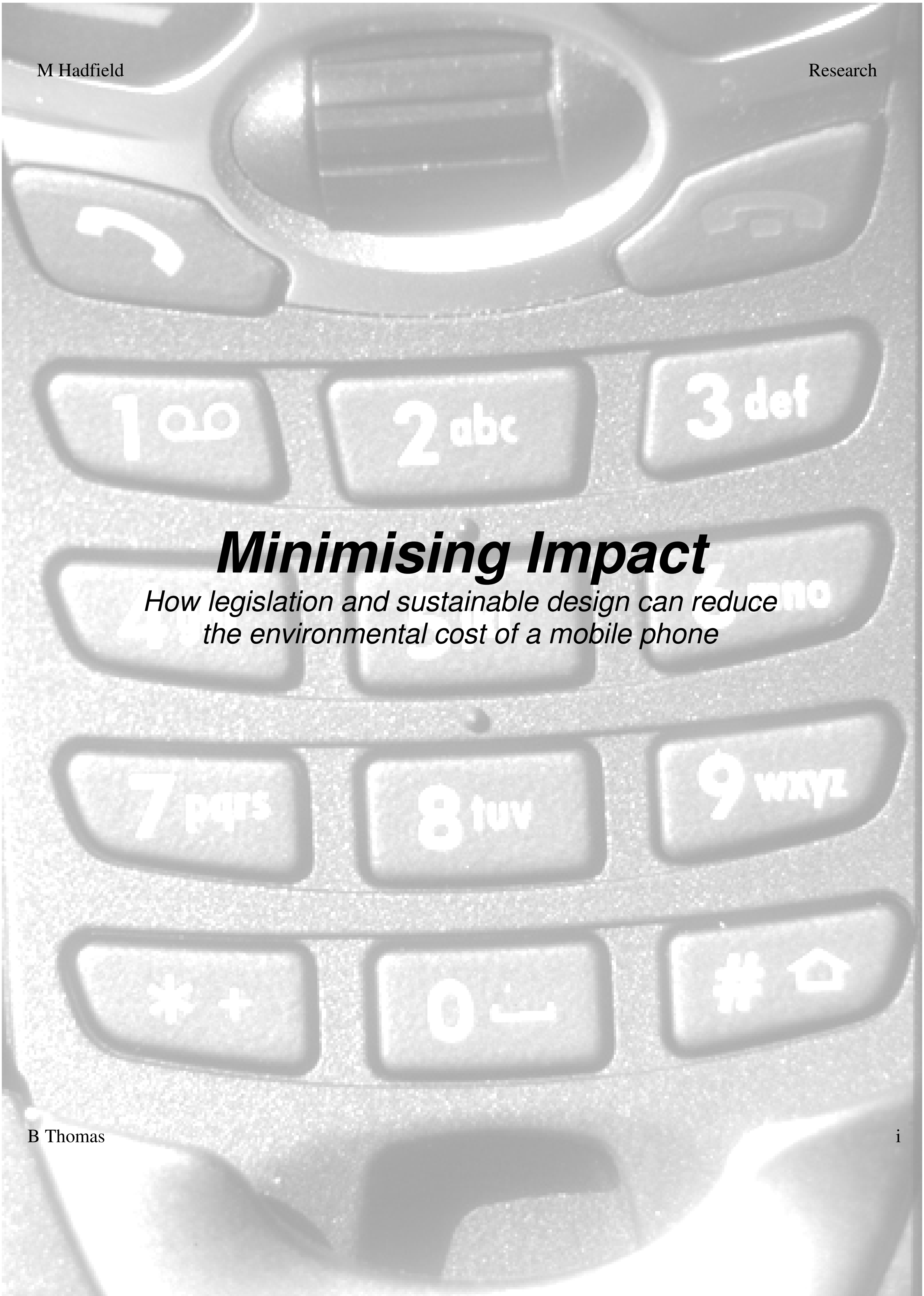


Minimising Impact

How legislation and sustainable design can reduce the environmental cost of a mobile phone

Acknowledgements

Contents

"Minimising Impact: How legislation and sustainable design can reduce the environmental cost of a mobile phone"

1. Abstract

This paper looks at the factors involved in the environmental cost of a mobile phone handset. It initially looks at the development of mobile handsets and the trends in weight, energy consumption, use life and mobile ownership. The environmental impacts of these trends are discussed, as is the issue of refurbishing mobile handsets for resale abroad.

The paper then examines the likely effects of forthcoming EU legislation, in particular the Waste Electrical and Electronic Equipment (WEEE) Directive, the various options available at End of Life for handsets (i.e. recycling, refurbishment for resale and disposal to landfill) and the effects of various sustainable design modifications on the overall environmental cost of the handset.

Each factor is evaluated using Life Cycle Analysis (LCA) to compare their effects on the overall impacts of both an older mobile phone design from 1999 and a modern phone (2004). LCA is used to compare the impacts of the older phone with the newer phone, investigate the effects of material substitution for environmental gain, the effects of the forthcoming WEEE directive and the effects of the power consumption targets for chargers outlined in the voluntary Code of Conduct on the Efficiency of External Power Supplies (2000). The environmental impacts of refurbishing mobile phones for resale abroad are also examined.

The paper concludes from the LCA results that the greatest impact of EEE over its life cycle is from the energy consumed during the use phase, and that this is the main difference between the environmental impact of newer and older handsets. It also notes that while material substitution for environmental gain is beneficial, increasing energy efficiency has a far greater effect on the overall impact of the handset. Similarly it notes that the gains to be made by the implementation of the WEEE directive (which requires manufacturers to be responsible for the collection and recycling of their products at End of Life (EoL) and to meet recycling for material recovery targets of 65%) are small compared with those made voluntarily by mobile manufacturers in the Code of Conduct on the Efficiency of External Power Supplies (2000). It is also shown that design for recycling can greatly improve the economic incentives for recycling of handsets at EoL.

Finally, the paper recommends legislation to enforce the targets voluntarily laid out by the voluntary Code of Conduct on the Efficiency of External Power Supplies (2000) and calls for environmental legislation to take into greater account the effects of mobile handsets over their entire life cycle.

On the issue of refurbishing mobile handsets for resale abroad the paper concludes that this has no environmental benefit as the reduced power consumption of newer mobile handsets outweighs the benefits of extending the use life of mobile handsets. It is recommended that refurbished handsets be fitted with modern, energy efficient chargers before they offer any real environmental benefit to the developing world over newer handsets.

2. Introduction

Mobile phones are becoming an increasingly ubiquitous part of everyday life, there are currently over 50 million mobile phones in use in the UK and approximately 75% of the population have at least one mobile phone[1]. Mobile communications technology is advancing very quickly and handsets are replaced, on average every 18 months. This means that there are an estimated 15 million mobile phone handsets thrown away every year, presenting hazardous materials into the waste stream[2].

To take advantage of the fast turnover of mobile phones, a number of collection and recycling schemes for mobile phones have been set up. These usually refurbish handsets and chargers (replacing batteries, SIM cards e.t.c.) before selling the phone on to developing countries in Africa, Asia and South America. Most of these schemes are commercial operations, though many give some donation to charity, and all emphasise their 'green' credentials in their publicity. This practice of refurbishing old handsets is presented as a safe and environmentally friendly way of extending the useful life of mobile phones, however the environmental benefits of this are dubious. With an average use-life of 18 months, mobile phones have a short design life, and so, even with refurbishment it is doubtful how long the phone is going to continue to function. At the end of their life the phones will still need to be disposed of safely in order to prevent hazardous chemicals leaching into ground water, and most of the Developing countries buying the phones lack the necessary facilities for this. It is questionable whether these schemes are really providing useful technology or simply exporting electronic waste under the guise of recycling.

The export of electronic waste is banned under the Basel convention, to which the UK, along with all the OECD countries except the US are committed. Supplementary EU legislation is also in place in the form of the Regulation on the Shipment to Certain Non-OECD Countries of Certain Types of Waste (1999)[3]. Despite this, and despite import bans on electronic waste by many of the countries most affected, electronic waste for 'recycling' still appears in large quantities in countries like China and Pakistan in the form of computers, phones and other consumer electronics from the developed world.

In the EU, Waste Electrical and Electronic Equipment (WEEE) is the fastest growing single waste stream currently accounting for 4% of municipal waste and growing at 3 – 5% per annum[4]. This means that in 5 years this will have increased by 16 – 28%, and in 12 years it will have doubled. 90% of WEEE collected goes to landfill, incineration or is recovered without any pre-treatment[4] and this accounts for a large portion of the pollutants in the municipal waste stream. Electrical and Electronic Equipment (EEE) is also notable for the resources it consumes in its manufacture, particularly energy. This is very much greater than the resources consumed by other municipal waste streams.

Mobile phones contain a number of potentially hazardous materials that can cause problems at disposal. From landfill, hazardous materials such as lead, arsenic and beryllium can leach into the surrounding groundwater and if incinerated the brominated fire retardant used in plastics and circuit boards can, particularly in the presence of copper, produce dangerous dioxins.

New EU regulation in the form of the Waste Electrical and Electronic Equipment (WEEE) directive aims to reduce the problems caused by the disposal of electrical equipment by increasing producer responsibility for the safe disposal and/or recycling and reusing of their products. The directive also emphasises the need for separate collection facilities for such waste.

"In order to reduce the amount of electrical and electronic waste disposed of in landfills and incinerators the proposed WEEE directive seeks to establish separate collection and recycling systems for such waste. It also implements the principle of producer responsibility to provide incentives for producers to take into account, already at the product design stage, the need to reduce the use of hazardous substances and to improve the recyclability of these products." [4]

This means that mobile phone manufacturers, in common with other electrical and electronic goods manufacturers, are required to accept responsibility for the environmental impact of their products. They are obliged to provide collection facilities and, by 2006 must ensure that 65% of the weight of the product is 'recovered'. This requires manufacturers to design their products with EOL dismantling and recycling in mind. Manufacturers are also required to substitute certain environmentally hazardous materials such as heavy metals and brominated flame retardants for less harmful substances by 2006.

While the WEEE directive concentrates its legislation on ensuring proper end of life collection and recycling of EEE, it also heavily emphasises the need for recyclability and waste minimisation to be addressed at the design stage of new products.

"The costs for reuse and recycling will be lowered in future through better design of new equipment due to the feedback mechanism of producer responsibility and through additional instruments such as design standards and general obligations for Member States to encourage eco-design"[5]

Sustainable design practices will need to be implemented across the EEE industry if the conditions of the new directive are to be met. The strict recycling targets will likely require manufacturers to reduce the number of materials used and increase the ease of dismantling the product at EOL. The requirement to phase out certain hazardous chemical by 2008 is also likely to affect the design and complementary legislation in the form of the Restriction of Hazardous Substances Directive will also mean certain substances, particularly lead, will have to be phased out of EEE by 2006.

All this is particularly relevant to mobile phones. Currently mobile phones have too short a life cycle, contain too many hazardous materials, and are too difficult to recycle. There is a danger that the E-Waste situation seen with computers and other household electronics will soon include significant numbers of mobile phones if a solution to these problems is not found soon. Currently it is extremely difficult to recover much of the materials used in mobile phones at EOL due to dismantling difficulties and the mixture of materials involved. Even with the best mobile takeback schemes much of the plastic used in a mobile phone is either incinerated for power or shredded and made into low grade plastic for traffic cones or horse gallops.

It is clear that much of the environmental impact of the mobile phone is inherent in its design and with the emphasis on sustainable design in the new European WEEE directive there will soon be a legal imperative for sustainable design. In the case of mobile phones, more sustainable design would need to focus on the reduction or removal of toxic substances in the phone and its accessories, the minimisation of waste during manufacture, improving recyclability at end of life by reducing the number of materials used and increasing ease of dismantling, and looking at ways to reduce the environmental impacts during the use phase of the handset.

2.1 Research framework

This dissertation will investigate the environmental impacts of the disposal options for mobile phones at their End of Life (EoL). Initial research will establish the limits of the paper, firstly investigating the current situation. This paper will concentrate on the situation within the EU as Asian and American markets have very different trends and technologies and in order to set some limit to the scope of the paper. This will involve looking at the current options for mobile handsets at EoL, talking to recyclers, refurbishers, and manufacturers for their opinions on the various options. This will also require investigating the current state of the industry and determining the major and emerging manufacturers. It will also require the environmental impacts of each EoL option to be determined, so some system of measuring impacts will need to be found.

Secondly, it will be necessary to investigate the trends in mobile phone design and EoL options in order to further understand the nature of the industry and the drivers behind the design of the products. This will involve looking at changes in weight, design, functionality, power consumption and disposal options.

Next, it will be necessary to investigate the current environmental legislation regulating the industry; this will allow the legal drivers affecting mobile phone usage and design to be established.

Then it will be necessary to investigate future trends in design, phone usage and legislation, to identify the changing direction of the mobile industry and the drivers likely to affect the future design and disposal of mobile handsets.

It will also be necessary to look at the history of the mobile phone, looking at how it has developed, how usage has spread and the problems this has caused. A historical perspective can also allow the drivers that have driven mobile phone development in the past to be identified; these can then be compared with the current and future factors affecting the designs.

A historical perspective on the environmental legislation governing mobile handsets will also prove useful, identifying the rising environmental problems that have prompted legislation and why these have been particularly identified for regulation.

Finally, techniques and measures for minimising the environmental impact of mobile handsets will need to be identified. This will require looking into the rising role of the environment in the design of mobile handsets, and the principles of sustainable development that govern this. This will also involve looking into methods for evaluating the environmental impact of products such as Life Cycle Analysis.

The analysis stage will require evaluating the environmental implications of the various EoL options currently available for mobile handsets, the impact of current and forthcoming legislation on this and the impact of possible design modifications to target and reduce areas of environmental impact.

From this research and analysis it is hoped that the comparative benefits of the different environmental legislation and design options will be identified and conclusions on the effectiveness of each to be drawn. Recommendations for future action based on the effectiveness of these in reducing environmental impact can then be made.

2.2 Literature Review

Looking firstly at the EoL options available for mobile phones, the largest UK scheme for the collection and refurbishment of mobile handsets is a scheme called FoneBak. It is supported by the five mobile service operators in the UK and by the Dixons group. The scheme itself is run by a company called Shields Environmental, who are an Environmental management company that have close ties to the mobile phone industry. Information about the refurbishment process and the recycling for phones that cannot be recycled is found in a number of Frequently Asked Questions factsheets[2]. Further information about the company and its environmental policy is available on its website[39]. Further questions about their operations were discussed via E-mail correspondence and this is provided in Appendix C. Other mobile handset takeback schemes were also investigated but FoneBak, being the largest and having broad based industry support, is typical of the more environmentally conscious operators. For this reason data for refurbished mobile handsets comes mostly from this source.

The second source of information was the mobile handsets manufacturers themselves, having identified the largest manufacturers[16], information on their environmental policy, attitudes to sustainable design, EoL options, EU environmental legislation, the current environmental impact of their handsets and future trends were collated. While all 5 of the major manufacturers provided information towards these areas, the greatest amount of literature by far was provided by Nokia. Sony-Ericsson also provided literature. For this reason (and because with 55.3% of the UK market[16] they are also the market leader) the majority of the information on manufacturer attitudes to these issues is provided by Nokia. Attitudes of the other mobile manufacturers are similar however, but with less environmental information provided would not have allowed as detailed analysis.

Information on the early development of the cell phone and cell phone technology was found on the web in a comprehensive series of articles[6]. Information on trends in mobile phone ownership across the OECD is from EU publications[7]. The UK telecommunications regulator OfCom's report into mobile ownership[9] and revenues also revealed data on the current size and state of the industry.

General information on the development of environmental legislation was provided in T Brenton's 'The Greening of Machiavelli'[24], which provides a useful summary of historical environmental thinking, legislation and trends. More specific information on EU legislation affecting the Electronic industry was provided by the Environment Agency[40], and by mobile manufacturers[32].

More specific information on the problems presented by electronic waste was provided by a number of news sources, notably from the BBC[41] and CNN[11]. Justification for future legislation was also outlined in the Proposal for a Directive of the European Parliament and of the Council on Waste Electrical and Electronic Equipment and on the Restriction of Certain Hazardous Substances in Electrical and Electronic Equipment (2000)[4]. Information on the growing problems of electronic waste being exported to the developing world was found in the Basel Convention[42], the Regulation Establishing Common Rules and Procedures to apply to shipments to Certain Non-OECD countries of Certain Types of Waste[3]. The Report, Exporting Harm – The high Tech Trashing of Asia[12] from the Basel Action Network was also useful in exposing the health risks associated with electronic waste.

The EU was able to provide the full directives on Waste Electrical and Electronic Equipment (2003)[18] and the Restriction of Hazardous Substances (2003)[23] identified as being the primary legislation affecting the electronics and electrical manufacturing industry. These allowed the specific impacts of this legislation on the mobile phone industry to be evaluated.

Information on sustainable design principles was gathered throughout this Sustainable Product Design MSc with particular reference made to Prof. G Howarth's 'Sustainable Product Development Guidance for Designers'[43]. Information on Life Cycle Analysis principles was provided by Pré Consultants[34], with specific information on the use and limitations of Eco Indicator 95 provided by the Eco Indicator 95 Manual for Designers[36]. Material properties and other information in appendices A and B is from the Cambridge Engineering Selector[38] (CES) materials database.

3. Historical Overview

3.1 History of Problem

The history of cell phones begins in 1947 when American researchers proposed a system for mobile car phones that used ‘cells’ or ranges of service area and frequency switching to greatly increase the traffic capacity of existing systems. The technology to implement this was still a long way off however and the Federal Communications Commission (FCC) was reluctant to allocate the necessary radio spectrum frequencies to the new technology. The frequencies made available for cell phones only allowed 23 simultaneous conversations in each service area severely limiting any potential commercial applications of the new technology.

This situation continued until 1968 when the FCC issued a statement that:

“if the technology to build a better mobile phone service works, we will increase the cellular phone frequencies allocation, freeing the airwaves for more mobile phones." [6]

Following this pronouncement AT & T proposed a cellular phone system consisting of a number of small, low powered broadcast towers each covering a ‘cell’ of a few miles with the towers collectively covering a far larger area. Each tower was to use only a few of the frequencies allocated to the network and as cars moved across the area the signal from their cell phone would be transferred from tower to tower.

In 1977 AT & T developed a prototype cell phone system, this was extended in 1978 to public trail of the new system in Chicago. In 1979 the first commercial cell phone network was opened in Tokyo and the modern commercial cell phone became possible.

Cell phone networks were introduced to Europe in 1981 when the Nordic Mobile Telephone System began operating in Denmark, Sweden, Finland, and Norway. This was also the first multinational application of the new technology. In 1985 the UK introduced its own Total Access Communications System (TACS), quickly followed by the West German C-Netz System, the French Radiocom 2000 system, and the Italian RTMI/RTMS system. Soon Europe had nine separate, incompatible radio telephone systems. This situation was not sustainable however and in 1982 plans were first developed for a single, digital, European wide system called Group Speciale Mobile (GSM). GSM was introduced commercially throughout Europe in 1991.

Handset technology was also increasing at pace with phones rapidly developing from bulky, briefcase sized units, via converted police radio designs to the first truly handheld digital GSM phone, the Ericsson Olivia in 1989. (see diagram 3.12).

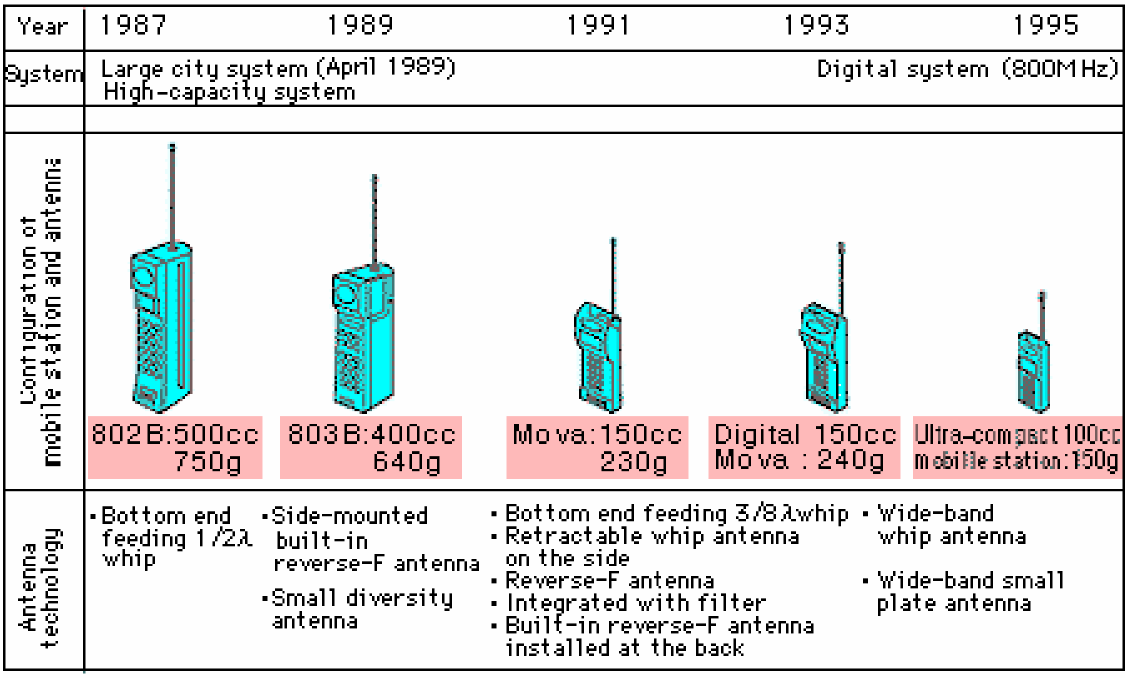


Fig: 3.12: Development of Mobile Handsets[6]

Cellular phone technology proved immensely popular, and ownership has increased across thee OECD from just 1% in 1990 to 27% in 1999[7]. Since then ownership has continued to increase exponentially and it is estimated that there are currently 50 million mobile handsets in circulation in the UK representing 75% of the population[1].

As the technology develops mobile phone handsets have become smaller, lighter and have longer battery life. This is illustrated by the diagram above which graphically shows the rapid reduction in size and weight of mobile handsets during the early stages of the European digital GSM network. Mobile handsets today are a fraction of the size and weight of the early ‘brick’ phones and offer far greater functionality and battery life. Indeed the technology has developed to the point where the size and weight of a conventional mobile handset is now limited by ergonomics rather than technological abilities and this has led to a levelling off in the trend for ever lighter, smaller mobile phones. As the diagram below shows the weight and energy efficiency of mobile handsets have continued to improve though show some signs of levelling off.

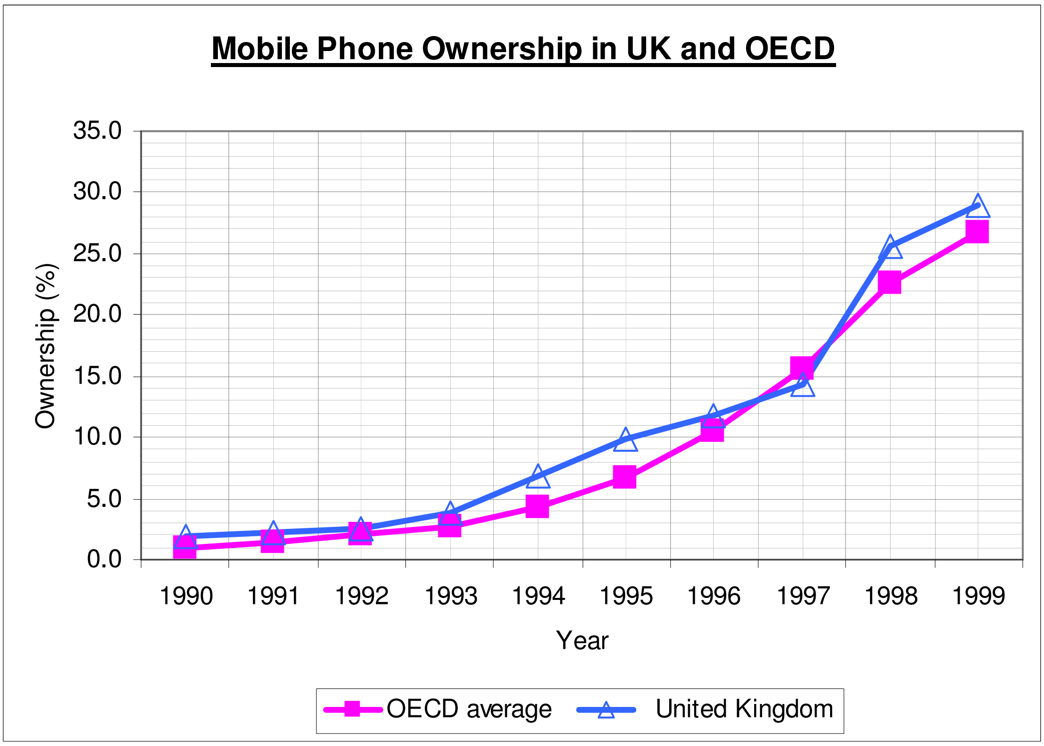


Fig 3.13: The growth in UK and OECD Mobile Ownership[7]

New emerging technologies such as 3G allowing very fast data exchanges and video calls, and the combining of mobile handsets with digital cameras and palmtop computers in the form of Personal Data Organisers (PDA's) have led to a slight increase in size, weight and power consumption in recent years but this is offset by the far greater range of services offered.

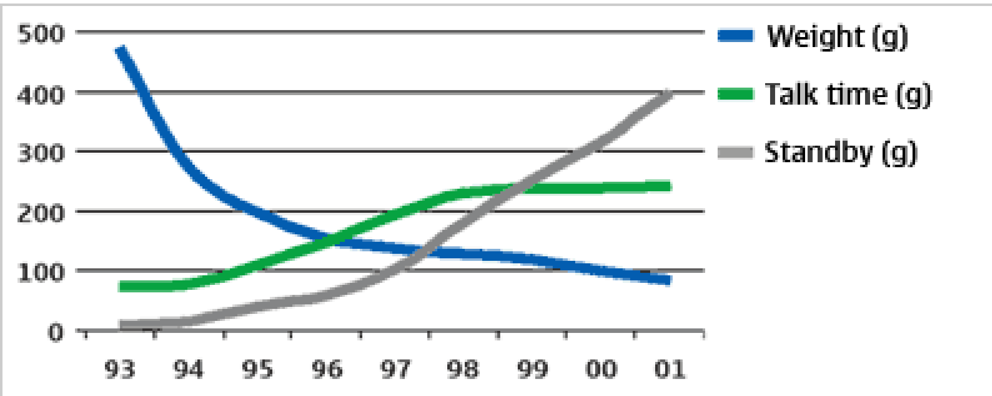


Fig 3.14: Mobile Weight and Efficiency trends[8]

The range of services available on standard 2G mobile phones has also broadened with text messaging and ever more customisable ring tones, covers and screensavers proving immensely popular. This broadening of services is likely to continue as 3G technology becomes more widespread and the mobile handset looks set to become far more than a simple portable telephone.

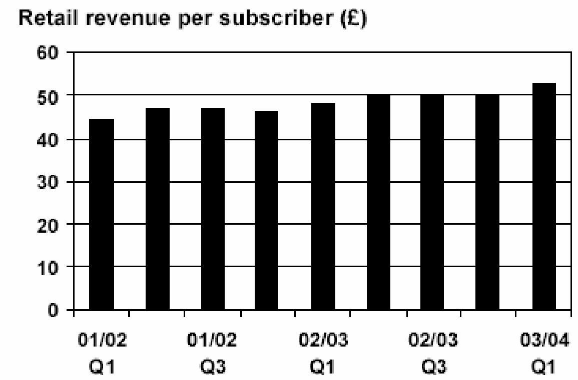


Fig: 3.15: Revenue from mobile calls in the UK[9]

The most recent figures for the UK (2003) show that the number of mobile handsets in circulation has exceeded 50 million with 75% of the population now owning at least one mobile handset[1]. Calls made form mobile phones account for 15% of the total volume of calls made in the UK and 47% of the revenue, with the retail revenue per customer for service providers increasing to its highest level in 3 years, illustrating the size of the market for mobile phone manufacturers and providers[1].

3.2 The Rise of WEEE

The number of household electronic and electrical goods has been growing rapidly as more and more labour saving and entertainment devices appear. As technology accelerates the useful life of household Electronic and Electrical Equipment (EEE) has shortened. For example, in the 1960's the first computers were used for an average period of 10 years, today that period has shrunk to 4.3 years and, for the most innovative products like mobile phones, already less than 2 years[10]. This has meant that EEE has increasingly become a significant and rapidly growing waste stream. Today WEEE is the fastest growing waste stream in Europe, more than 90% of it is either landfilled or incinerated[4] and due to the complex mixture of materials in EEE it is responsible for a large proportion of various pollutants found in the municipal waste stream.

According to a new study by environmental research group Inform, people living in the United States will soon be getting rid of about 130 million mobile phones every year.
"That's about 65,000 tons of cell phones and ultimately they are thrown away," says Joanna Underwood, spokesperson for Inform. Manufacturers offer a steady stream of newer, multi-function models, prompting the average customer to purchase a new wireless phone every 18 to 24 months."[11]

In order to combat this rise in potentially toxic waste the EU has introduced a number of directives aimed at minimising the impact of WEEE. The two most significant of these are the WEEE directive, which obliges manufacturers to collect their products at disposal and meet certain recycling targets at EoL, and the Restriction of Hazardous Substances in Electrical and Electronic Equipment directive (RoHS), which calls for the significant reduction or elimination of potentially harmful substances in Electronic and Electrical Equipment, in particular lead, a major component of solder for electronic components. These directives will mean a far greater accountability for manufacturers to the waste and environmental hazards their products create. EEE and the environment are likely to be increasingly linked at the design stage and these directives will present significant design challenges in meeting recycling targets and material substitution for substances like lead, used in solder and restricted under the RoHS directive. Both of these directives are likely to have significant impacts on the future designs and actions of household electrical and electronic goods manufacturers and these are discussed further in section 3.3.

3.21 Restrictions On Movements Of Potentially Harmful Substances

Increasing environmental awareness through the 80's prompted the creation of an international treaty regulating the trade in toxic wastes. The Basel convention was proposed in 1989 and entered force in 1992, and aims to regulate the international movement of hazardous waste. The Convention calls for countries to become self-sufficient in the management of their hazardous waste and to reduce the generation of such waste. The Convention also sets strict controls on the 'trans-boundary movements' of hazardous waste aiming to prevent the export of waste from developed countries to developing countries for economic means. The exporting country is required to notify and obtain the consent of the importing country and the export of waste from OECD countries to non-OECD countries is totally banned.

The Basel convention has already been cited with regard to the economic export of computer and other household electronic waste for repair and recycling in Asia and Pakistan. A report, called Exporting Harm: The High Tech Trashing of Asia[12] details specific case studies of villages in China, Pakistan and India where piles of computers, telephones and cell phones arrive from the US for 'recycling'. The WEEE is then dismantled and valuable components salvaged (though the most valuable components are usually removed by the 'recycling' companies responsible for exporting the WEEE). The waste is the burnt over open fires or has acid poured on it to release small quantities of precious metals which are then sold. This causes significant health problems releasing dangerous carcinogens and heavy metals such as lead, cadmium and mercury into the air and into the water table.

Fig 3.21: Electronic waste from OECD Countries in China[41]

A case could be made for applying the Basel convention to the economic export of refurbished mobile phones. Again 'recycling' is being used to justify the shipment of potentially hazardous goods with limited performance and life span to the developing world. By exporting these phones as refurbished goods OECD countries are able to sell to non-OECD countries which have limited resources for dealing with the potentially dangerous substances these contain at end of life. If refurbished mobile handsets are dealt with at disposal in this way they will simply add to an already serious problem. As the life cycle analysis of mobile phones in section 5 indicates, there is a significant environmental burden generated by the high numbers of components and potentially dangerous substances at end of life. Refurbishment and export of mobile handsets shifts the environmental burden of disposing of the handset to the developing world.

Mobile phone refurbishment is also opposed by mobile phone manufacturers; they see the sale of refurbished handsets overseas as direct competition, the performance of refurbished handsets as potentially damaging to their image and are keen to point out the environmental dangers of disposing of the phones at EoL without sufficient waste management resources. Nokia illustrates the unease with which manufacturers view this emerging industry in the following quote (For full correspondence see Appendix C):

"Nokia does not carry out refurbishment business as a company. We do not currently support any refurbishment carried out by refurbishment companies.

There are two reasons for this:

First of all Nokia has no control over the quality or safety of the phones that are resold after restoration. Furthermore we do not want to make the third world a place where the industrialised world dumps old technology. We believe that a more sustainable solution is to utilise the significant advances made in technology in the past decade, and offer products that are optimised for developing markets."[13]

Nokia also cites the Basel convention in reference to the safe disposal of mobile handsets at end of life in its environmental policy.

"Nokia has entered broad-based cooperation on the environmentally sound management of end-of-life mobile phones under the aegis of the UN Basel Convention to promote, among other things, environmentally sound take-back of end-of-life mobile phones."[14]

In addition to the Basel convention the European Union has passed the directive on the Trans-boundary Shipment of Wastes which also limits the shipment of certain types of waste to non-OECD countries like those receiving refurbished mobile handsets.

3.3 State of the Art

Currently the mobile handset market in the UK is dominated by 5 major manufacturers, with Nokia holding by far the greatest share. Siemens, the second largest manufacturer, has increased its market share in the UK by 5% over 2002 to overtake its rivals. The market for mobile handsets is extremely fickle, with trends and fashions playing a major part in determining the fortunes of a new handset. This is graphically illustrated by the plight of Motorola, once one of the world leading mobile handset manufacturers, now lagging behind relative newcomers like Siemens in market share and facing financial difficulties.

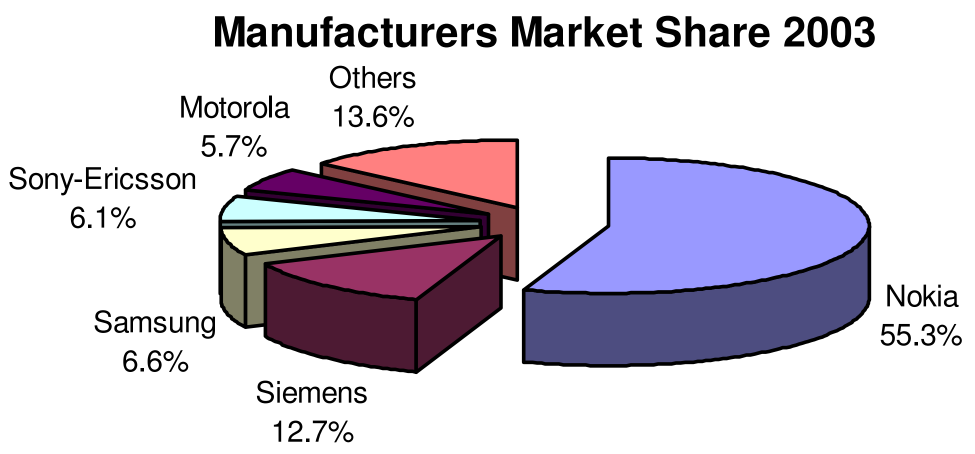


Fig 3.3: Manufacturers Market Share 2003[16]

The mobile market is however one of rapidly evolving technologies and advances like third generation phones ('3G') and the combined personal data assistants (PDA) and cell phones may well significantly change the market balance in the coming years.

At the present time imminent environmental legislation in the form of the WEEE directive is forcing many household goods manufacturers including mobile phone manufacturers to reassess the design of their products to ensure they are able to meet the new strict recycling targets required.

Looking at the environmental policies of some of the larger mobile handset manufacturer's shows sustainable design principles emphasised. For example, the market leader Nokia has an extensive section of their web site devoted to the companies' environmental policy, particularly highlighting the need for full life cycle analysis on all products to evaluate their true environmental impact. The policy also outlines the key design principles used to minimise energy and materials consumption while maximising the possibility for recycling and reusing at end of life. These are listed as:

- Use recyclable materials
- Use compatible materials

- Avoid contaminants
- Use simple fastening methods to join materials together
- Use clear material identification and marking
- Ensure easy removal of batteries and printed wiring boards[14]

Each of these design aspects is discussed further and ranked for their potential effect on a mobile handsets environmental impact in section 4.

There is no mention of increasing the use life or repairability of the handsets though as these would likely reduce the turnover of mobile phones and thus the number of customers for handsets this is not really surprising.

The policy also outlines 'focus areas' for improving sustainable design in their mobile phones, these are:

- Material substitution
- Disassembly – aids the separation of materials for recycling
- Recyclability
- Energy efficiency of power supplies[14]

Reducing the energy consumption of power supplies can be extremely significant in reducing the overall environmental impacts of mobile handsets, as this is the main cause of environmental impact during the use phase of the product. Though there is currently no legislation enforcing efficiency targets for power supplies, Nokia, in common with other mobile phone manufacturers and household EEE manufacturers, has signed up to the EU's voluntary Code of Conduct on Efficiency of External Power Supplies (2000)[15] which sets targets for reducing the power consumption of power supplies, in particular the stand by power consumption. The impact of this is discussed further in sections 4 & 5.

Sony-Ericsson also presents a similarly impressive environmental policy, again emphasising the use of life cycle analysis in sustainable design. Recycling is again mentioned as a focus area for reducing the impact of mobile handsets, and is again the only EoL option discussed.

On the subject of end of life practices both companies focus on recycling as the primary method of reducing the environmental impact of their products. Nokia outlines the need for manufacturers to collect their products at EoL citing schemes in Finland, Asia and Australia to illustrate differing ways of doing this. Neither company mentions in their recycling policy the possibility of refurbishing handsets to extend their use life or expresses any opinions on this option.

3.31 Recycling at EoL

Current methods of recycling mobile phones at EoL (in common with most EEE) are relatively crude, mostly hindered by the difficulty of separating out different materials for individual recycling. The ease of disassembly of their handsets is an area already highlighted by Nokia for particular focus in their environmental policy.

Nokia's environmental policy also gives a brief description of the recycling process used:

"In a typical process, mobile phones are shredded after the battery has been removed. Plastics and metals are then separated - precious metal refining and copper smelting are used to recover the metals and the plastics and attached materials can be used as fuel during metal recovery."[14]

There is usually some manual pre-treatment to remove obvious components containing precious metals or those requiring special treatment. Recycling in this way recovers metal content but plastics and other materials are usually burnt as fuel. This is because it is difficult to fully separating the plastics for recovery and they are often contaminated with decals, paints and flame retardants or bonded to dissimilar plastics or other materials. Burning these plastics as fuel allows some recovery of the energy invested in their manufacture.

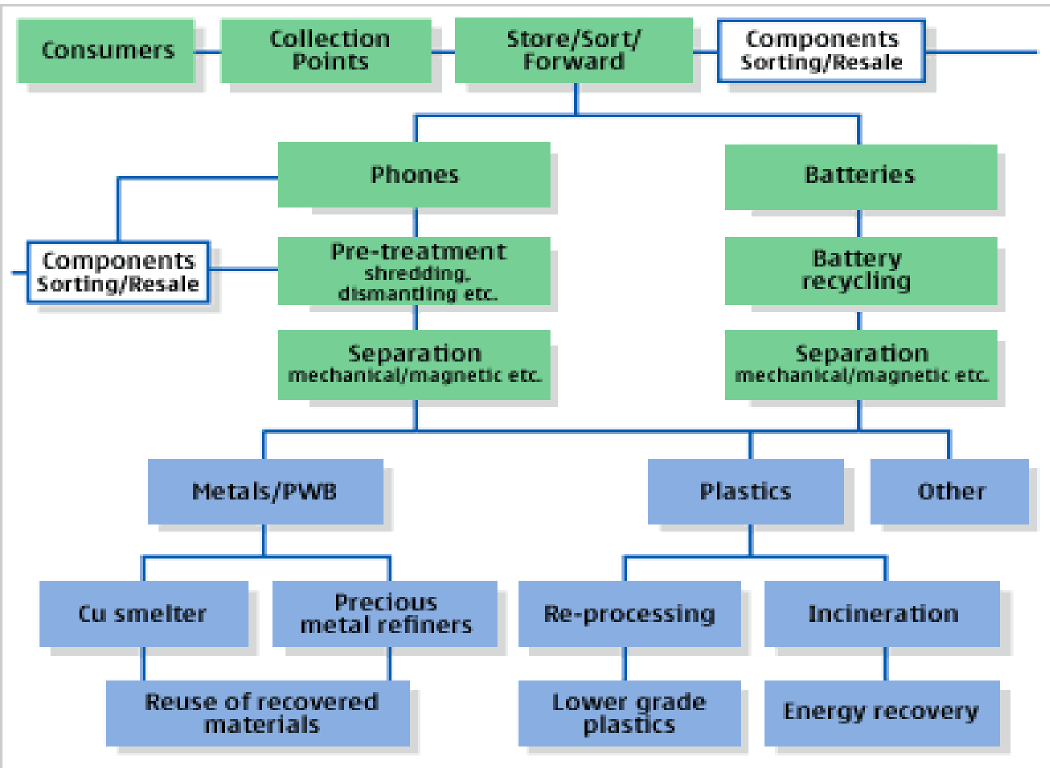


Fig 3.31: Flow chart for typical mobile handset recycling[14]

Recycling in this way can still prove economically viable however and Nokia is keen to point this out:

"Our studies show that it definitely pays to recycle products. The recovery of metals is valuable, as recovered metals will have lower energy content than virgin metals. Where commercial companies are involved, competition has also greatly reduced recycling fees."[14]

The economic viability of recycling is likely to increase as landfill taxes for WEEE increase prior to the full implementation of the WEEE directive which may provide an additional incentive for companies to adopt 'design for recycling' concepts at the design stage.

Sustainable design concepts facilitating ease of disassembly and material separation at end of life are already in place for the majority of phone manufacturers and this is set to increase as the WEEE recycling targets come into force.

New technologies such as Active Disassembly using Smart Materials (ADSM) are also being developed which, if they can be economically implemented would allow far greater material separation and therefore greater material recovery. ADSM technology is discussed further in section 3.5.

3.32 Re-using

Many mobile handsets in this country however, are not recycled at end of life. A number of companies specialising in repairing and refurbishing mobile handsets for sale overseas have appeared, the largest being Fonebak, which is run by Shields Environmental and supported by the 5 big UK mobile operators and a number of high street retailers. Handsets are collected through collection points in retail outlets or through freepost envelopes. Of the collected handsets between 50-80%[17] are then refurbished and repaired (this consists mainly of checking and replacing batteries, removing old SIM cards, unlocking the handsets and replacing simple damaged components like LCD displays) before being sold throughout Europe, the Middle East, Africa and Asia. Handsets that cannot be repaired are cannibalised for useable components before being recycled in a similar way to that described above, i.e. with metals recovery for recycling and energy recovery from plastics and other components.

The fonebak scheme handles about 100,000 handsets annually and earned shields environmental £25 million from overseas sales last year (2002)[2].

Manufacturer's reactions to reuse and reselling schemes like Fonebak have so far been to consider it direct competition. This is because the refurbished phones are being sold in competition with new handsets in emerging markets. There is also contention over the effect of such sales on the perceived image of the company. It is unlikely that a refurbished mobile handset, which will already be nearing the end of its design life and has been transported to a new climate, will be as reliable as a new handset and this may damage the reputation of the original manufacturer.

When questioned as to the attitude of manufacturers to the refurbishment and resale of their handsets at EoL Nokia responded by saying that they did not support this practice because of its potential effects on the perceived quality of the brand and impact at EoL in countries with insufficient waste management infrastructure to deal with WEEE (see Appendix C for full correspondence).

However, as new legislation in the form of the WEEE directive comes into force, complete with a clause in article 6 stating that *"Member states shall give priority to the re-use of whole appliances"*[18] it is hoped by Fonebak that support will grow. However the proposal for the WEEE directive also includes the statement:

"The recycling targets of Article 6 merely refer to waste equipment which has been separately collected according to Article 4 of the Proposal. The re-use of components, not the re-use of whole appliances, contributes to the achievement of these targets."[19]

This implies that such schemes are not going to contribute to the recycling targets set, and therefore manufacturer support is unlikely to be forthcoming.

3.4 Current legislation

As awareness of the problems posed to the environment by the ever increasing use of technology, and particularly by the impacts of potentially dangerous materials finding their way into the waste stream through the disposal of Electrical and Electronic Equipment a raft of new EU environmental legislation has been introduced. This legislation and its likely impacts on the mobile phone industry are summarised below.

3.41 The WEEE Directive

To combat the environmental impact of rising levels of WEEE and other waste throughout the EU, a number of directives have been passed. Potentially the most significant of these is the WEEE directive (2003). This directive aims to greatly reduce the volume and impact of EEE in the waste stream. This is to be achieved by increasing producer responsibility to include takeback schemes for electrical equipment at the end of its life in order to separate them from the household waste stream towards specific recycling facilities. Restrictions on the use of some of the more hazardous chemical and additives are also imposed to prevent these leaching into the surrounding soil from landfill sites. Perhaps the most significant aspects of the WEEE directive however are the recycling requirements for EEE at EoL. These require EEE manufacturers' products to be between 65 and 85% recyclable by weight depending on the nature of the EEE, for mobile phones the figure is 65%.

The WEEE directive, particularly the recycling targets it outlines are likely to have a significant impact on the design, marketing and disposal of electronic products such as mobile phones. The directive, in common with other EU environmental directives, adheres to the 'polluter pays' principle outlined at the start of the directive:

"The objectives of the Community's environment policy are, in particular, to preserve, protect and improve the quality of the environment, protect human health and utilise natural resources prudently and rationally.

That policy is based on the precautionary principle and principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay."[20]

This means that it is the manufacturers' responsibility to ensure their products comply with the new regulations and are collected, disassembled and recycled at EoL to meet the recycling targets.

The directive also indicates the need for more sustainable design to minimise the impact of electronic equipment over its life cycle. Sustainable Design concepts involve minimising the likely impacts of a product at all stages of its production. With this emphasis the EU aims to deal with likely environmental impacts at the source:

"The establishment, by this Directive, of producer responsibility is one of the means of encouraging the design and production of electrical and electronic equipment which take into full account and facilitate their repair, possible upgrading, reuse, disassembly and recycling."[21]

And:

"Member States should encourage the design and production of electrical and electronic equipment which take into account and facilitate dismantling and recovery, in particular the re-use and recycling of WEEE, their components and materials. Producers should not prevent, through specific design features or manufacturing processes, WEEE from being reused, unless such specific design features or manufacturing processes present overriding advantages, for example with regard to the protection of the environment and/or safety requirements."[20]

The directive also indicates re-use as the most environmentally sound technique for minimising the environmental impact of EEE:

"Where appropriate, priority should be given to the reuse of WEEE and its components, subassemblies and consumables. Where reuse is not preferable, all WEEE collected separately should be sent for recovery, in the course of which a high level of recycling and recovery should be achieved. In addition, producers should be encouraged to integrate recycled material in new equipment."[22]

This seems to indicate that the refurbishment of old mobile handsets complies with the WEEE directive and indeed seems to be encouraged, however the proposal for the directive includes the statement:

"The recycling targets of Article 6 merely refer to waste equipment which has been separately collected according to Article 4 of the Proposal. The re-use of components, not the re-use of whole appliances, contributes to the achievement of these targets."[18]

This indicates that refurbishment cannot be counted as contributing to the recycling targets the WEEE directive sets out. When questioned as to where the refurbishment of mobile handsets sits in relation to the WEEE directive FoneBak responded as follows:

"The WEEE Directive encourages reuse as a better alternative to materials recycling – in order for reuse to take place mobile phones have to be refurbished"[17]

The effect of the increased recovery of materials from mobile phones at EoL that will follow the full implementation of the WEEE directive on the total environmental impact of mobile handsets is investigated further in section 5. The environmental impact of refurbishing mobile handsets is also discussed in section 5.

3.42 The Restriction of Hazardous Substances Directive

The Restriction of Hazardous Substances Directive (2003)[23] affects manufacturers of electrical and electronic equipment containing lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls or polybrominated diphenyl ethers. Each of these substances is to be phased out due to their hazardous affect on health. The directive is intended to complement the WEEE directive in reducing the environmental impact of EEE. The most significant of the restricted substances for the EEE sector is lead. This is a major component in solder for electrical and electronic components and the transfer to lead free solder is likely to cause manufacturing problems. The directive comes into force in 2004 and the hazardous substances it names must be eliminated from all new EEE but a few special exemptions by 1 July 2006. The environmental effects of eliminating these substances from mobile handsets are discussed in section 4.

3.43 The Basel Convention

The Basel Convention, and the complementary EU Regulation Establishing Common Rules and Procedures to Apply to Shipments to Certain Non-OECD Countries of Certain Types of Waste (1999) make it clear that the export of WEEE and the dangerous chemicals it contains is to non-OECD countries is not allowed. This affects mobile handset refurbishers, who, as they are exporting EEE technology which would otherwise enter the waste stream, could be considered to be exporting WEEE. In reality the case is more complex than this. When asked as to how mobile handset refurbishment fits into the new WEEE directive FoneBak responded by claiming that the average design life of a mobile handset is 7 years (see Appendix C for a full transcript of correspondence). However literature supplied with new mobile phones suggests that the battery, at least should be replaced every 6 months[44] and are only guaranteed for this period of time. As batteries contain a significant proportion of the dangerous chemical within mobile handsets this would suggest that even handsets exported with new batteries may need replacement batteries in just 6 months.

The issue of what constitutes waste electrical goods is a complex one; however Life Cycle Analysis (LCA) in section 5.7 indicates that there may be other environmental impacts from refurbished phones (namely their energy efficiency) that make it difficult to justify refurbishment for resale abroad in environmental terms. It should be noted however that economically this business can be very lucrative for refurbishment schemes run for profit.

3.5 Critique and Summary

3.51 Legislation

Environmental legislation remains the primary tool for governments to enforce the protection of the environment and since the first rise in public awareness over environmental issues in the 1960's. Since then, a huge raft of both domestic and international environmental legislation has been put in place with varied success. Historically the success of environmental legislation has been dependant on realistic targets and effective enforcement with sufficient penalties for non compliance to deter polluters. This has been illustrated by the situation in the former USSR where unachievable targets, light penalties and an economy that remained overwhelmingly focussed on production targets meant that the legislation was largely powerless with fines for non-compliance in many cases simply budgeted in advance[24].

The new wave of environmental legislation within the EU, and in particular the WEEE directive set very strict targets and are aimed at generating a cultural shift towards a sustainable economy at all levels. The WEEE directive and the forthcoming End of Life Vehicles Directive[25] set new and unprecedented standards in producer responsibility for the environmental impact of their products at EoL. Both directives require manufacturers to develop and implement collection schemes for their products, removing them from the environment so they can be recycled and disposed of safely. The Restriction of Hazardous Substances Directive requires the phasing out of hazardous substances such as lead in electronic equipment (in particular in solder) by 2006. These directives are part of the European Union's drive towards sustainability and aim to encourage sustainable design principles in design including techniques such as Life Cycle Analysis to look at the full impact of products along their life cycle, particularly at EoL. The EU has tried to ensure these directives are successful through industry consultation and the gradual phasing in of targets but the pitfalls that hampered the effectiveness of environmental legislation in the former USSR in the form of unachievable targets, little state support for necessary improvements, inadequate policing and very light penalties for non compliance still apply. These new directives provide a very real incentive for companies to adopt sustainable design concepts for their products, but this is dependant on real enforcement of the directives.

It is also important for the true benefits of the environmental legislation in question to be evaluated. In section 5 the environmental impacts of a typical mobile handset over its life cycle are analysed using Life Cycle Analysis (LCA), the changes to the total environmental impact caused by the introduction of the WEEE directive, the voluntary Agreement on the Efficiency of Power Supplies and the Reduction of Substances Hazardous to Health directive can then be shown. This can illustrate which, if any of these measures significantly reduces the environmental impact of the handset.

3.52 EOL options and design limitations

Currently mobile phones face either refurbishment, limited recycling or dumping with conventional household waste at end of life. Given the problems outlined above and in section 5.7 with refurbishing old mobile handsets for export excluded from the recycling targets, with 50-80% of phones sent for recycling refurbished and the forthcoming WEEE directive strictly controlling the disposal and recycling of electronic waste it seems likely that the collection and recycling rate of mobile handsets will have to be greatly improved if the target of 65% by weight of material recovery for mobile handsets is to be met economically.

In order to meet the recycling targets of the WEEE directive there will need to be real action by mobile manufacturers, stores and mobile network providers to increase the collection and separation of EEE for recycling. Currently the recycling of EEE is economically viable, but only just, for there to be real economic as well as environmental drivers towards recycling the ease of recycling mobile handsets must be increased. This is also the case with meeting the material recycling targets, again it is possible to recycle many mobile phones for material recovery but it is an energy intensive process and is dependant on the recovery of valuable metals to subsidise the recovery of other materials. Increasing the ease of recycling mobile handsets will reduce the amount of energy invested in recycling to meet the WEEE directive targets and allow the recycling industry to become more economically viable.

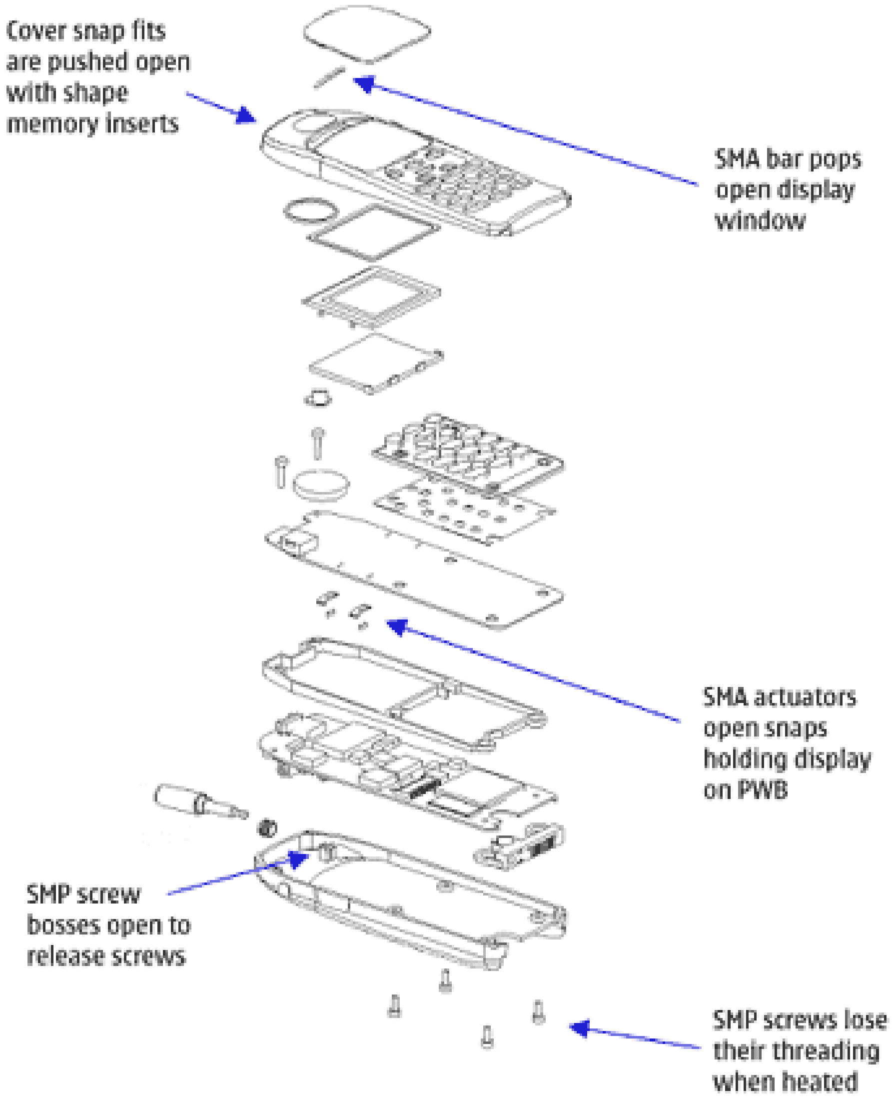
So what are the factors limiting the recyclability of mobile handsets? The prime problem is the difficulty of dismantling the handset components to isolate individual materials. Mobile phones are a complex and compact mix of electronic components, circuit boards, metal housings and plastic casings. The extreme difficulty of separating out these separate components severely limits the ability to recover potential materials through recycling and current solutions involve grinding down the handsets to isolate metal components for recycling, the remaining plastics, circuit boards, ceramics and epoxies are then incinerated as fuel to recover energy.

The simple answer would seem to be to increase the dismantability of mobile handsets, but in order for recycling to continue to flourish it must be economically viable, the work required to dismantle the handsets cannot be so excessive as to make the entire operation financially unfeasible. Another factor would be to reduce the number of materials used; this would simplify the segregation of materials for recycling. It is also important to consider the recyclability of the materials used, certain plastics, ceramics and epoxies are simply not recoverable, and flame retarding additives to plastic casings make it very difficult to recycle these also.

There is a good deal of research into increasing the disassembly of electrical equipment. Current strategies range from simplifying the fasteners used and reducing the number of bonded dissimilar components to using advanced shape memory metals and polymers to automatically disassemble the handsets. Such automatic disassembly is called Active Disassembly using Smart Materials (ADSM) and uses materials called Shape Memory Alloys (SMA's) and Shape Memory Polymers (SMP's) which can be moulded into a specific shape for normal use but will return to their original shape when heat is applied. This ability to have two shape phases allows catches and clasps to open automatically at certain temperatures disassembling the handset. It is also possible to set different fasteners to open at different temperatures allowing sequential separation of different material types. Nokia has been researching the possibility of using this technology to increase the recyclability of its handsets and has produced prototype handsets based on their popular 5110 model (shown in fig. 3.52 below).

These prototypes show that this technology can be used to aid dismantling for recycling without greatly increasing the size of the handset. Instead certain fastening components can be directly replaced with similar shape memory components that release their fastening when heated. One of the more promising applications of this is in the manufacture of screws and bosses that release their threads at the phase shift temperature.

ADSM technology, though promising is still a long way off being economically viable at this time however and the gains in the recyclability of mobile handsets that are likely to be necessary will have to be achieved through simplifying the disassembly of the handset, using more recyclable materials and reducing the number of materials used at the design stage.



In this Nokia 5510 prototype, smart materials disassemble the phone into sections when heated. Shape Memory Alloy (SMA) actuators curve to open the snap fits holding the cover, display, and display window in place. The screws and screw bosses are made out of a Shape Memory Polymer (SMP), such that no extra parts are required for active disassemby.

Fig: 3.52 Shape Memory Components Could Allow Mobile handsets to automatically disassemble themselves[26]

3.53 LCA to evaluate environmental impact and design solutions

One important tool for evaluating the environmental impact of a product is Life Cycle Analysis (LCA). LCA involves looking at the full impact of a product at all stages in its life cycle, these are generally divided into raw material abstraction, manufacture, distribution, use and disposal. Life Cycle Analysis is extremely useful for illustrating the true environmental impacts of a product and where they occur. These may not be immediately obvious, but identification can be used to focus on the areas where the environmental impact is most pronounced. Typically with household electronic equipment the greatest environmental impact comes from the energy consumed during the use phase, with the impacts from manufacture and disposal also significant.

Environmental impacts during the disposal phase mostly occur from the pollutants emitted during incineration or leaching into the surrounding soil from landfill. Recycling at disposal also give the opportunity to recover much of the energy invested in the raw material abstraction required for the production phase. This would immediately identify increasing power efficiency, reducing the hazardous content of the item and increasing the recyclability as the prime methods for reducing the environmental impact of individual handsets. Detailed LCA however can be used to identify in far greater detail the consequences of improving the handsets environmental performance in these areas and can be used to prioritise the changes producing the greatest reduction in environmental impact.

This ability to precisely identify the environmental impact of each stage of an item’s life cycle makes LCA a very useful tool for minimising the potential environmental impact at the design stage.

LCA is also useful for evaluating the effects of environmental legislation on the impact of the handset. The WEEE directive, voluntary Agreement on the Efficiency of Power Supplies and the Reduction of Substances Hazardous to Health directive each provides differing design challenges and the impact of these changes in each case can be identified.

3.6 Need for design solution

With the raft of existing and forthcoming environmental legislation expected to grow, action to minimise the environmental impacts of mobile handsets should be taken. This is most economically done at the design level, by incorporating sustainable design concepts and using tools such as life cycle analysis to identify likely impacts and tackling these at source. Life cycle analysis allows the impacts at manufacture, distribution, use and disposal to be itemised and quantified. Typically household electronic equipment such as mobile phones have the single greatest environmental impact during the use phase of their life cycle due to the electricity they consume. The energy consumed during production is usually the second biggest impact followed by the environmental impacts of any potentially harmful substances at disposal. The distribution costs of a product can be highly variable and, though an important consideration when analysing the overall impact of a product are beyond the scope of initial design modifications.

This gives three distinct areas for improving the environmental performance of mobile handsets. Firstly, the energy consumed during manufacture and the environmental impacts of the materials used in the handset can be minimised. This can be achieved through materials selection including increasing the use of recycled materials, adopting new lower energy manufacturing processes and looking at the arrangement of the factory as a whole to maximise efficient material flow.

The second area of environmental impact is the use phase. In a mobile phone this is due to the power consumed by the charger charging the battery. Improvements in phone power efficiency, battery technology and charger efficiency can all help to minimise the impact at this stage. Of particular interest is the stand-by power consumption of chargers, modern chargers require about 160 mins[27] to charge the battery, the remainder of the time they are in stand-by mode. This means that on a typical overnight charge the energy consumed by the charger while it is on standby can have a significant contribution to the total power consumed. Minimising this stand-by power consumption is one area that can significantly reduce the overall environmental impact of mobile handsets during their use phase.

Actual environmental impacts at disposal for many household electronic goods are less that might be expected however, the disposal of waste throughout the EU is becoming a significant environmental issue as landfill sites fill up and the volumes of household waste continue to increase. EEE is the fastest growing household waste stream and legislation in the form of the WEEE directive is already in place to reduce the amount of EEE that enters the household waste stream. This may make the reduction of environmental impacts at disposal an issue of legislation rather than true environmental benefit. The prime method for reducing the levels of WEEE outlined in the directive is the responsibility of the manufacturers to collect and ensure the correct disposal of their products and end of life. The directive sets out strict recycling targets to further minimise the impacts at EoL.

Currently the theoretical recyclability of mobile handsets lies between 65 and 80%[28], this is within the recycling targets outline in the WEEE directive however, this is difficult to achieve in practice as the difficulty and time involved in segregating the various materials can make the process uneconomical. Minimising the environmental impact at disposal, as well as meeting environmental legislation will involve the reduction or elimination of dangerous substances from mobile handsets and improving the ease of recyclability at EoL by increasing the ease of dismantling, minimising the number of materials used and increasing the number of recyclable materials used.

The following section outlines in more detail specific design improvements for minimising the environmental impact of mobile handsets.

4. Design Solutions

The easiest way to reduce the environmental impact of a product is to do it at the design stage; this is identified in the relevant European environmental law as being the priority. Sustainable design involves designing products and processes with reducing the likely impacts on the environment from the raw materials used to the impacts throughout the products life very much in mind. The aim is to create products that do not cause environmental problems through their production, use or disposal by identifying and minimising the impacts at each of those stages. The use of LCA software can be an extremely useful aid in identifying where the greatest impacts lie, the causes of the impacts and can be used to test out the effects of different materials and technologies on the overall impacts of the handset.

In this section design solutions for improving various aspects of the environmental performance of a mobile handset are proposed before each is evaluated using LCA software in the following section. This allows the likely benefits of improving each of these aspects to be identified and this can be used to prioritise and rank the design modifications according to their effect on the handsets overall environmental impact.

Unfortunately the full data for the processes energy used in the production of mobile handsets is unavailable, so the environmental cost of production is based solely on the environmental costs of abstracting the materials that typically constitute a mobile phone. This means that material substitution in order to minimise manufacturing and disposal costs may not incorporate potential increases in energy consumption or waste arising from any new or modified manufacturing processes that may be necessary.

Another area that affects the environmental cost of production is the overall efficiency of the factory, this not only includes the energy consumption and efficiency of each process used, but also the efficiency of material flow through the factory. Historically similar manufacturing processes have been grouped together but this may lead to very convoluted and inefficient material paths through the factory. Techniques such as rank order clustering can aid in organising factories so that the length of the material paths through the factory for individual products is minimised. Such techniques however would require detailed information on the layout, processes and energy consumption of mobile phone factories and this is beyond the scope of this dissertation.

The following aspects of mobile phone design are analysed using life cycle analysis in section 5 to evaluate their effect on the overall environmental impact of the phone. In each case modifications are proposed based on two estimates of a typical mobile handsets material composition. The first of these is data from mobile takeback sites in 2001[29] and shows a reasonable average weight percentage of materials for the phone they have received for refurbishment or recycling. Given that handsets sent to the takeback scheme were most likely bought between 18 months and 2 years prior to the publication of these figures this can be assumed to be a typical consumption for older mobile phones from around 1999. Full details of the material properties for the materials in this composition are given in Appendix A.

ABS-PC	**29%**
Ceramics	**16%**
Cu and compounds	**15%**
Silicon Plastics	**10%**
Epoxy	**9%**
Other Plastics	**8%**
Iron	**3%**
PPS	**2%**
Flame Retardant	**1%**
Nickel and Compounds	**1%**
Zinc and Compounds	**1%**
Silver and Compounds	**1%**
Al, Sn, Pb, Au, Pd, Mn, etc.	**>1%**
TOTAL	**100%**

Table 4.1: Typical Takeback Phone Composition[29]

The second mobile phone composition is from Nokia[30] and can be regarded as representing the typical consumption of a modern mobile phone, designed with sustainability in mind. Full material properties for each of the materials in this composition are given in Appendix B.

ABS-PC	**20%**
Cu	**19%**
Glass	**11%**
Al	**9%**
Fe	**8%**
PMMA	**6%**
SiO2	**5%**
Epoxy	**5%**
PC	**4%**
Si	**4%**
POM	**2%**
PS	**2%**
TBBA	**2%**
Ni	**1%**
Sn	**1%**
LCP	**1%**
TOTAL	**100%**

Table 4.2: Typical Nokia Phone Composition[30]

These two compositions can be regarded as representing an older design of handset and a more modern handset designed with greater regard to sustainability principles. A comparison of the two compositions and summary of assumptions made for overall environmental impact of each is shown in section 5.2.

4.1 Material Substitution

This is the process of substituting potentially harmful materials in the handsets for less harmful and/or more recyclable materials. This can involve identifying the most damaging substances involved, and then finding more environmentally sound alternatives or minimising the impact of the materials used by specifying a higher recycled content. For instance, 100% recycled copper has less environmental impact than virgin copper because the environmental damage involved in abstracting and purifying it is higher than the damage involved in recycling it. So specifying recycled copper can help to reduce the overall impact of the handset.

The effects of material substitution for environmental gain are shown using two examples; the first is the compulsory materials substitution to be brought in force by EU legislation, namely the RoHS Directive. The second example takes a more wide ranging view and shows how material substitution can reduce the environmental impact of a handset on a material by material basis.

4.11 The Restriction of Hazardous Substances in Electrical and Electronic Equipment directive

The first case looks at the effect of the soon to be introduced Restriction of Hazardous Substances in Electrical and Electronic Equipment directive, which will require mobile handsets (in common with other EEE) to remove lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls or polybrominated diphenyl ethers from their composition by 2006. This is aimed at encouraging material substitution of the most environmentally damaging materials found in EEE for safer alternatives.

For mobile handsets the most significant of these materials is lead as it is used in solder and other electrical components that are not specifically excluded from the directive. Cadmium and traces of Chromium VI are also currently present in modern mobile phones. The remaining chemicals, polybrominated biphenyls and polybrominated diphenyl ethers are used as flame retardant additives.

In the case of the Takeback phone, lead is listed as a trace material at less than 1% of the total mass of the phone while the other restricted materials are not listed. While it is likely that some of these materials are present they are only at very low levels and without accurate data, cannot really be evaluated for their environmental impact. However the Proposal for The Restriction of Certain Hazardous Substances in Electrical and Electronic Equipment (2000) outlines the case for removing lead from EEE as follows:

"Lead can damage both the central and peripheral nervous systems of humans. Effects on the endocrine system have also been observed. In addition, lead can adversely affect the cardiovascular system and the kidneys. Lead accumulates in the environment and has high acute and chronic toxic effects on plants, animals and micro-organisms.
Under Council Directive 67/548/EEC on the classification and labelling of dangerous substances, as amended, lead compounds are classified:

- R20/22 Harmful by inhalation and if swallowed,

- R33 Danger of cumulative effects.

The relative importance of any single source of exposure is difficult to predict and will vary with geographic location, climate and local geochemistry. In any case, consumer electronics constitute 40% of lead found in landfills. The main concern in regard to the presence of lead in landfills is the potential for the lead to leach and contaminate drinking water supplies.'[31]

In the Nokia phone none of the substances listed in the RoHS Directive are listed in the typical phone composition it provides, though in their environmental policy Nokia do state that Lead, Cadmium and traces of Chromium VI are still present in their phones[32]. Again, without data on the quantities involved it is not really possible to measure the change in overall environmental impact resulting from the implementation of the RoHS Directive.

4.12 Material substitution to minimise environmental effects

The second case concentrates on replacing materials with high environmental cost with materials that carry less environmental impact. This may mean using materials that have a higher recycled content, are more recyclable or are less damaging to the environment in abstraction or disposal.

Takeback Phone

Table 5.33 in section 5.3 shows the full material substitution options for the takeback phone composition. Materials such as steel and aluminium are listed as containing a typical percentage of recycled material for their application. As can be seen directly substituting the Copper, Steel and Aluminium used for entirely recycled materials greatly reduces the environmental burden caused by each material during the production phase. It is difficult however to find quality sources of entirely recycled metals and these may carry an economic penalty or involve environmental impact due to increased transportation distances from the few factories able to provide the materials.

It is also possible to replace other materials with less environmentally damaging materials and this is shown for the use of the plastic ABS-PC in mobile phone casings. The process of material substitution in this case involved looking at the mechanical properties of plastics with lower environmental burdens to find any suitable replacements. Section 5.31 shows that the material properties of PP are similar enough to replace ABS-PC in mobile handset casings while reducing the environmental load at production.

Nokia Phone

Table 5.31 in section 5.31 shows the material substitution options available for the Nokia phone composition. Again, materials such as steel, copper and aluminium are listed as containing typical percentages of recovered material for their application. As is the case with the Takeback phone composition, directly substituting these metals with wholly recycled alternatives give considerable environmental savings during the production phase, again however the same drawbacks of availability and possible increases in the environmental impact of distributing the recycled material increased distances apply.

Also in section 5.31 the case for replacing ABS-PC with the lower environmental impact PP is made using a comparison of material properties.

Tables 5.31 and 5.33 show the comparison between the overall and production specific environmental impacts for each mobile phone composition before and after material substitution have been performed.

A full list of the mechanical and environmental properties, as well as the nature of the individual environmental impacts of each of the materials in each mobile handset compositions is shown in appendices A and B.

4.2 Recyclability

The recyclability of mobile handsets affects the environmental impact at the end of their life. Other than re-use, which involves no energy or material losses, recycling is the best option for reducing the impact of a handset at EoL. The recyclability of mobile handsets is the degree to which they can be recycled. Currently recycling mobile handsets is hindered by the difficulty and time involved in disassembling and segregating the various materials. The plastics in mobile handsets are often too contaminated with flame retardants, paint and decals or bonded to dissimilar materials to allow them to be recycled for material recovery; instead they are burnt to recovery some of the energy invested in their manufacture. The number of materials involved in a mobile handset also affects the time and effort required to segregate all the materials so that they can be recycled. The fewer materials involved, the less separation is required. Recyclability is also hindered by the fact that some materials simply cannot be recycled.

Increasing the recyclability of mobile handsets therefore involves increasing the ease of disassembly and segregation of materials in handsets, reducing the number of different materials involved and increasing the number of materials that can be recycled.

4.21 Materials Reduction

The number of materials used in the mobile handset can have an effect on the recyclability of the handset at EoL. The more materials the handset contains, the more segregation is needed to maximise material recovery when it is recycled. Materials reduction looks for materials that have similar physical properties and aims to replace them with just one suitable material. In mobile handsets each of the materials involved performs a quite specific function and analysis for materials reduction has proved difficult. In each potential case the benefits of reducing the total number of materials in the handset were offset by increases in the environmental cost of the materials involved or by the unsuitability of the replacement material.

Substituting materials in this way can increase the material recovery percentages for recycling mobile handsets at EoL but the overall benefits will still depend on the degree of material separation and nature of the recycling process.

4.22 Ease of Disassembly

The ease of disassembly of a mobile handset affects the amount of work required to segregate the different materials it contains. Currently, only limited disassembly is performed on mobile handsets as the complexity and time involved makes further disassembly uneconomical. Increasing the ease of disassembly would mean reducing the number and complexity of fastenings in the handset.

Currently the limited disassembly performed on mobile phones is estimated to take a human operator on average 2 minutes per phone at a cost of 0.3-0.8 Euros[33].

New technology such as ADSM could allow great improvements in the speed and ease with which a phone is dismantled. It is estimated that ADSM could reduce disassembly times to just 2 seconds[33], with the bulk of the cost borne in the initial investment in the new shape memory materials at production and modifications to the disassembly line. This would likely increase the overall material recovery fraction as it would remove the need for manual dismantling; where the cost and time involved limits the degree to which dismantling is performed.

Again, this technology is still emerging and so precise details of the benefits cannot be analysed using LCA.

4.23 Recyclability of materials

The recyclability of individual materials is the degree and ease with which they can be recycled. At EoL some materials simply cannot be recycled or a re very difficult to recycle and if these can be replaced with similar materials that are easier to recycle the overall material recovery percentage at EoL will be increased. This process is shown for each of the mobile phone compositions in section 5.4.

4.3 Recovery percentage (WEEE)

The EU WEEE Directive calls for targets for the recycling of EEE at EoL in order to reduce their environmental impact at EoL. For mobile phones the material recovery percentage is to be 65% by 2006. This not only involves incorporating design modifications like those outlined above to increase the recyclability of handsets but also separating them from the household waste stream towards specialised recycling companies. This is one of the primary aims of the WEEE directive which establishes producer responsibility for the recovery of their WEEE from the household waste stream for recycling. The effects of meeting the recycling targets outlined in the directive on the overall environmental performance of both handset compositions are shown in section 5.5. Here the 65% recycling target is compared with the worst case scenario of the entire handset going to landfill and a best case scenario of 100% material recovery by recycling to show the impact of these different disposal options on the overall environmental impact of the handset.

4.4 Energy Efficiency

For most household electronic products the greatest environmental impact occurs during the use phase of their life due to the electricity they consume. Recognising this, the EU has introduced the voluntary Code of Conduct on Efficiency of External Power Supplies (2000)[15] which sets targets to minimise the standby power losses of

EEE including mobile phone chargers. The standby power consumption of chargers is the amount of energy they consume, having charged the battery while still plugged in to the socket. As battery charge times fall to around 2 hours and many mobile phones are left on overnight charges the standby power consumption can be a significant factor in the overall power consumption. The Draft Commission Communication on Policy Instruments to Reduce Stand-By Losses of Consumer Electronic Equipment (1999) identifies cellular phone stand-by power consumption to be around 2W. The Voluntary Code of Conduct that followed sets out the following targets for the reduction of standby power consumption for the charger power range.

No load Power Consumption			
Previous to agreement	**Phase 1**	**Phase 2**	**Phase 3**
1999	**2001**	**2003**	**3005**
~2.0W	1.0W	0.75W	0.3W

Table 3.41: Targets For Reduction In Stand-By Power Consumption Of Mobile Chargers Set By The Code Of Conduct On Efficiency Of External Power Supplies (2000)[15]

Currently mobile phones charger stand-by power consumption is between 0.6 and 0.3W which meets the targets the Code of Conduct sets out. The effect of these targets for reduction in stand-by power consumption on the overall environmental performance of the mobile handset using LCA is shown in section 5.6.

4.5 Refurbishment for Resale

Currently a popular EoL option for mobile handsets is to send them for refurbishment and resale abroad. Companies involved in schemes like these offer incentives like small donations to charity and discounts on new mobile handsets. The refurbishers emphasise their environmental credentials claiming that this reuse allows handsets that would previously have been discarded to aid communications in the developing world. In section 5.7 LCA is used to analyse the environmental effects of this.

The impact in the country of resale is modelled and compared with the manufacturers preferred solution of offering new ‘cost optimised’ products. The suspicion is that as for most electronic products the majority of the overall environmental impact is contributed by the use phase, the increases in energy efficiency in recent years will mean that for the country receiving the refurbished handsets the reduced impact from not having to manufacture the handsets will be offset by the increased power consumption of the older refurbished phones.

4.7 Discussion

The design ideas outlined above are all prompted by the increasing awareness of the environmental impacts of technology and the emergence of sustainable design philosophies that aim to minimise this. Sustainable design involves looking not only at the functionality of designs but also at their overall environmental impacts. Environmental impacts are becoming increasingly quantified as the understanding of the nature of the effects of substances and emissions on the environment increases. This allows the designer to more accurately predict the relative impacts of the materials and processes involved in each stage of the life of a product and work towards reducing this.

Sustainable design philosophies involve developing an environmental accountability for products that allows continued technological development without damaging the environment we live in. Life Cycle Analysis (LCA) is one tool that enables designers to evaluate the overall impact of product throughout their life span. The process involves assigning values to each way in which a substance or process affects the environment. This allows the impact of a product at each stage in its life cycle to be evaluated for its overall effect on the environment. The nature of the assumptions involved in assigning values to the various environmental effects of products with LCA means that it is primarily useful as a tool for comparing design options rather that giving an absolute value of the impact of a product. The complexity of evaluating every possible environmental impact of a substance or process also means that a comprehensive LCA of a product is a long and laborious process and it is often the case that LCA results are subject to assumptions as to the nature of the products use, the materials involved and the impacts that go with these. Section 5 involves using LCA to evaluate the relative benefits of the design modifications mentioned above and also includes a more detailed description of the LCA process and the specific software used in this case.

5. Life Cycle Analysis

Life Cycle Analysis (LCA) is a technique for evaluating the environmental impact of a product throughout its life cycle. Evaluating the full environmental effects of a product is a very difficult and time consuming process, it involves looking at the specific energy and materials used and wasted at every stage of its manufacture, distribution, use and disposal. Because of this it is very difficult to give an absolute value for the environmental impact of a product. LCA has been developed to simplify this process and to allow designers to compare similar products or test design modifications in comparison with the original design in terms of the environmental impact.

LCA software uses the processes, materials and energy used during a products life cycle to give an indicator as to the impact at each stage. This can help the designer to identify areas where the environmental impact is high and investigate ways of reducing this.

5.1 Methodology of LCA

5.11 Evaluating Environmental Impact

Every product impacts on the environment in some way, the materials involved must be abstracted, which involves energy use, the burning of fossil fuels, possible environmental damage e.t.c, then there is the material waste, energy use and fossil fuel emissions from the processes involved. The distribution of the material and the product also involves the burning of fossil fuels or the use of electricity, and then there are the materials, energy and emissions produced by the product during its life time. Finally there is the damage caused by the product at disposal, either from landfill, causing environmental damage and possibly allowing dangerous chemicals to leach into the surrounding water, incineration, and the emissions that may occur and any special treatment involved in preventing the waste product from harming any person or animal.

This is by no means an exhaustive list of the potential impacts a product may have, so it can be seen that to itemise and identify each potential impact is extremely difficult and time consuming, but for a true evaluation of the environmental impact of a product over its life cycle it is necessary to take into account all these factors.

LCA software relies on predefined databases that identify the environmental impacts of a material or process. The software used in this dissertation is Eco-It from Pré consultants[34], and the database used in called Eco-indicator 95[35]. In this database materials and processes are evaluated for environmental effects that damage ecosystems or human health on a European scale using the following criteria:

Greenhouse effect: The emissions of certain greenhouse gases, primarily Carbon Dioxide (CO_2) from the burning of fossil fuels contribute to the 'greenhouse' effect by affecting the way the Suns energy is retained by the atmosphere. Increasing quantities of greenhouse gases from increasing industrialisation are acting to insulate the Earth, trapping more of the Suns energy and causing the Earth's climate to gradually warm. This climate change is likely to have far reaching consequences in the future, affecting global weather patterns and causing unpredictable and potentially devastating weather conditions.

Ozone layer depletion: Certain gases, particularly Chlorofluorocarbons (CFC's), when emitted can reach the higher atmosphere can react with the ozone layer causing it to deplete. The ozone layer is important in shielding the Earth from the Sun's ultraviolet rays and depletion of the ozone layer will result in more of these rays reaching the surface of the Earth. This can cause damage to the eyes and skin resulting in quicker sun burning times and an increase in skin cancers. This effect is distinct from the climate change associated with 'greenhouse' gases, though many of the gases that cause ozone depletion, including CFC's also contribute to global warming.

Acidification: Certain emissions can cause an increase in the acidity of water resulting in conditions like acid rain, which can damage forests and ecosystems.

Eutrophication: The effects of certain substances on poor soils can act as fertilisers and change the aquatic ecosystem resulting in the disappearance of rare plants that depend on the poor soil conditions to grow.

Smog: The emission of sulphur compounds, low level ozone, dust and other particulates can result in smog, which can cause respiratory problems

Toxic substances: This includes substances that are toxic in ways other than those described above, for example heavy metals, carcinogens and pesticides[36].

These effects and their causes are evaluated to the best of the knowledge at the time. Materials and processes are evaluated as to their contributions to these environmental problems. These contributions may not be immediately obvious but may derive from the energy used and the greenhouse gases emitted during the generation of the energy for instance. A weighting system is used to assess the severity of the contributions to these effects as shown below in table 5.11. This weighting allows the overall impacts of materials to be collated into a single score called an Eco-Indicator. This allows the comparison of different materials and processes for their overall environmental impact.

Environmental Effect	Eco-Indicator weighting
Greenhouse Effect	2.5
Ozone Depletion	100
Acidification	10
Eutrophication	5
Summer Smog	2.5
Winter Smog	5
Heavy Metals	5
Carcinogenic Substances	10

Table 5.11: Weighting System For Evaluating Environmental Impacts In Eco-Indicator 95[36]

Materials and processes are rated using this system and awarded Eco-Indicator points (Pt's) accordingly. The sum of the Points accumulated by a product during its manufacture, distribution, use and disposal gives a comparative indication of the overall environmental impact of the product.

5.12 Using LCA software

The LCA software that has been used in this dissertation is a program called Eco-It by Pré Consultants[34]. It is a relatively straightforward program in terms of LCA software, but it allows comparisons between different products to be made quickly and easily. The database of materials and processes used is Eco-Indicator 95[35], again a relatively basic database but sufficient for the scope of this dissertation.

The first stage in using LCA software is to assess the level of precision required in describing the materials, processes and energy use during the life cycle. It is very difficult to get an entirely accurate picture of this so certain assumptions need to be made. This is called 'defining the functional unit', and outlines the assumptions made in production, distribution, use and disposal. For example in the case of the mobile phone, the impacts of the use phase are determined by assuming that the phone is charged overnight for 8 hours over a life of 2 years. This is only an approximation of the true usage but it is sufficient to allow the life cycle to be analysed. Also, in this case environmental costs due to distribution are ignored due to variability and lack of data, though these ought to be included in a more thorough life cycle analysis.

The next stage is to determine the impacts at each stage of a products life cycle. Starting with the production phase a full analysis requires a complete breakdown of the materials, production processes (e.g. injection moulding) and energy used in making the product. These can then be listed by subassembly to give a total environmental loading for the production phase. In this case the full data for the processes and energy used during manufacture was not available so the data for the production phase consists of the environmental costs of the materials that comprise a mobile phone. The scores for each material and process at this stage can be used to determine areas of greater environmental impact which can be targeted for reduction.

The same process is repeated for the use phase, in the case of the mobile phone the only consumption during use is the energy it consumes while charging. Having defined the functional unit (i.e. 8hr overnight charge and a life of 2 years) the impacts can be calculated.

Finally the process is repeated for the disposal phase. Eco-It allows a number of different disposal scenarios to be modelled. In this case the materials comprising the phone are modelled as either being landfilled (in common with most household waste), incinerated (in a modern, low emission incinerator) or recycled. When the recycling model is used, the material recovery is compared with the cost of abstracting the original raw material. This can lead to negative values for environmental impacts where the impacts due to recycling are less than those caused by producing the original material.

After the analysis for all these phases has been completed it is possible to compare them to find the areas of greatest environmental impact along the life cycle and thus target specific areas for reduction.

The analysis that follows uses two distinct mobile phone compositions, one representing an older phone of the type currently being refurbished for resale modelled from data provided by mobile takeback sites, and the other representing the composition of a modern mobile phone according to Nokia. These compositions are modelled for a number of different scenarios and for the design modifications indicated in section 4 as well as the likely impacts of impending EU environmental legislation.

5.2 LCA of typical mobile phone compositions

Two mobile phone compositions are available one of which represents a typical older phone from about 1999 and is based on data from mobile takeback sites[29], the other represents a more modern phone and is based on data from Nokia's web site[30] of the typical current composition of one of their phones.

For these calculations the overall weight of the handset is assumed to be 100g for the modern phone, this is roughly the average weight for a standard modern mobile handset and for the older composition is assumed to be 130g based on data for the average weight of standard handsets around this time[8]. Energy consumption for the Nokia phone is based on average charging and standby data from Nokia's more recent mobile phone chargers and is modelled as a charging power consumption of 5.6W, a standby consumption of 0.3W and a charge time of 1.5 hours. The use phase is modelled as having a daily an 8 hour overnight charge and a use life of 2 years.

For the Takeback phone, the energy consumption is based on data from the Draft Commission Communication on Policy Instruments to Reduce Stand-By Losses of Consumer Electronic Equipment (1999)[37] which estimates stand-by power as 2W, charging power consumption is taken from a typical charger of the time and is 11.5W. Charging time is estimated as 5 hours, again based on a typical charger of the time. The use phase power consumption is again modelled for a daily 8 hour overnight charge and a use life of 2 years.

In each case the environmental cost of manufacture is mainly the cost of abstracting the phones constituent materials, it does not include full data on the energy consumption of the manufacturing process as this data is unavailable. Environmental cost of disposal is based on a worst case scenario of the handset being discarded with household waste and ending up in landfill. Environmental impact data was unavailable for some materials, and in these cases materials with similar environmental impacts have been used.

5.21 LCA analysis of the Takeback Phone Composition

Given the assumptions outlined above, the environmental impacts at each phase of the takeback phone's life cycle are:

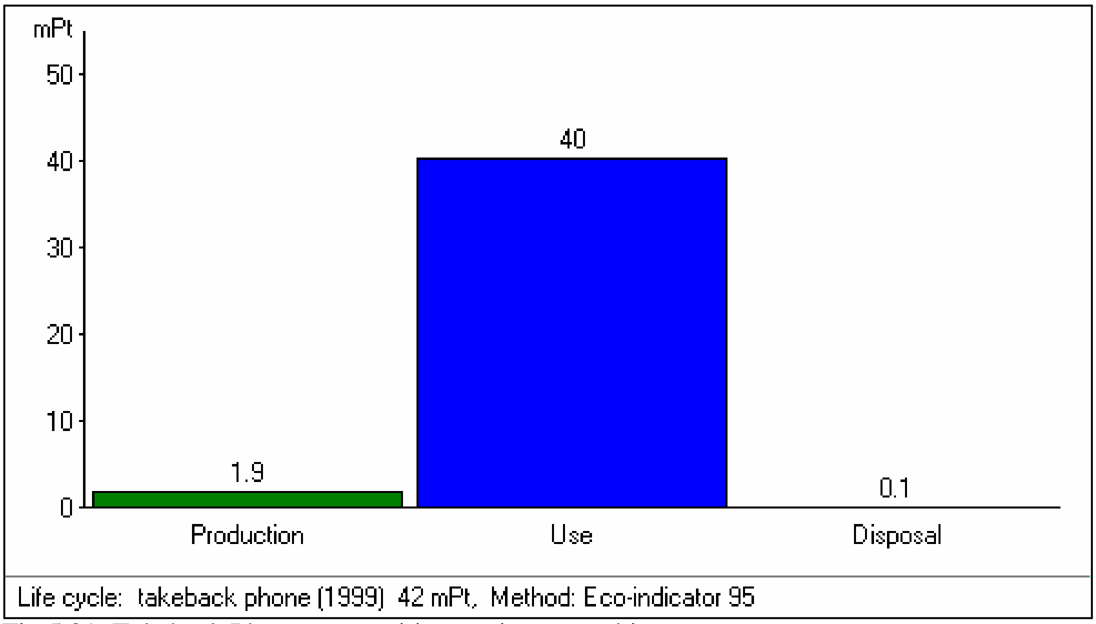


Fig 5.21: Takeback Phone composition environmental impacts

Life Cycle Phase	Production	Use	Disposal	Total
Environmental Cost (mPt)	1.9	40	0.1	42
Percentage of total (%)	4.5%	95.2%	0.24%	100%

(note; due to rounding, percentages may not add to 100%)

Table 5.21: Takeback Phone composition environmental impacts

As the chart above shows, by far the greatest impact is made during the use phase of the phone due to the electricity it consumes (it should again be noted here that data for the energy consumed during production was unavailable). The impacts of this use phase far out weigh the impacts during production, and particularly at disposal even though this LCA has modelled the disposal option as going to landfill, the worst case scenario. This analysis would seem to indicate that reduction in the power consumed during the use phase of the handset should be the priority for designers wishing to minimise the overall impact of the handset.

5.22 LCA analysis of the Nokia phone composition:

Given the assumptions outlined above, the environmental impacts at each phase of the Nokia phone composition's life cycle are:

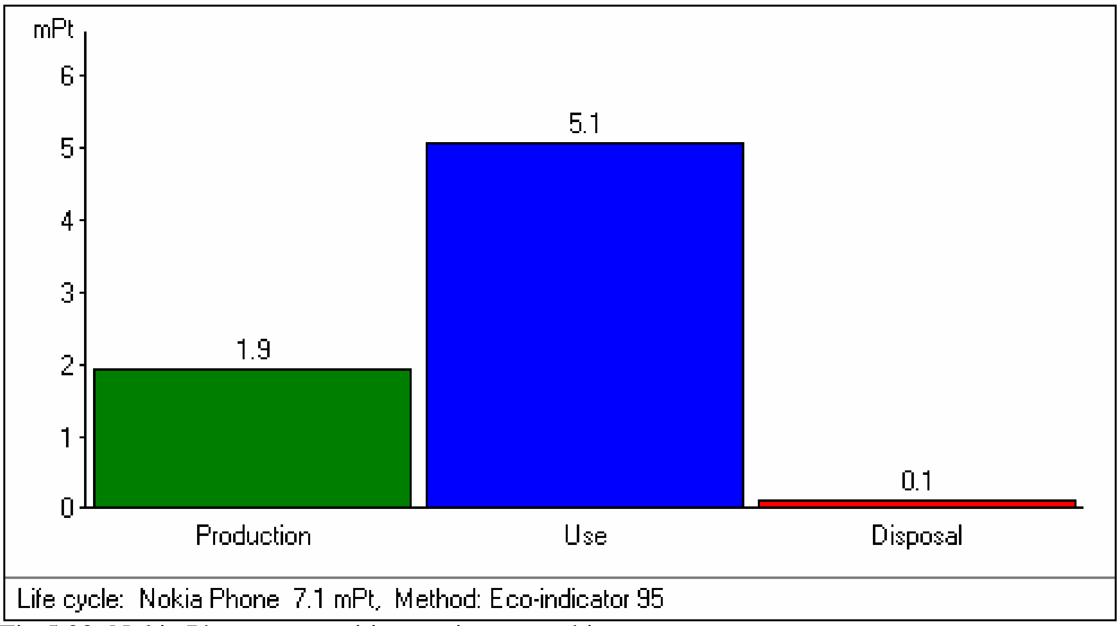


Fig 5.22: Nokia Phone composition environmental impacts

Life Cycle Phase	Production	Use	Disposal	Total
Environmental Cost (mPt)	1.9	5.1	0.1	7.1
Percentage of total (%)	26.8%	71.8%	1.4%	100%

(note, due to rounding, percentages may not add to 100%)

Table 5.22: Nokia Phone composition environmental impacts

Again the chart shows the greatest impact occurs during the use phase of the phone, though advances in reducing charging time and standby power consumption have significantly reduced this in comparison to the Takeback phone composition (again, it should be noted here that data for the energy consumed during production was unavailable). The impacts of the use phase however still far out weigh the impacts during production, and particularly at disposal even though this LCA has modelled the disposal option as going to landfill, the worst case scenario. Despite the progress made in reducing the impacts during the use phase, this is still clearly the most significant impact and should remain the focus for designers looking to reduce the overall environmental impact of their phones.

5.23 Comparison

As can be seen the environmental cost of production and disposal are almost the same for each phone, the only difference between them is the energy used during the use phase of their life. Comparing the two on the chart below it is clear that the improvements in energy consumption in recent years have had the most significant effect in reducing the overall environmental burden of mobile handsets though it is perhaps surprising that the environmental cost of manufacture and disposal has remained the same. It should be noted however that significant improvements in the numbers of phones being recycled or reused at disposal have already been made so modelling the disposal scenario as going to landfill may be misleading. EU legislation in the form of the WEEE and RoHS directives are likely to further increase the recycling and recovery rate and reduce the impact at disposal in the coming years.

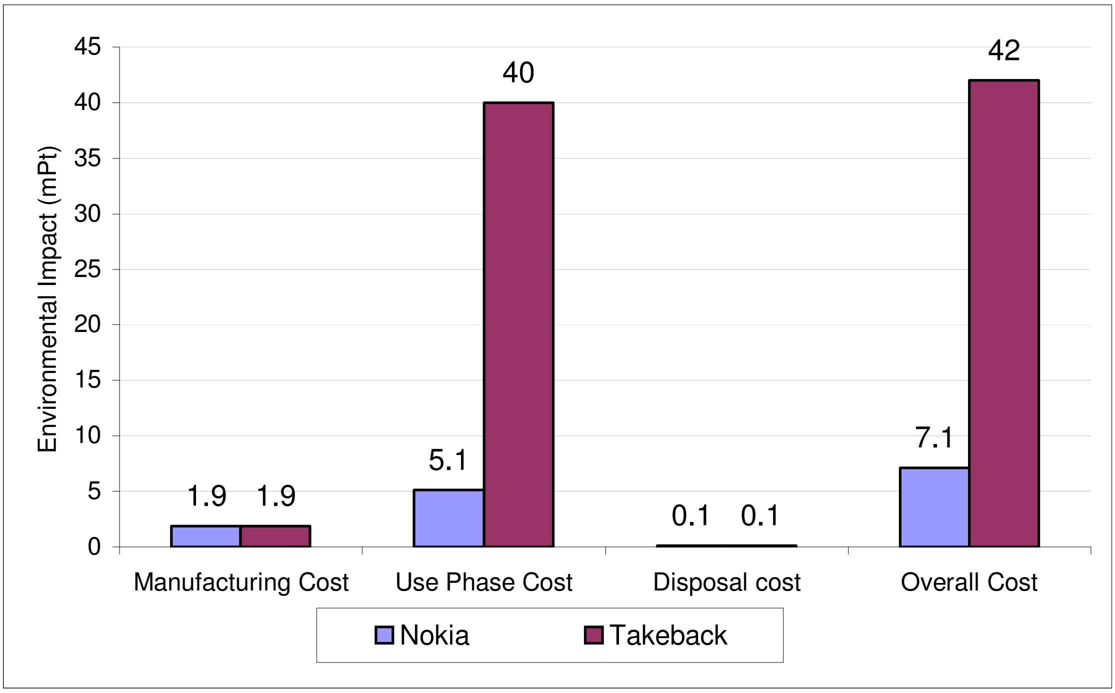


Fig 5.23: LCA Comparison of Nokia and Takeback Phone Compositions

Phone	**Environmental Impact (mPt)**			
	Production	**Use**	**Disposal**	**Total**
Nokia Composition	1.9	5.1	0.1	7.1
Takeback Composition	1.9	40	0.1	42

Table 5.23: LCA Comparison of Nokia and Takeback Phone Compositions

5.3 LCA for Material substitution

Material substitution involves replacing environmentally damaging materials with less damaging materials. The first area to be investigated is the effects of the Restriction of Hazardous Substances in Electrical and Electronic Equipment directive which will mean eliminating certain substances from EEE by 2006. Of these substances only lead is listed the takeback composition of two mobile phone compositions here. However as it is a major component of solder it is likely the true Nokia composition also contains lead, Nokia even admits that lead has yet to be eliminated from its handsets on its website[32]. Because the quantities of lead in the phones composition are either unlisted or very low it is not possible to analyse the effects of removing this from the phone compositions. However section 4.11 shows the potential health risks associated with this material.

It is also possible to reduce the environmental impact during the manufacturing and disposal phases of a mobile handset by replacing certain materials with more environmentally friendly ones. This can be as straightforward as selecting the same materials with higher recycled content but can also involve looking at the physical properties of materials and selecting materials with similar properties that have a lower environmental burden. With LCA it is possible to identify materials with a particularly high environmental cost and these can be targeted for substitution. Using the databases provided by LCA software, in this case Eco Indicator 95, the comparative environmental impact of different materials can be assessed, combined with material databases like Cambridge Engineering Selector (CES)[38], these can be compared for their mechanical properties to find suitable replacement materials. This process is shown in tables 5.31 and 5.32 below for each mobile phone composition.

5.31 Material Substitution for Typical Nokia Handset

In the Nokia handset copper, aluminium and steel have been modelled as containing typical amounts of recycled material for European suppliers according to Eco Indicator 95. In Europe copper is supplied containing 40% recycled material, aluminium is supplied containing 20% recycled material and steel is supplied containing 20% recycled material. Replacing these metal compositions with 100% recycled materials give significant reductions in the environmental impact of production as show in table 5.31. However it is difficult to obtain 100% secondary metals and this may involve an economic penalty.

Other material substitutions for reducing the environmental impact of production include substituting the ABS-PC used in the casings of handsets for plastics with lower environmental production costs. ABS-PC is chosen as the casing for mobile handsets as it has the highest impact resistance of all polymers, is tough, resilient and accepts colour well. It can also be easily moulded and has good chemical and thermal resistance. As shown in table 5.31 below, substituting this with PP give significant reductions in environmental impact at production. PP was chosen as a likely replacement material as it has similar material properties. These are shown in table 5.33 below using data from CES.

Material Properties

	ABS-PC	**PP**	**Units**
General properties			
Density	1.01 - 1.21	0.89 – 0.91	Mg/m^3
Price	1.05 - 1.97	0.6008 – 0.8782	GBP/kg
Mechanical properties			
Young's Modulus	1.1 - 2.9	0.89 – 1.55	GPa
Shear Modulus	0.3189 - 1.032	0.3158 – 0.5483	GPa
Bulk modulus	3.8 - 4		GPa
Poisson's Ratio	0.3908 - 0.422	0.4052 – 0.4269	
Hardness – Vickers	5.6 – 15.3	6.2 – 11.2	HV
Elastic Limit	18.5 – 51	20.7 – 37.2	MPa
Tensile Strength	27.6 – 55.2	27.6 – 41.4	MPa
Compressive Strength	31 – 86.2	25.1 – 55.2	MPa
Elongation	1.5 - 100	100 – 600	%
Endurance Limit	11.04 - 22.08	11.04 – 16.56	MPa
Fracture Toughness	1.186 - 4.289	3 – 4.5	MPa.m^1/2
Loss Coefficient	0.01379 - 0.04464	0.02581 – 0.04464	
Thermal properties			
Thermal conductor or insulator?	Good insulator		
Thermal Conductivity	0.188 - 0.335	0.113 – 0.167	W/m.K
Thermal Expansion	84.6 – 234	122.4 – 180	µstrain/K
Specific Heat	1386 – 1919	1870 – 1956	J/kg.K
Glass Temperature	87.85 - 127.9	248 – 258	°C
Maximum Service Temperature	61.85 - 76.85	356 – 380	°C
Minimum Service Temperature	-123.2 - -73.15	150 – 200	°C
Electrical properties			
Electrical conductor or insulator?	Good insulator	Good insulator	
Resistivity	3.3e21-3e22	3.3e22 – 3e23	µohm.cm
Dielectric Constant	2.8 - 3.2	2.2 – 2.3	
Power Factor	3e-3 - 7e-3	5e-4 – 7e-4	
Breakdown Potential	13.8 – 21.7	22.7 – 24.6	1000000*V/m
Optical properties			
Transparent or opaque?	Opaque	Translucent	
Eco properties			
Production Energy	*91 - 102		MJ/kg
Carbon dioxide per kg of material	*3.27 - 3.62		kg/kg

Recycle	True	
Downcycle	True	
Biodegrade	False	
Incinerate	True	
Landfill	True	
A renewable resource?	False	
Environmental Resistance		
Flammability	Poor	Poor
Fresh Water	Very Good	Very Good
Salt Water	Very Good	Very Good
Weak Acid	Good	Very Good
Strong Acid	Average	Very Good
Weak Alkalis	Good	Very Good
Strong Alkalis	Good	Very Good
Organic Solvents	Poor	Average
Sunlight (UV Radiation)	Average	Poor
Oxidation at 500C	Very Poor	Very Poor
Wear Resistance	Poor	Average

Table 5.31: Comparison of ABS-PC and PP for material substitution

PP can be modified by catalysis to give very precise control over the impact strength, it is easy to mould and the addition of fire retardants and stabilizers give it good environmental resistance. It can accept a wide range of vivid colours and is exceptionally easy to recycle.

The use of ABS-PC in phone covers allows far greater control over aesthetic effects such as surface finishing and colouring than would be the case with PP. However, if the environmental impact of the phone is to be minimised some aesthetic compromise may be necessary. ABS is easy to recycle but not as easy as PP and it consumes far greater energy during production. The environmental impacts of this are modelled using power generated from modern European power stations and are likely to be greater for less modern, more polluting power stations such as those in the developing world. This would point to the substitution of PP for ABS-PC being particularly suitable for handsets manufactured in the developing markets where functionality rather than aesthetics are the primary concern.

When all the material substitutions for environmental gain are made the overall cost of production falls to 48% of the original cost and the overall environmental cost falls to 89%. This shows that materials substitution can play an important role in minimising the environmental impact of mobile handsets.

5.32 Material Substitution for Typical Takeback Handset

The same process is performed on the typical takeback handset composition. Again, metals used are substituted for 100% recycled metals. PP is also substituted for ABS-PC again. The results of these material substitutions are shown in table 5.33 below.

The case for substituting PP for ABS-PC in the handset housings is made in the Nokia material substitution section.

When all of the material substitutions for environmental gain are made the production cost of the Takeback handset falls to 49% of its original value and the overall impact falls to 89%. Again material substitution allows significant savings in the environmental impact of production but it should again be emphasised that this is still small in comparison with the environmental impacts of the use phase of the handset due to its power consumption.

5.4 LCA for increased recyclability

Increasing the recyclability of mobile handsets involves replacing materials that cannot be recycled with materials that can. In the case of the two mobile phone compositions investigated here the only material that technically cannot be recycled is the epoxy adhesive used for bonding components. This can be seen in appendix A for the typical Nokia composition and appendix B for the typical takeback composition which list the material properties and environmental impacts of the materials involved.

The Takeback phone composition contains 9% epoxy while the Nokia composition contains 4%. Replacing the epoxy in both handsets with a recyclable material would raise the theoretical recycling ratio for material recovery to 100%. Epoxy resins are thermosetting adhesives used to strongly bond dissimilar materials and as such have no simple material substitute. However, advances in the use of shape memory polymers and metals in forming fastenings that automatically disassemble with heat may allow the replacement of epoxy in some situations. The emergence of Active Disassembly using Smart Materials (ADSM) is discussed further in section 3.52. The application of this technology to replace the use of epoxies would not only increase the recyclability of handsets but would also make the entire process of material segregation for efficient recycling much simpler. The environmental benefits of increased recycling for material recovery are shown in section 5.5 below.

5.5 LCA for the effects of the WEEE directive

The WEEE directive will require all mobile handsets to be collected separately and recycled for material recovery of 65% of their mass by 2006. This is likely to have a significant economic impact on the mobile phone manufacturers. To determine the effects of this on the overall environmental impact of the phone LCA is performed on mobile phone recycling rates of 65%, 100% (representing a best case scenario) and 0% with the phone going to landfill as a worst case scenario.

5.51 LCA for a handset without recycling

This LCA describes both the older 1999 takeback phone composition and the newer Nokia composition in a worst case scenario of being discarded by landfill.

5.511 LCA for Takeback phone composition discarded by landfill

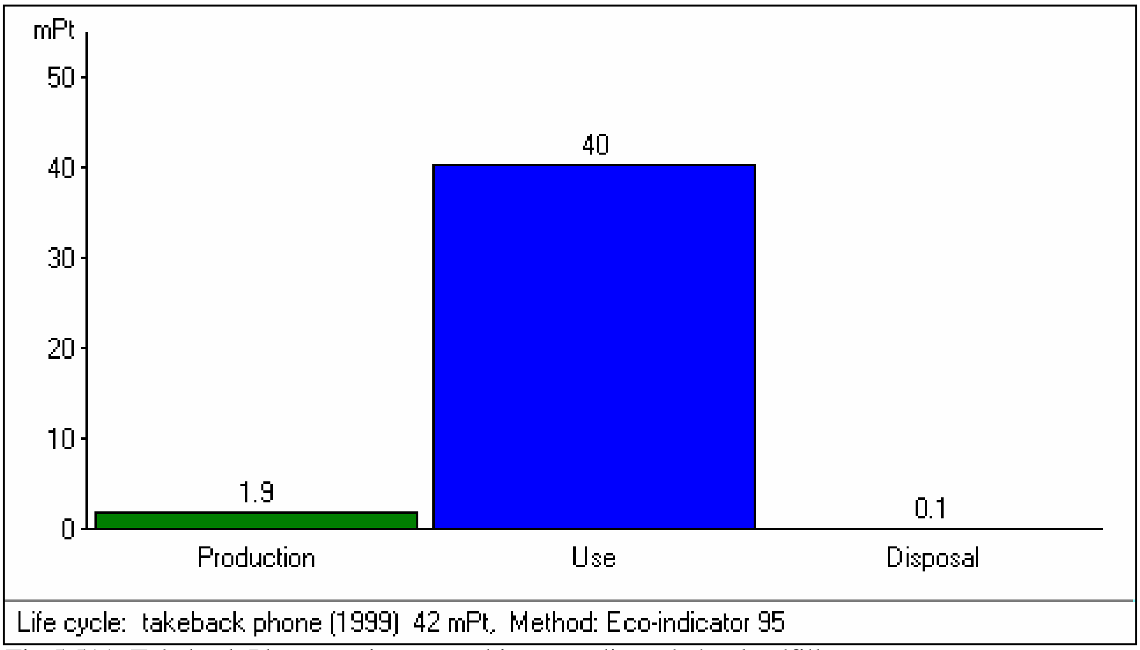


Fig 5.511: Takeback Phone environmental impacts discarded at landfill

Life Cycle Phase	Production	Use	Disposal	Total
Environmental Cost (mPt)	1.9	40	0.1	42
Percentage of total (%)	4.5%	95.2%	0.24%	100%

(note, due to rounding, percentages may not add to 100%)

Table 5.511: Takeback Phone environmental impacts discarded at landfill

5.512 LCA for Nokia phone composition discarded by landfill

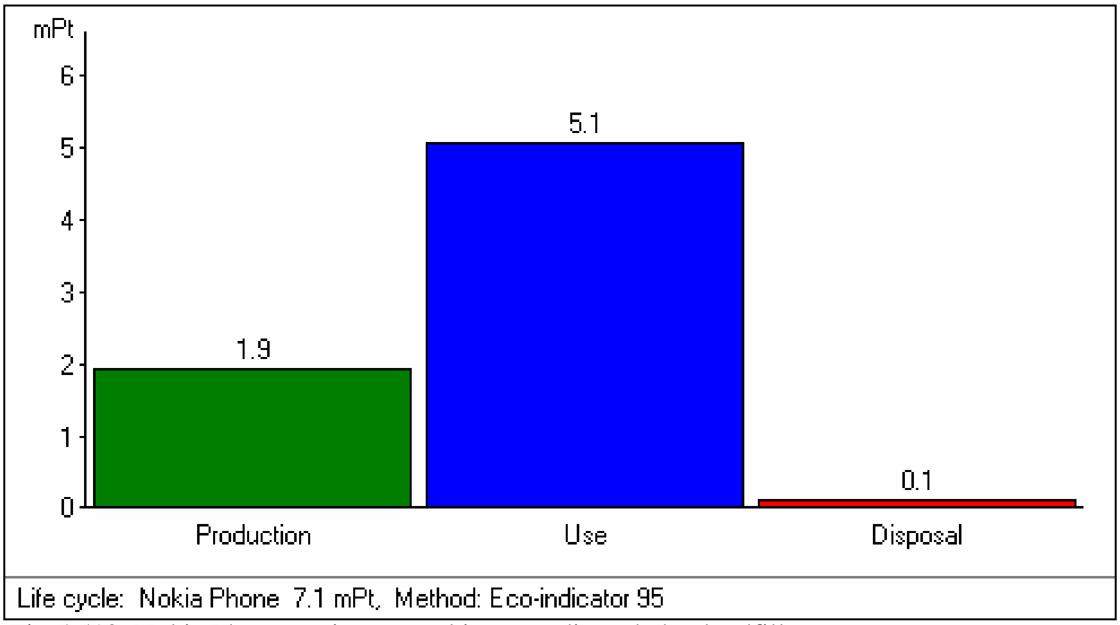


Fig 5.512: Nokia Phone environmental impacts discarded at landfill

Life Cycle Phase	Production	Use	Disposal	Total
Environmental Cost (mPt)	1.9	5.1	0.1	7.1
Percentage of total (%)	26.8%	71.8%	1.4%	100%

(note, due to rounding, percentages may not add to 100%)

Table 5.512: Nokia Phone environmental impacts discarded at landfill

The impacts at disposal for both phone compositions are the same at 0.1mPt, this is a fraction of both the production cost (1.9mPt in both cases) and the use phase cost (40 for the older takeback phone, 5.1 for the newer Nokia phone).

5.52 LCA for a Handset 65% recycled

The following sections analyse both the older Takeback and the newer Nokia compositions for their environmental impacts when recycled for 65% material recovery as required by the WEEE directive.

5.521 LCA for Takeback phone composition 65% recycled

The following data is for the older composition of the typical Takeback mobile phone separated from the household waste stream and recycled for 65% material recovery:

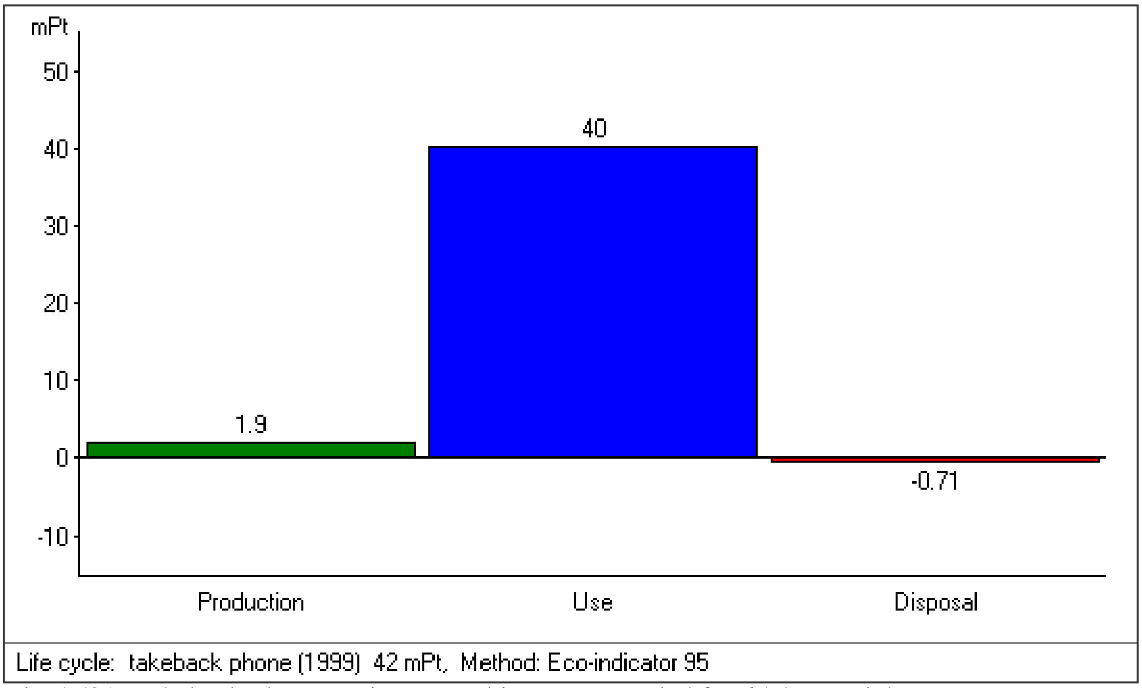


Fig 5.521: Takeback Phone environmental impacts recycled for 65% material recovery

Life Cycle Phase	Production	Use	Disposal	Total
Environmental Cost (mPt)	1.9	40	-0.71	41.19
Percentage of total (%)	4.6%	97.1%	-1.7%	100%

(note, due to rounding, percentages may not add to 100%)

Table 5.521: Takeback Phone environmental impacts recycled for 65% material recovery

For the takeback composition the recycling at the EoL does reduce the overall impact, but this is a very small contribution to the overall environmental impact, the majority of which still comes from the energy consumed during the use phase. Recycling the Takeback composition of mobile handsets to the targets of the WEEE directive reduces the overall environmental load of the handset over its life cycle by just 1.93%.

5.522 LCA for Nokia phone composition 65% recycled

The following data is for the typical composition of a modern Nokia mobile phone separated from the household waste stream and recycled for 65% material recovery:

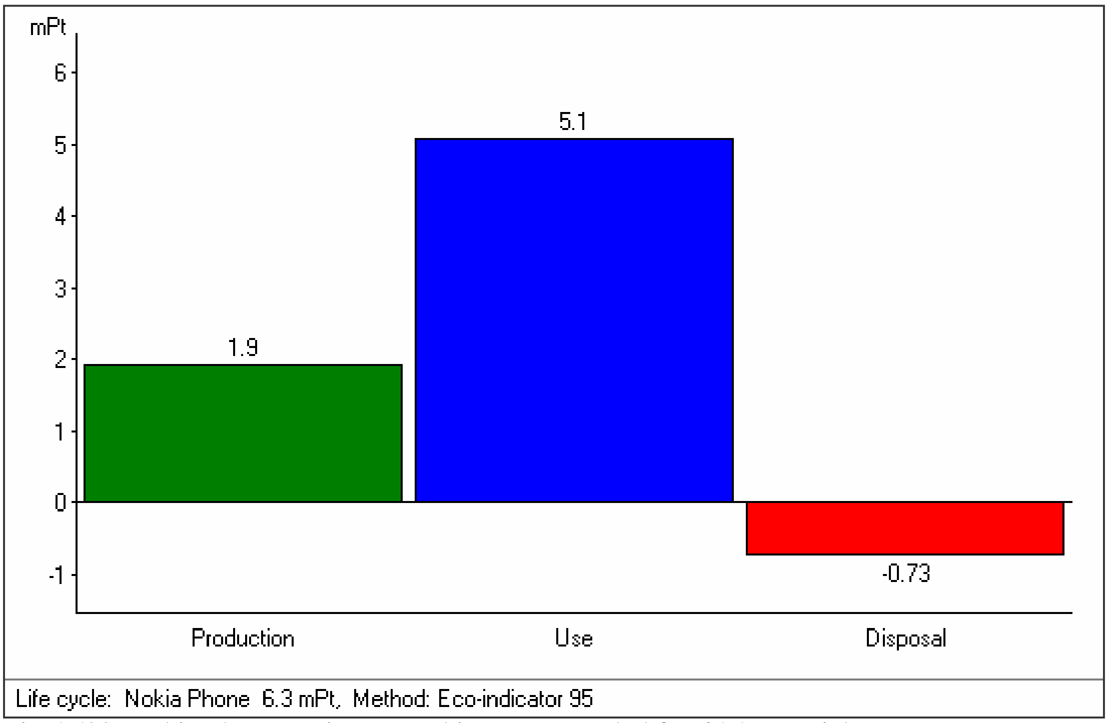


Fig 5.522: Nokia Phone environmental impacts recycled for 65% material recovery

Life Cycle Phase	Production	Use	Disposal	Total
Environmental Cost (mPt)	1.9	5.1	-0.73	6.27
Percentage of total (%)	30.3%	81.3%	-11.6%	100%

(note, due to rounding, percentages may not add to 100%)

Table 5.522: Nokia Phone environmental impacts recycled for 65% material recovery

Recycling this phone composition has a far greater relative environmental effect than the Takeback phone, thought still smaller than the impacts during production and use. Recycling at EoL to the targets of the WEEE directive reduces the overall impact of the Nokia phone composition by 11.7% compared with disposal at landfill.

5.53 LCA for Handset 100% recycled

The following sections analyse both the older Takeback and the newer Nokia compositions for their environmental impacts when recycled for 100% material recovery to illustrate a best case scenario.

5.531 LCA for Takeback phone composition 100% recycled

The following data is for the older composition of the typical Takeback mobile phone separated from the household waste stream and recycled for 100% material recovery. This is a best case scenario and unlikely to be achievable in practice, but serves to illustrate the effect recycling at EoL has on the overall environmental impact of the phone:

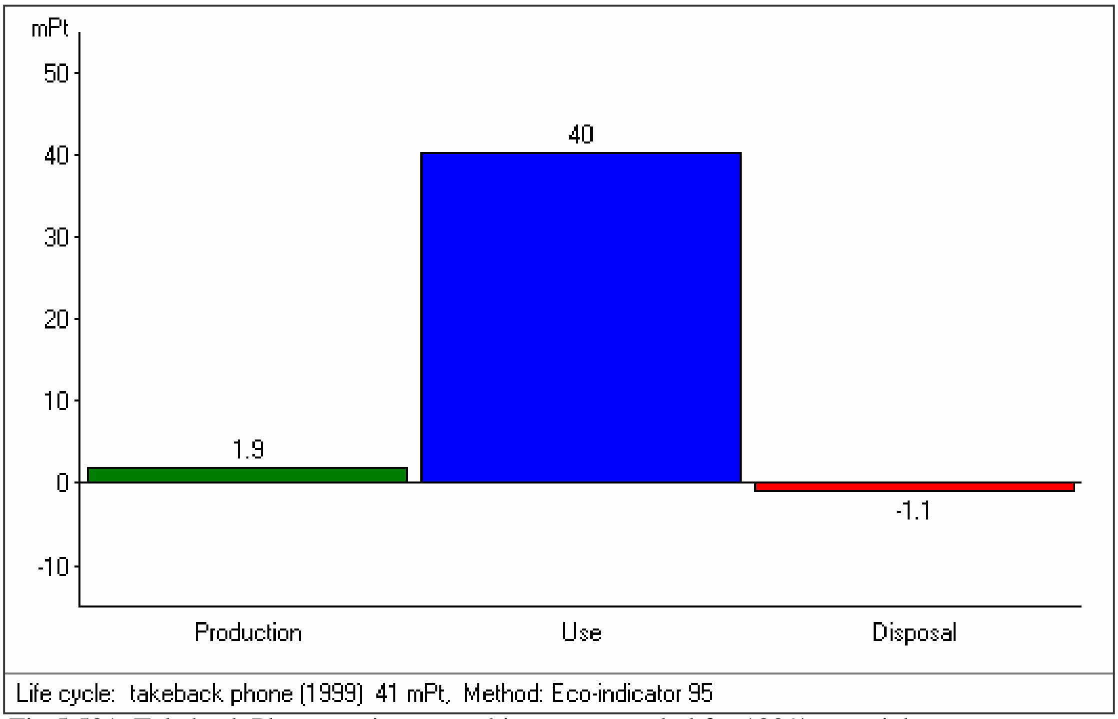


Fig 5.531: Takeback Phone environmental impacts recycled for 100% material recovery

Life Cycle Phase	Production	Use	Disposal	Total
Environmental Cost (mPt)	1.9	40	-1.1	40.8
Percentage of total (%)	4.7%	98.0%	-2.7%	100%

(note, due to rounding, percentages may not add to 100%)

Table 5.531: Takeback Phone environmental impacts recycled for 100% material recovery

Despite this best case scenario of recycling for 100% material recovery the benefits compared to the overall environmental impact of the phone are small. The electricity consumed during use still remains the overriding impact and even 100% material recovery at EoL only reduces the total environmental impact of the phone by 2.9% compared to the same composition disposed by landfill.

5.532 LCA for Nokia phone composition 100% recycled

The following data is for the typical composition of a modern Nokia mobile phone separated from the household waste stream and recycled for 100% material recovery. This is a best case scenario and unlikely to be achievable in practice, but serves to illustrate the effect recycling at EoL has on the overall environmental impact of the phone:

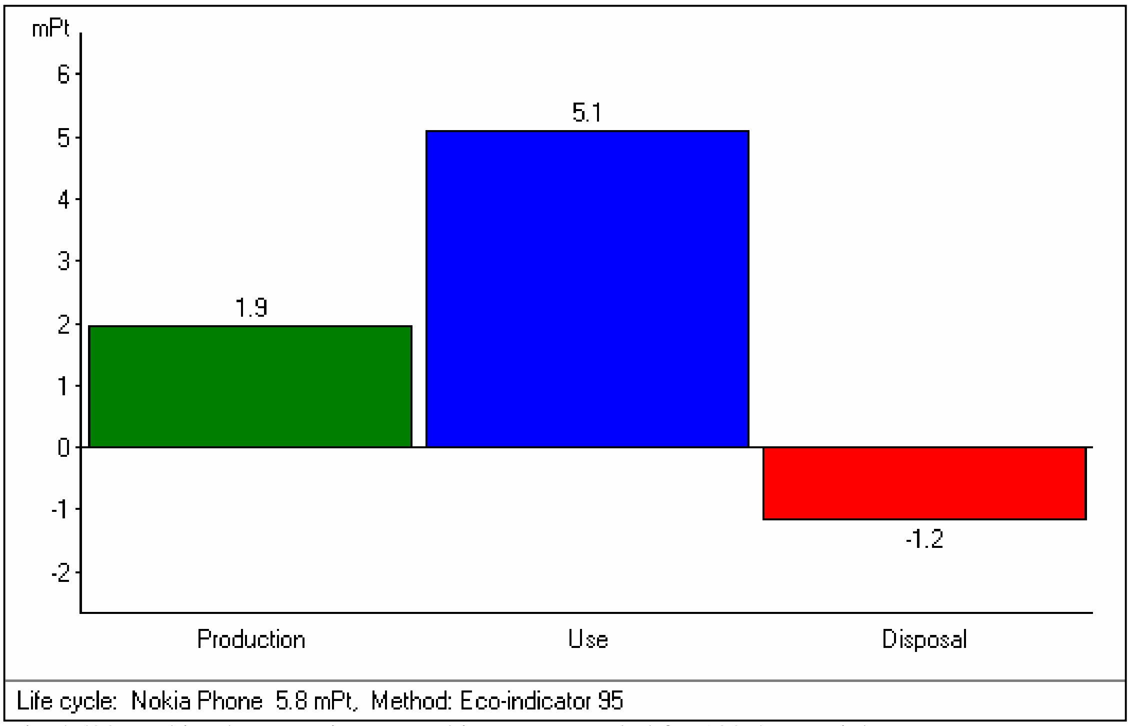


Fig 5.532: Nokia Phone environmental impacts recycled for 100% material recovery

Life Cycle Phase	Production	Use	Disposal	Total
Environmental Cost (mPt)	1.9	5.1	-1.2	5.8
Percentage of total (%)	32.8%	87.9%	-20.7%	100%

(note, due to rounding, percentages may not add to 100%)

Table 5.532: Nokia Phone environmental impacts recycled for 100% material recovery

Despite this being a best case scenario that is unlikely to be achieved, it does show that high levels of recycling at EoL can have a significant effect on the overall impact of a modern Nokia phone. Here, recycling the phone for 100% material recovery gives an 18.3% reduction in the phone environmental impact over its life cycle.

5.54 Discussion

The two models used for this investigation give very different responses as to the effectiveness of recycling mobile handsets at EoL. For the older, Takeback phone, the environmental impacts during the use phase far outweigh the impacts during production and disposal, so any environmental gains made by recycling the phone at EoL are slight compared with the overall impact. For handsets similar to this model the focus should be on reducing the energy consumption during the use phase by reducing standby power losses for chargers and improving battery efficiency. In this case a 2% reduction in the use phase power consumption over the lifetime of the handset would match the environmental gain from recycling the handset to the WEEE directive's 65% target. This would have the same overall change in environmental impact without the difficulty of separate collection schemes to separate the handset from the municipal waste stream and the disassembly and segregation of materials that is required for effective recycling.

For the Nokia phone the benefits of recycling are more defined. The greatest contribution to the overall environmental impact is still the use phase, though reductions in charging times and in particular, stand-by power losses of chargers have significantly reduced this. This means the environmental benefits of recycling at EoL are much more significant in reducing the overall environmental impact of the handset. Further targets for reducing stand-by power consumption in the coming years are outlined in the voluntary Code of Conduct on Reduction of Stand-by Power Losses. This will mean that as the environmental impacts of the use phase are reduced, the relative importance of the environmental benefits of recycling at EoL will increase.

5.6 Energy Efficiency

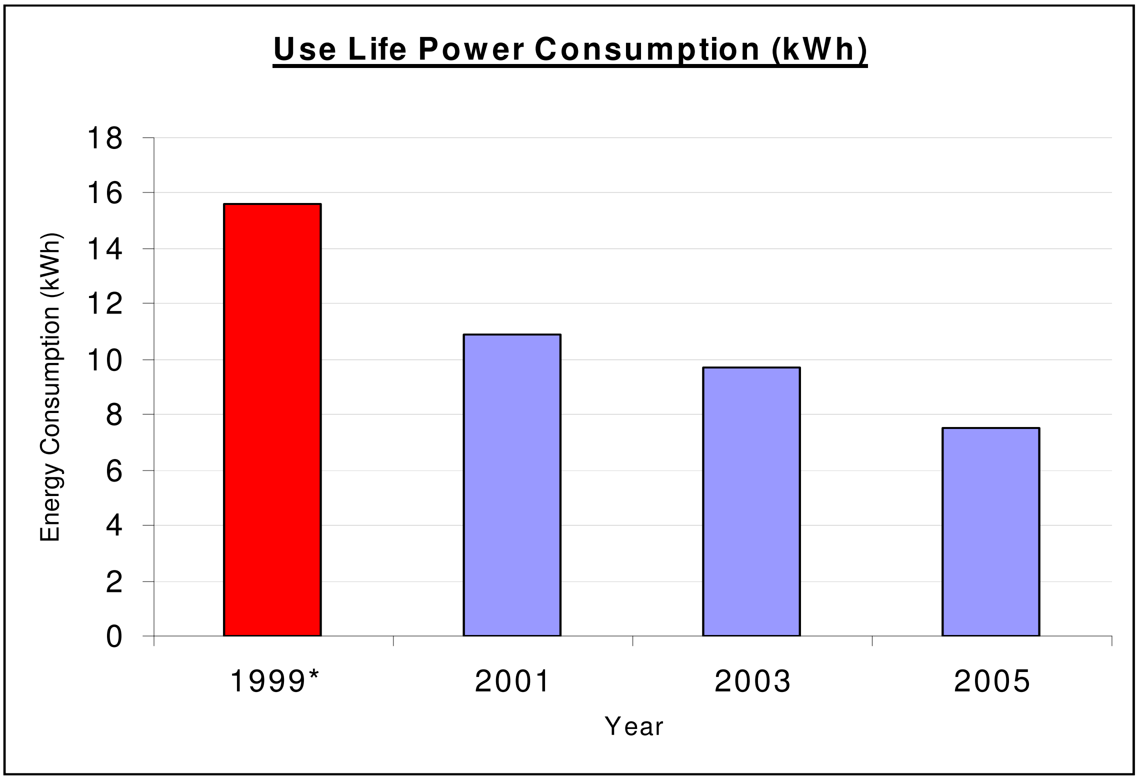
The energy consumed during the use phase of a mobile handset is the largest contributor to the overall environmental cost of the phone. The voluntary Code of Conduct on Efficiency of External Power Supplies commits signatories to reduce the energy consumed by power supplies in stand-by mode. For the mobile phone industry the stand-by power consumption targets are shown in table 5.61 below.

Year	**1999***	**2001**	**2003**	**2005**
Standby Consumption (W)	2	1	0.75	0.3

(* Estimated average consumption before introduction of targets[37])

Table 5.61: Stand-by Power Consumption Targets as specified by the voluntary Code of Conduct on Efficiency of External Power Supplies

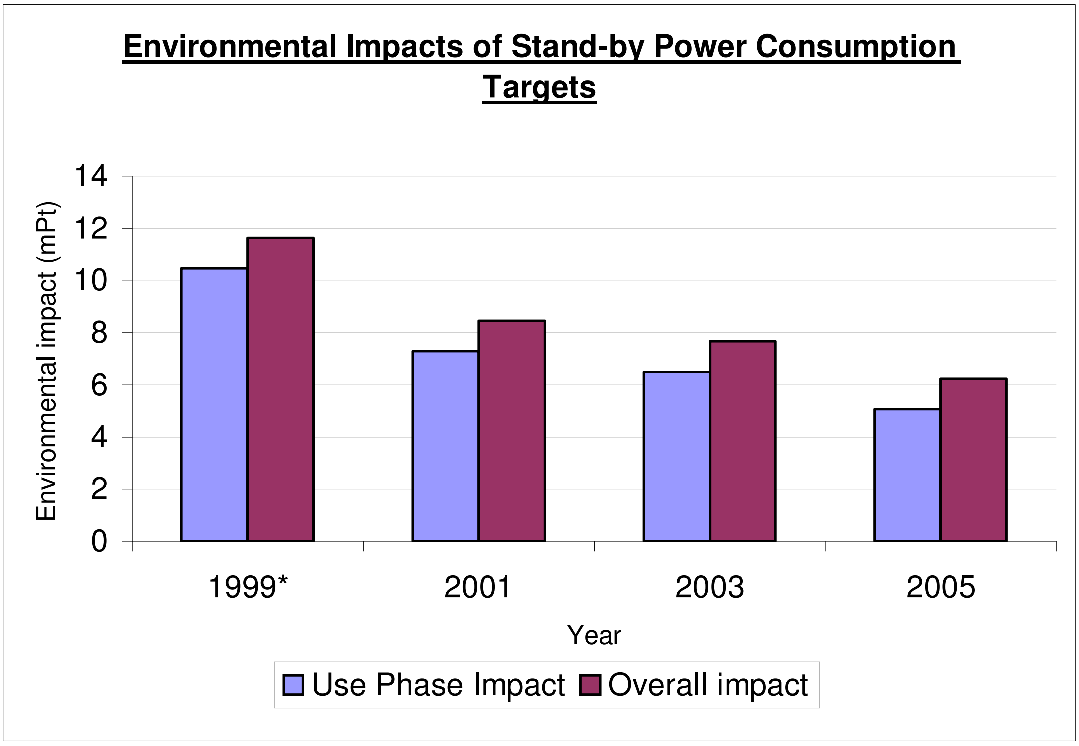
LCA is used to analyse the effects of these targets on the overall environmental impact of the handset. Here, the composition of a typical, modern Nokia mobile phone is used and energy use is modelled for an 8 hour overnight charge, battery charging time of 1½ hours and charging power consumption of 5.6W. These figures are for a modern Nokia charger. Stand-by power consumption follows the targets outlined in the Code of Conduct. The chart below shows the impact of the Code of Conduct targets on the overall energy consumption of mobile handsets.



(Code of Conduct applies 2001-2005, figures for 1999 are typical for the year)

Fig 5.61: Nokia Phone energy consumption with Code of Conduct Stand-by power consumption targets

As can be seen from the chart, stand-by power consumption can have a very significant effect on the overall power consumption of the handset. As the LCA in section 5.2 shows, the use phase of a handsets life cycle has the greatest environmental impact due to the energy it consumes. This was the main difference in the overall environmental impact of the older Takeback phone and the newer Nokia model. Reducing the energy consumed during the use phase of the phone is the simplest way to reduce the overall impact as the chart below shows. Here, the environmental impact during the use phase and the overall environmental impact of the handset are shown for the same conditions as above for the stand-by power consumption targets outlined in the Code of Conduct. The overall impact is measured assuming the 65% recycling for material recovery required by the WEEE directive.



(Code of Conduct applies 2001-2005, figures for 1999 are typical for the year)
Fig 5.62: Nokia Phone energy consumption with Code of Conduct Stand-by power consumption targets

As the chart shows the voluntary Code of Conduct on Efficiency of External Power Supplies will lead to significant reductions in the overall environmental impact of mobile handsets. The reduction in environmental impact from the Code of Conduct is far greater than the reductions from the WEEE directive and the RoHS directive. It seems strange that a voluntary Code of Conduct has a greater effect in reducing the impact of mobile phones than the forthcoming EU legislation.

5.7 Refurbishment

At EoL many phones are collected by companies such as FoneBak, who then refurbish the phones for resale abroad in the developing world. This practice is not supported by mobile manufacturers who point out that this could be considered to be the industrialised world dumping old technology on the third world. Manufacturers would prefer to take advantage of advances in the efficiency and overall environmental impact of phones in recent years to develop mobiles specifically targeted for the third world (this would of course allow them to sell more phones and generate more profit). The following LCA compares the environmental impact of a refurbished phone with the Nokia 2100, which has been designed to be a 'cost optimised product' for developing markets.

This LCA assumes that both mobiles are sold in a country where there is no waste collection infrastructure to segregate electronic waste for recycling, so both are modelled as being discarded by landfill. The refurbished phone is modelled using the older takeback phone composition though as it has been refurbished to continue its life the environmental cost of production in the country of sale is zero. Energy usage is modelled in the same way as in section 4.2, i.e. an 8 hour overnight charge, power consumption of 11.5W, charge time of 5 hours, standby power consumption of 2W and a use life of 2 years.

The Nokia 2100 phone is modelled using data from Nokia's environmental declaration for the product. Charging power consumption is 3W, charging time is 1 hour 45 minutes and standby power consumption is 0.39W. Again energy use is modelled for an 8 hour overnight charge and use life of 2 years.

The chart below shows the overall environmental impacts of each phone at each stage in its life cycle.

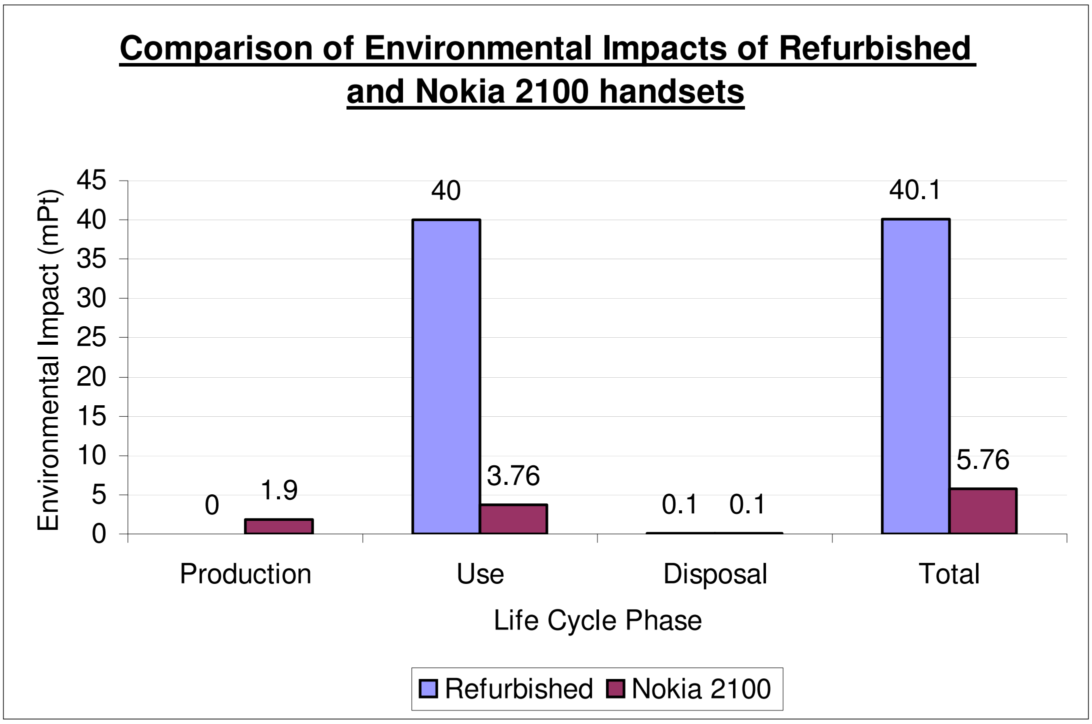


Fig 5.71: Comparison of Environmental Impacts of Refurbished and Nokia 2100 Handsets

This chart shows that despite there being no production costs for the refurbished phone, the overall environmental impact is still far higher due to the less efficient charger and far higher energy consumption in the use phase. The chart below shows the overall environmental impacts of both phones over time.

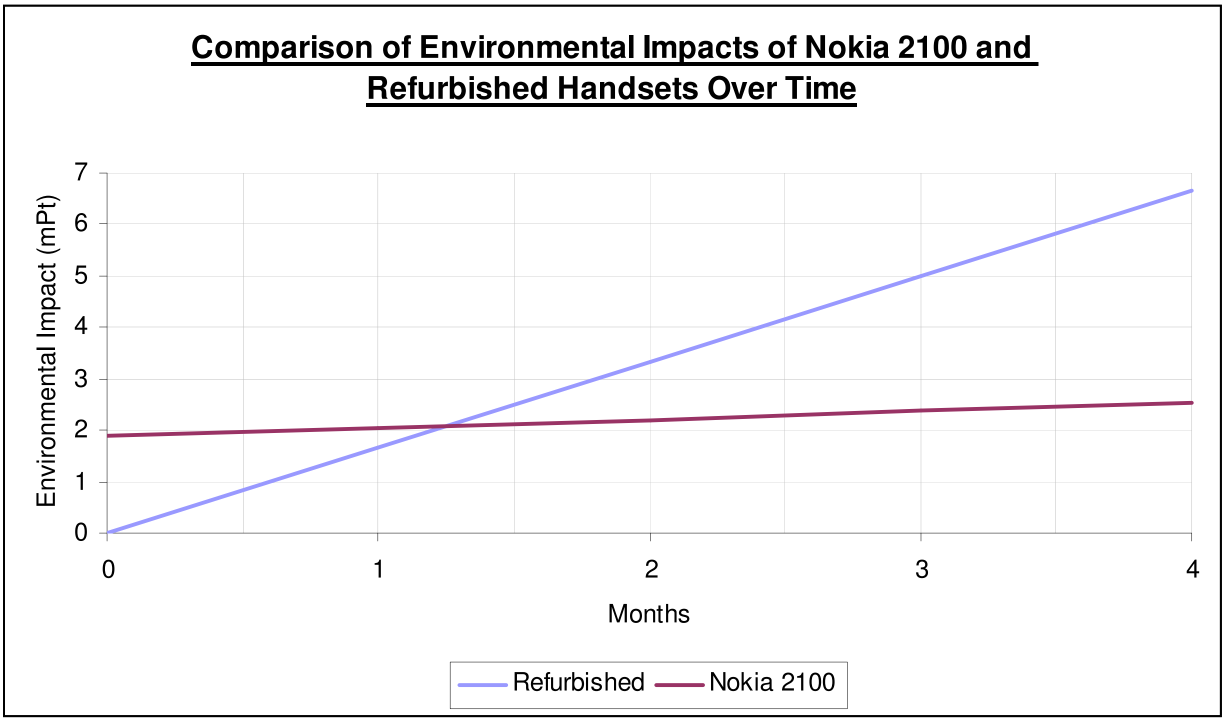


Fig 5.72: Comparison of Environmental Impacts of Refurbished and Nokia 2100 Handsets Over Time

As the chart shows, the environmental impact of manufacturing the Nokia 2100 is soon offset by the benefits of its increased energy efficiency compared to the refurbished phone. The saving in manufacturing impact for the refurbished phone ceases to give reduced environmental impact after just 5 weeks of use. These results would seem to indicate that the practice of refurbishing mobile handsets for resale abroad has very little environmental justification. This is even without the higher levels of potentially dangerous substances in older phones. The disposal scenario used here represents a modern European landfill site where potential leaching of dangerous chemicals into surrounding groundwater has been minimised. In many of the countries where these refurbished phones are sold this is not the case and the environmental impact at disposal is likely to be far higher. Electricity usage in this model is also based on modern European power stations where pollution and emissions are likely to be lower than in the developing world. This would make the difference in energy efficiency between the refurbished phone and the Nokia 2100 even more environmentally damaging.

6. Conclusions

The analysis above shows how LCA can be used to evaluate a wide range of design variables, legislation and disposal options to minimise the environmental impacts of mobile handsets over their life cycle. From the analysis above it can be seen that:

- The greatest impact of EEE over its life cycle is from the energy consumed during the use phase.

- The gains in overall environmental performance in more recent mobile handsets compared to older models are due to the reduction in energy usage during this use phase.

- The gains in energy efficiency that have resulted in this reduction in overall impact have been prompted not by Legislation, but by the Voluntary Code of Conduct on the Efficiency of External Power Supplies.

- Material substitution can significantly reduce the environmental impact during the production phase of mobile handsets.

- This can involve simply replacing materials such as metals with the same material with higher recycled content with no compromise to the material qualities required, though sourcing these materials may involve some economic penalty.

- Further reductions in production costs can be achieved by the selection of materials using environmental impact rather than aesthetic considerations as the primary driver e.g. replacing ABS-PC with PP for the mobile handset housing.

- Theoretically, almost all the materials in am mobile handset are recyclable. Only the epoxy adhesives used are not.

- Replacing these adhesives with shape memory fasteners may be possible but it is the ease and energy involved in disassembly rather than the recyclability of the materials involved that limit the economic recycling of mobile handsets for material recovery.

- The effects of the WEEE directive on the overall environmental impact of mobile handsets are significant but only once the use phase energy consumption has been reduced. For the higher energy consumption of the Takeback phone model the gains were small compared with even a slight percentage increase in energy efficiency.

- The gains in overall environmental performance resulting from the targets to reduce the stand-by power consumption of chargers outlined in the Voluntary Code of Conduct on the Efficiency of External Power Supplies are significant and will increase the environmental gains of recycling at EoL in relation to the overall environmental impact.

- The targets set for the reduction of charger stand-by power consumption by the Voluntary Code of Conduct on the Efficiency of External Power Supplies mean that the refurbishing of mobile handsets for resale abroad is likely to result in higher environmental impact than the sale of a new phone due to the energy consumed during the use phase.

The next section outlines recommendations developed from these conclusions for minimising the environmental impacts of mobile handsets.

7. Recommendations

The following recommendations are made based on the conclusions made in section 6, which follow the analysis of the design proposals in section 4 using LCA in section 5.

- The greatest reduction in environmental impact was made by mobile manufacturers adhering to the targets set out in the Voluntary Code of Conduct on the Efficiency of External Power Supplies. There seems no real reason for this code of conduct to remain voluntary, significant manufacturers from all areas of the EEE manufacturing industry have already signed up and establishing this as legislation would provide a more comprehensive and effective legal precedent for truly reducing the overall impact of mobile handsets.

- The effects of the WEEE and RoHS directives on reducing the impact of mobile handsets at disposal are significant but from the point of view of the overall environmental impact of handsets is small. The cost of setting up mobile collection schemes and producer responsibility for the EoL recycling of their products is however going to be very high. The implications of LCA to evaluated designs for environmental performance should be used in evaluating the likely environmental and economic implications of future legislation.

- Establishing a comprehensive and legally supported database for evaluating environmental impacts could allow legislation to provide a far more cohesive framework for reducing the environmental impact of mobile handsets. For instance, if a database establishing absolute rather than relative environmental impacts could be established products could be evaluated for their absolute environmental impacts throughout their life cycle and targets for reduction in environmental impacts set accordingly.

- The effectiveness of environmental legislation historically has been mixed, and success has largely been dependant on the economic as much as environmental impact of such legislation. A system allowing the absolute evaluation of products for their environmental impacts could allow a shift in managing the environmental impacts of products from legislation towards taxation. For instance if a tax on products exceeding overall environmental impacts for their class was introduced it may give companies greater incentive to evaluate their products for whole life impacts rather than simply following the letter of the law outlined in environmental legislation. The ability to vary the weighting systems already in place in LCA materials and processes environmental impacts databases would still allow the targeting of particular environmental problems and allow flexibility in the face of new scientific evidence.

- Finally, in the case of refurbishing phones for resale abroad, the environmental impacts could be reduced to compete with new handsets by fitting the phones with modern batteries and chargers. In this way not only would the environmental cost of producing new mobile handsets be avoided but the far lower overall impact of new phones due to the lower energy use during their use life could be applied to refurbished phones. As the comparison between the older Takeback handset and the newer Nokia handset composition in section 4.2 indicates the environmental cost of disposal is similar for both leaving only the energy consumption to differentiate their overall environmental impacts. With the absence of new production costs for refurbished handsets this could allow them to compete with new handsets in the developing world on an environmental as well as an economic basis.

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