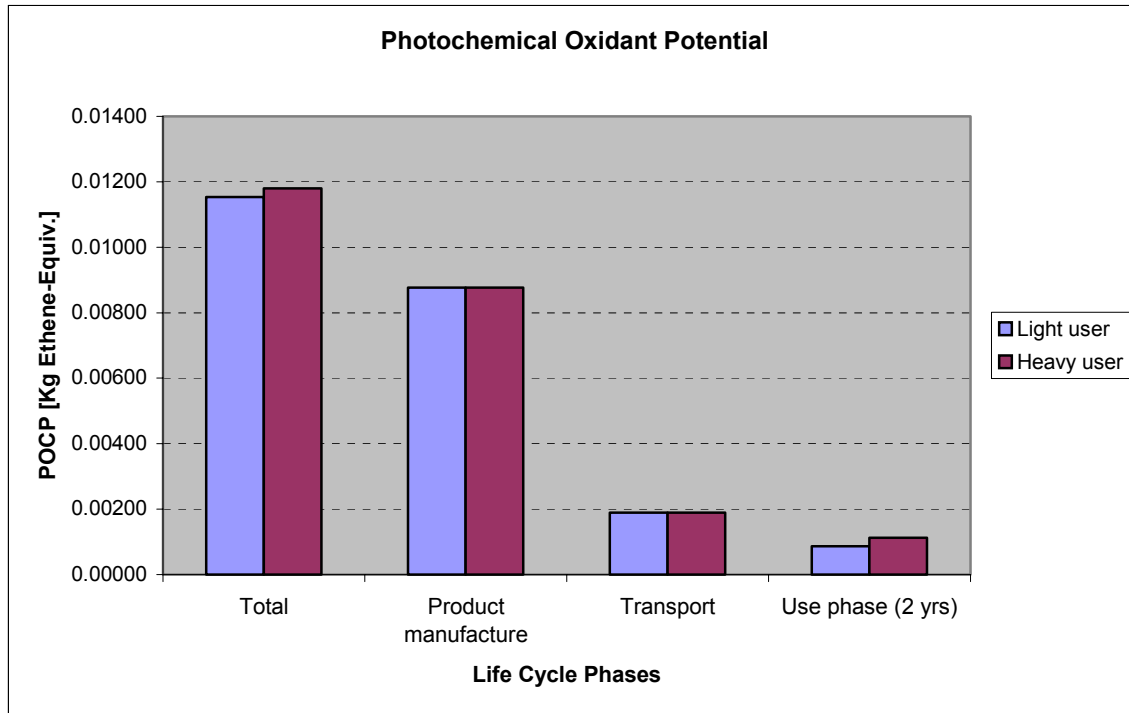


Figure C.11: Photochemical oxidant creation potential of a mobile phone

For the POCP indicator, the LCA identifies:

- The raw material acquisition and components manufacture phase jointly account for around 75% of the total POCP for both the scenarios.
- The use phase accounts for approximately 7% of the total POCP in the case of light user scenario and approximately 10% in the case of heavy user scenario.
- The transportation phase accounts for approximately 16% of the POCP. The transportation of the components contributes approximately 12% and the transportation of the phone to the first customer contributes approximately 4% of the POCP.
- The lead free solder paste accounts for 56% and the PWBs account for approximately 11% of the total POCP.

The following figure illustrates the contribution of various life cycle phases and components to the POCP in the case of light user scenario.

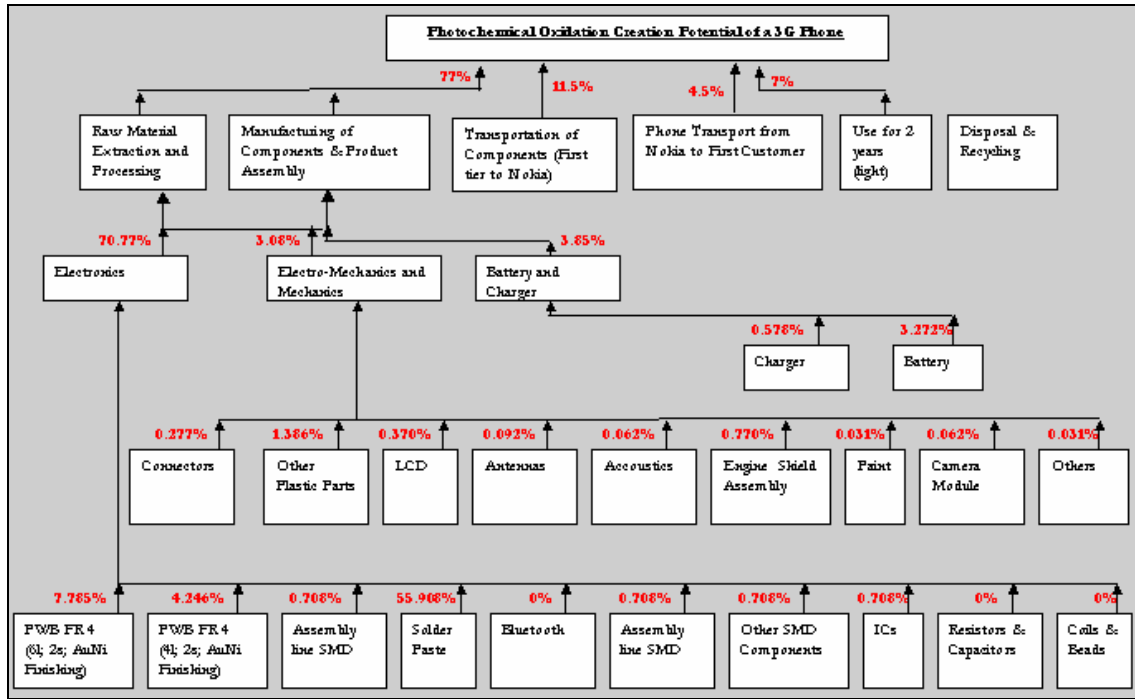


Figure C.11: Contribution of life cycle phases and components to the total POCP

Appendix D: LCA of a Mobile Phone by Nokia and IKP (2001)

This LCA was conducted by IKP University of Stuttgart for Nokia in accordance with the requirements of ISO 14040 series in 2001.

D.1 Goal and Scope

This LCA is a cradle to gate of the manufacture phase of a mobile phone. The functional unit was a specific Nokia phone model, and the study did not consider the battery and charger. The scope of the study was from raw material extraction and processing to the assembly plant.

D.2 Inventory Analysis

The power mix of Finland was used for PWB manufacture, assembly line and power consuming manufacturing processes (such as moulding of housings), power mix of average Europe for IC manufacture, and power mix of Germany for the rest of the processes. GaBi v3.2 database was used to assess the impacts of the phone, and the used impacts indicator categories were PEC, GWP, ODP, HTP and POCP. The weight of the phone was 103 g.

D.3 Impact Assessment and Interpretation

The results of this study are summarized below:

- The main share to the environmental profile of the phone especially for impact indicators on PEC, GWP and ODP was derived from two printed wiring boards, six-layered function PWB and four-layered key pad PWB.
- The gold and nickel used in PWB finishing caused the most significant environmental impacts in AP and HTP impact categories.
- The electronics components (both passives, and ICs) had the second highest impacts and were even dominating in the impact categories of AP and HTP. This was due to high energy consumption and presence of copper and precious metal (Ag, Au, and Pd) in the components.
- The SnPbAg solder had a higher share in AP and HTP than in the other impact categories, where it was not even visible. This high share was attributed to the presence of silver though the portion of silver in the solder paste was only 2%.
- Housing (front and back housing and a display window) showed its main contribution in the POCP impact category, the main reason being the emission of Volatile Organic Compounds (VOCs) during the extraction of crude oil, a process step in the manufacture of plastics.
- Gold finishing resulted in the connectors having the most significant environmental impact of rest of the mechanic and electro-mechanic parts. Shielding contributed

most to the impact categories of AP and HTP due to its CuZnNi alloy while screws had almost no contribution to the impact indicators.

Appendix E: Ecological Footprint Analysis (EFA) of a Mobile Phone (2002)

Nokia participated in this EFA study carried by Sibyllne D. Frey as a part of her doctoral thesis as it uses natural capital accounting. The ecological footprint for a particular population is defined as “The total area of productive land and water ecosystems required to produce the resources that the population consumes, and assimilate the wastes that the population produces, wherever on earth that land and water may be located using prevailing technology”. The EF assumes that all the categories of energy and material consumption and waste generation requires the productive or absorptive capacity of a finite area of land or water (Rees & Wackernagel, 1996). “The ecological footprint of the world changes in proportion with the global population size, average consumption per capita, and the resource technology used. The decreasing productive land space must be divided by an increasing population” (Frey, 2002).

The ecological footprint extends farther than LCA and converts the impacts identified from LCA into bioproductive areas required which can be further aggregated into a single score and compared to the ecological bottom line. To measure the ecological footprint of a mobile phone a life cycle approach was used in this study with a focus on total primary energy consumption and carbon dioxide (CO₂) emissions. The CO₂ emissions were used as a first order approximation of waste flows in subsequent EFA (Frey, 2002).

E.1 Goal and Scope

The main objective of this assessment was to identify the ecological footprint of a mobile phone. A life cycle energy approach was used as part of the EFA to identify an ecological footprint of a mobile phone.

A Nokia mobile phone weighing 90 grams, containing 100 different materials, and 90 different types of components was assessed. The functional unit in this analysis was the use of one mobile phone during its life cycle with an average consumer life time of 2.5 years and an average amount of daily talk time use. This assessment did not take into account the environmental impacts of the charger, phone battery, accessories, and the network infrastructure needed for using the phone. Environmental impacts other than carbon dioxide emissions were not included as they cannot be sufficiently accounted for in EFA (Frey, 2002).

E.2 Inventory Analysis

The LCA by Wright in 1999 was used as a basis for this study but major changes were included in raw material extraction and manufacturing energy. Data from other LCA studies conducted by Nokia was also utilised. This ‘cradle to grave’ study took into consideration raw materials production including extraction data where possible (TEAM 3.0 software tool was used for this life cycle stage), components manufacture and phone assembly (accounting only for materials remaining within the phone and not for the process materials), use and EoL phase. The transportation phase was not included in the energy analysis.

An overall estimation of the energy value was used for the manufacture so that **case A** used older manufacturing energy data and **case B** newly updated manufacturing energy data, supplemented by supplier’s information. The use phase was modeled in the same way as by

Wright in 1999 LCA, and in end-of-life 95% of precious metals were assumed to be recycled (granulated, smelted and recovered) and the remainder to be landfilled. A so-called ‘avoided energy approach’ was used, i.e. avoided energy by recycling a metal is equal to the energy that would have been required to mine and produce same quantity of a metal (Frey, 2002).

Following are the inventory related issues in this study (Frey, 2002):

- To identify the amount of energy required to extract an element, whose data was not available, the abundance and ecological rucksack values were used.
- For some components for which no data was available, the material contents were estimated based on the knowledge of similar components. This assumption was not critical, as the final results appeared to be relatively insensitive to these values.
- The energy for some of the PWB manufacturing processes was not considered, as the data quality was not reliable.
- It was assumed that 95% of the precious metals used in the phone are recycled and the remainders are landfilled.

E.3 Impact Assessment and Interpretation

E.3.1 Primary Energy Consumption

The primary energy consumption results for the cases A and B can be summarised as (Frey, 2002):

- For case A, both use of the phone and manufacture of its components contributed about half to the total primary energy consumption.
- For case B, the use phase had the biggest environmental impact contribution of 54% with components manufacture and phone assembly coming second with 45%.
- The production of raw materials had the lowest impact of approximately three percent in terms of energy consumption.

The following figure illustrates the primary energy consumption for the whole life cycle and different life phases for cases A and B.

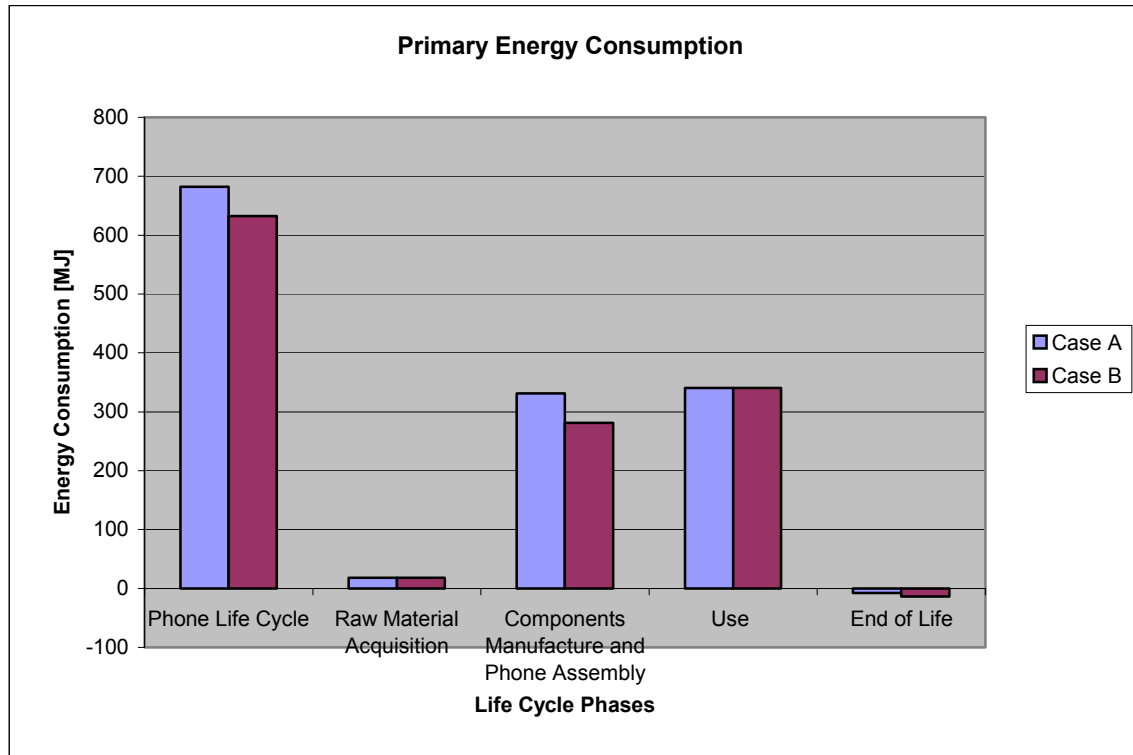


Figure D.1: Energy consumption in the various life cycle phases of a mobile phone

E.3.2 Carbon Dioxide Emissions

For the indicator on CO₂ emissions the study identifies (Frey, 2002):

- The components manufacture and phone assembly was the dominating life cycle phase for both cases A and B.
- The CO₂ emissions for the overall phone life cycle were about 39 kg of CO₂ for case A and about 36 kg for case B.
- The raw material acquisition contributes the least to the carbon emissions, which can be attributed to limited availability of data from this phase.

The following figure illustrates the contribution of the various life cycle phases to the total carbon dioxide emissions.

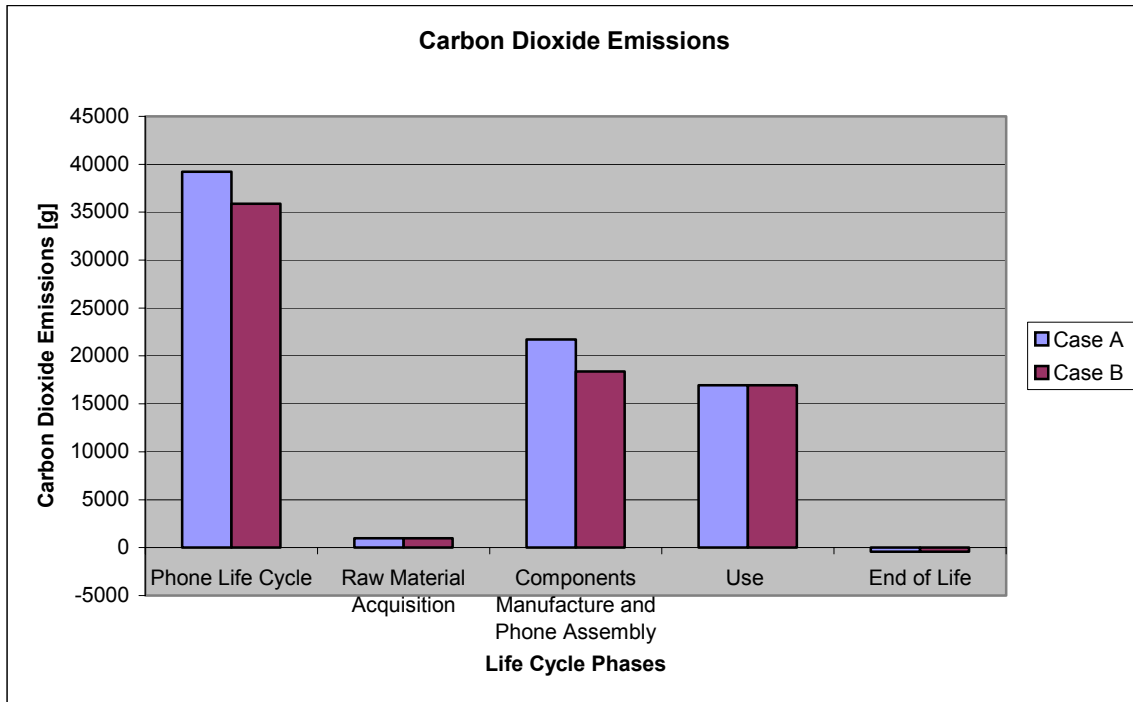


Figure E.2: Carbon dioxide emissions from the various life cycle phases of a mobile phone

E.3.3 Ecological footprint

To apply the EF concept the methodology was split into two sections (Frey, 2002):

- a) The estimation of direct land use from mining activities: The direct land use was calculated using density of materials, size of ore bodies, site specific data and ecological rucksacks.
- b) The estimation of indirect land use from CO₂ sequestration by land and sea: In this study CO₂ absorption by forests based on IPCC on biomass accumulation was used. CO₂ absorption rates by oceans were included according to information by Haddley Centre, UK.

E.3.3.1 Direct Land Use (DLU)

To find the DLU value for a mobile phone, raw material flows were multiplied by their respective land use values, DLU (m²kg⁻¹). Due to the non-availability of data not all resource flows could be included. For many materials like gold, silver, lead, nickel, zinc, magnesium and cobalt, and other uncommon materials no DLU values were found. For 53% (by type) of the material flows no DLU was available although by weight 97% of the resource flows were included for the phone (Frey, 2002).

The DLU result for case A was 2.23 m² and for case B it was 2.09 m². The following figure illustrates the DLU results for the various life cycle phases (Frey, 2002).

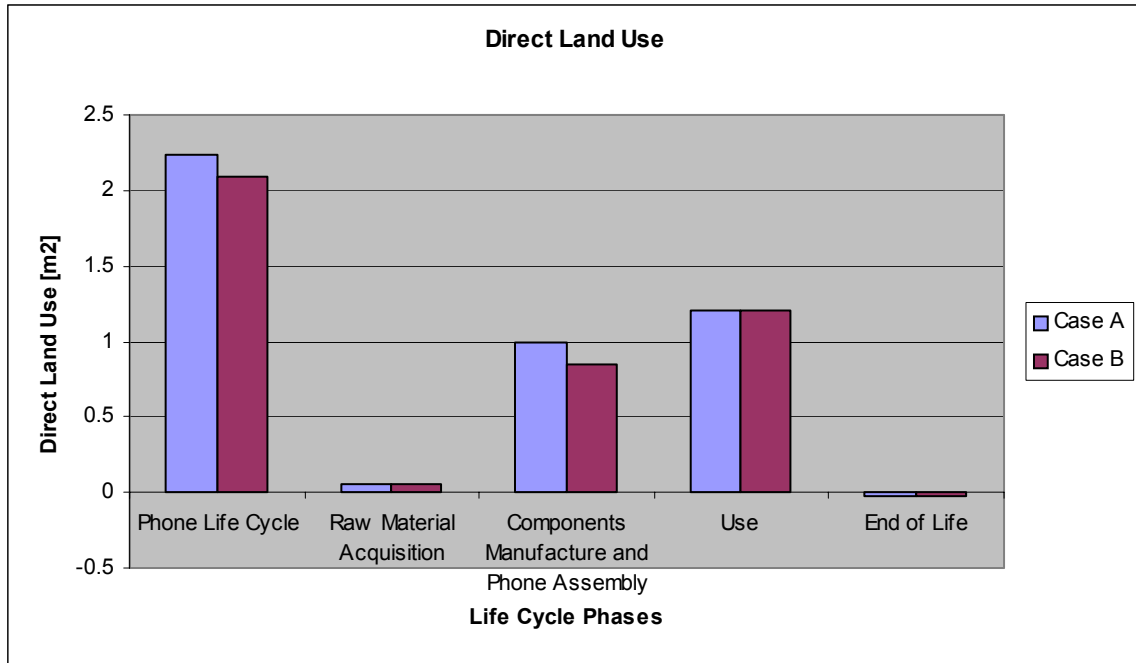


Figure E.3: Direct Land Use results for the various life cycle phases of a mobile phone

E.3.3.2 Carbon Sequestration Phone Life Cycle (Fossil Energy Land)

The CO₂ emissions from the life cycle of a phone were converted to fossil energy land. The fossil energy land is the land to be reserved for CO₂ absorption and refers to the spatial impact of fossil fuel use. The values for case A and case B included 25% ocean absorption. The fossil energy land required for the different life cycle phases of mobiles in the cases A and B is illustrated in the following figure (Frey, 2002).

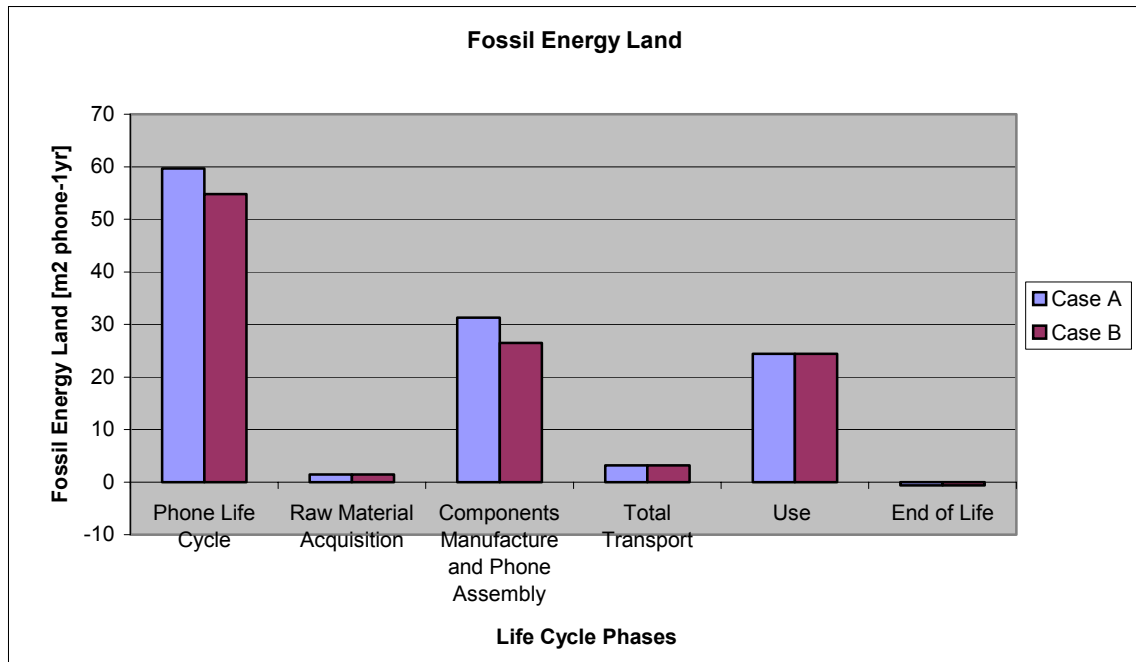


Figure E.4: Fossil energy land for the various life cycle phases of a mobile phone

For the cases A and B, the DLU areas and the fossil energy land were scaled with equivalent factors to calculate the global areas of bioproductive space. These areas were aggregated to get the EF for case A and case B. The ecological footprints were further compared to the available supply of biocapacity of 1.89 hectares (ha) per capita (ca) (in 1996), the ecological benchmark in this study to obtain the fair Earth share for both the cases. A fair Earth share is the amount of land each person would get if all the ecologically productive land on Earth were divided evenly among the present world population.

The ecological footprint of a mobile phone varied from 104 to 115 (m² phone⁻¹ yr) that is 7000 to 8000 times greater than its actual size. 94% of the EF was caused by carbon emissions of which 5-6% were attributed to transport. The remaining 6% (around 7 m² for both A and B cases) were caused by direct land use mainly due to mining operations. The ecological footprint becomes smaller with decreasing resource use in either material extraction or in energy use in manufacturing. While older mobile phone models require around 113 to 115 m² of bioproductive space, the newer mobile phone models need only between 104 and 106 m² of bioproductive space.

With regard to **the fair Earth share, the case A had a share on 0.60% and case B a share of 0.55%**. In both the cases, a mobile phone requires less than 1% of available bioproductive capacity per capita. The fair Earth share was calculated by dividing the ecological footprint with the existing global bioproductive capacity of 1.89 ha/ca.

Appendix F: References to Publicly Available Studies/Reports/Articles (in which Nokia has participated)

1. Arnaiz, S., Bodenhoefer, K., Harrison, D., Herrmann, C., Hussein, H., Irasarri, L., et al. (2004, September 6 -8). *Active Disassembly using Smart materials End-of-life Technology for WEEE - Results from the Framework V project*. Paper presented at the Electronics Goes Green 2004+, Berlin.
2. Arnaiz, S., Bodenhoefer, K., Constantin, H., Hussein, H., Irasarri, L., Schnecke, D., Tanskanen, P. (2002), *Active Disassembly Using Smart Materials (ADSM), a status report of the ongoing EU project*, Care Innovation, Vienna
3. Aspelin, T. (2004). *Life Cycle Assessment of Solder Pastes*. Lappeenranta University of Technology, Lappeenranta.
4. Braddy, T., O'Connell, S., Tanskanen, P., Bergman, R., Senfield, P., Hoekstra, J., et al. (2003). *Material Composition Profiles of Select IT Components. A Design for Environment Project with the High Density Packaging User Group (HDPUG)*. Paper presented at the IEEE International Symposium of Electronics and Environment, Boston.
5. Clift, R., & Wright, L. (1999). Relationships between Environmental Impacts and Added Value Along Supply Chain. *Technical Forecasting and Social Change*(May 1999).
6. Falcon, V. (2001). *Recycling of plastics from mobile phones*. Helsinki University of Technology, Helsinki.
7. Frey, S. (2002). *Development of New Ecological Footprint Techniques Applicable to Consumer Electronics*. Brunel University, Middlesex.
8. Järvinen, K. (2002). *Environmentally Sustainable Mobile Phone Development*. Åbo Akademi University, Turku.
9. Leskinen, K., Tanskanen, P., Takala, R., & Ahonen, H. (2003). *Disassembly of Mobile Phones with Induction Heating*. Paper presented at the International Electronics Recycling Congress ICM, Basel.
10. Lindholm, M. E. (2003). Towards Environmentally Consious Product Design - a Comprehensive DfE Implementation in New Generation Cellular Phones. *IEEE*, 251 - 254.
11. Mäkirintala, O-P. (2003). *The New Challenge for the Industry: Material composition - integrated approach using Rosettanet*. Paper presented at the Recycling Electrical and Electronic Equipment 6, Leatherhead.

12. McLaren, J., & Piukkula, N. (2004). *Life Cycle Assessment of a 3rd Generation Nokia Handset*. Paper presented at the Electronics Goes Green 2004+, Berlin.
13. McLaren, J., Wright, L., & Jackson, T. (1999). Dynamic Life Cycle Modelling of Mobile Phone Takeback and Recycling. *Journal of Industrial Ecology* (June 1999).
14. Nokia. *Nokia Suppliers and the Environment*, from www.nokia.com/environment
15. Nokia. (2001). */insight: Environmental Report of Nokia Corporation 2000*, from www.nokia.com/environment
16. Nokia. (2003). *Environmental Report of Nokia Corporation 2002*, from www.nokia.com/environment
17. Nokia. (2004). *Corporate Responsibility Report 2003*, from www.nokia.com/crr
18. Nystedt, M. (2002). *The Effect of Environmental Directives on Electronic Products in terms of Material Use*. Helsinki University of Technology, Helsinki.
19. Oiva, L. (2000). *Case Study on the Environmental Impacts of a Mobile Phone*. Paper presented at the Electronics Goes Green 2000+, Berlin.
20. Pesonen, I. (2001). *Development of Eco-Efficiency of Base Stations by means of the MIPS Indicator*. Helsinki: Ministry of the Environment.
21. Piukkula, N. (2003). *Life Cycle Assessment of a Third Generation Imaging Mobile Phone*. Unpublished Master's, Tampere University of Technology, Tampere.
22. Pongracz, E., Ylä-Mella, J., Nurminen, J., Tanskanen, P., Kaakinen, J., Phillips, P. S., et al. (2004). *Development of a sustainable WEEE recovery infrastructure in Finland and stages of end-of-life management of electronics*. Paper presented at the Electronics Goes Green 2004+, Berlin.
23. Singhal, P., Ahonen, S., Rice, G., Stutz, M., Terho, M., & Wel, H. v. d. (2004). *Key Environmental Performance Indicators (KEPIs): A new approach to environmental assessment*. Paper presented at the Electronics Goes Green 2004+, Berlin.
24. Takala, R., & Tanskanen, P. (2002). *Outlining Opportunities of Engineering Processes and Technology on Environmental Impacts of the End-of-life Treatment of Mobile Terminals*. Paper presented at the IMAPS Nordic Annual Conference, Stockholm.
25. Takala, R., & Tanskanen, P. (Submitted). A decomposition of the End-of-life process. *Journal of Cleaner Production*.

26. Tanskanen, P., & Takala, R. (2002). *Concept of a mobile terminal with an active disassembly mechanism*. Paper presented at the International Electronics Recycling Congress, Davos.
27. Tanskanen, P., & Takala, R. (2003). *Engineering Paradigms for Sustainable Design of Mobile Terminals*. Paper presented at the International Conference on Engineering Design ICED 2003, Stockholm.
28. Tanskanen, P., & Takala, R. (2003). *Integrierte Demontgemechanismen für Tragbare Elektrogeräte*, Z. Konstruktion
29. Wright, L. (1999). *Product Life Cycle Management, EngD Thesis*. University of Surrey, Guildford, UK.
30. Wright, L., McLaren, J., Jackson, T., & Parkinson, S. (1998). *Mobile phone takeback and recycling: analysis of the ECTEL project*. Paper presented at the IEEE International Symposium on Electronics and the Environment, Chicago.