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The environmental impacts of mobile computing

A case study with HP

Final Report, April 2003

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1. Reader's Guide

This report includes the results and calculations of the HP case study within the Digital Europe project. This case study investigates the environmental effects of mobile computing devices as an element of the growing ICT infrastructure for applications such as ecommerce, egovernment and telework. Specifically, the resource intensity of a notebook computer and a handheld device will be analysed and discussed.

For confidentiality reasons, not all figures used in the case study will be disclosed to the general public. The document is structured in six main chapters, outlined in the following table:

Table 1-1: The structure of the paper.

Chapter	Description of content
2	Introduction to the research objectives, scope and limitations as well as the research methodology.
3	Description and definition of the handheld device's service unit.
4	Description of electronic equipment's life cycle and identification of the system under investigation.
5	Description of the data sources and material intensity calculations.
6	Summary of the results and comparative analysis.
7	Discussion of the findings and future research needs identified.

2. Background & Objectives

2.1 Digital Europe: Ebusiness and Sustainable Development

Digital Europe: Ebusiness and Sustainable Development (henceforth referred to as *Digital Europe*) constitutes the first comprehensive analysis of the relationship between ebusiness and sustainable development in Europe. The project is rooted in a unique partnership between three leading sustainable development research organisations, leading European companies, and regional bodies from across the EU. It draws on the knowledge and expertise of a range of member state and EU policymakers. In doing so, *Digital Europe* focuses on the current realities of ebusiness in Europe in order to identify opportunities for ebusiness to contribute more effectively to sustainable development.

2.2 Hewlett Packard (HP)

HP is a leading global provider of products, technologies, solutions and services to consumers and businesses. The company's offerings span IT infrastructure, personal computing and access devices, global services and imaging and printing. After the merger with Compaq the company had a combined revenue of approximately $81.7 billion in the fiscal year 2001 and operations in more than 160 countries. The new HP provides jobs for 150,000 employees.[1]

With respect to environmental commitment, HP provides the following information: “HP is committed to providing customers with inventive, high quality products and services that are environmentally sound and to conduct HP’s operations in an environmentally responsible manner. That commitment continues to be one of the guiding principles that are deeply ingrained in HP’s values. It is from this history and these values that HP has become a leader in delivery of environmentally sustainable solutions for the common good. HP meets this commitment with a comprehensive environmental policy, strict environmental management of the operations and worldwide environmental programs and services.”[2]

2.3 The HP Case Study

Increasingly, regulators and other stakeholders are concerned about the obsolescence of electrical equipment, in particular consumer products which, as prices and life times reduce due to technical innovations, are increasingly seen as “disposable” technologies. But environmental benefits may be provided by access to information through personal computing products such as dematerialization through size reductions. As technology moves from “boxes” to “systems of interconnected devices”, handheld technologies are increasingly discussed as an important element of mobile computing. However, little is known so far about the environmental aspects of such devices. This case study investigates the environmental aspects of handheld devices. The specific case study objectives are to:

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1 HP (2002). Company information. Available atwww.hp.com/country/us/eng/companyinfo.html

2 HP (2002) Programs & Policies. Available at www.hp.com/hpinfo/community/environment/envprogram/index.htm

1. Describe the function/service units of handheld devices and analyse which physical function/service unit (e.g. calendar) they substitute both in theory and based on current consumer behaviour.

2. Investigate the environmental aspects associated with handheld computing devices compared with different product configurations providing similar services.

3. Time permitting, look at a number of different HP products and configurations in order to understand the environmental trade-offs being made for greater connectivity, speed of computing and portability.

For the environmental comparison of different mobile computing devices, a handheld (Jornada 565) and a notebook (Omnibook 500) have been selected. For both, material intensity analyses are conducted using the MIPS methodology.

2.4 Methodology – the MIPS Concept

Underlying the MIPS methodology are the concepts of 'Factor Four/Ten'. In 1997, Weizsäcker, Lovins and Lovins introduced the 'Factor Four' target with the publication of their book "Factor Four. Doubling Wealth, Halving Resource Use". The 'Factor 4' target states that global eco-efficiency must increase fourfold. In essence, this means quadrupling resource productivity, or in other words the amount of welfare for each unit of natural resource used (EEA, 1999). On the basis of per capita consumption being about five times higher in OECD countries than in developing countries, Schmidt-Bleek has proposed that the material intensity in OECD countries should be reduced by a factor of ten (Weizsäcker et al., 1997). The 'Factor 10' target addresses the absolute amount of natural resources used, as opposed to 'Factor 4' which addresses the ratio of eco-efficiency (EEA, 1999).

Schmidt-Bleek has developed a methodology to calculate the material input per service unit (MIPS, Schmidt-Bleek, 1993a), which he proposes as the unit of output for Factor 4/10. MIPS is defined as the tonnes of materials that must be moved on a 'cradle-to-grave' basis (in other words the material flows) for any given good or service. By associating the material fluxes connected to energy generation, it integrates energy intensity as well. The concept of MIPS is based on the idea that it is the service provided by a certain good that is of interest to the user of that good, i.e. as opposed to the good itself. The service of a handheld computer would be, for example, the storage of contact and meeting information and mobile access to this information.

MIPS can be used as a tool to facilitate eco-efficiency improvements in the design process of goods and infrastructure. As a measurement for the material intensity per service unit, MIPS can be illustrated as a fraction:

$$\textbf{MIPS} = \frac{\textbf{Resource consumption (Material intensity/input)}}{\textbf{Service provided (Service unit)}}$$

Following the MIPS methodology, 'resources' removed out of their environment[3] to provide an economic service can be divided into three categories: energy use; the necessary

[3]Material movements are accounted for as soon as they pass the threshold between Ecosphere and

tangible mass; and the use or distortion of the earth's surface. Based on this scheme, MIPS differentiates five input categories:

- Abiotic raw materials, like mineral raw materials, fossil fuels, excavation residues;
- Biotic raw materials, like animal and plant biomass from farmed and non-farmed areas;
- Soil movements (in agriculture and forestry), e.g. soil cultivation, erosion;
- Water, e.g. surface water, ground water;
- Air (compounds), e.g. combustion, chemical synthesis.

The sum of all material inputs required to provide one service unit represents material intensity. The part of the material turnover – measured in tons, kilograms or grams – that does not enter the product itself, is commonly called its ecological rucksack.

In order to compare material inputs for different products and services they need to be related to one comparable unit: the 'service unit'. Introducing this 'comparison unit' is necessary since similar products often do not yield the same use; e.g. their lifespan might be different. Defining a service unit allows the fact that true ecological cost is dependent on the lifetime of the product or service to be taken into consideration. Depending on the number of uses a product yields, the material intensity will grow or shrink (unless the material consumption per service unit in the use phase is higher than the one in the production and end-of-life stage). For example, the service unit for comparing modes of transportation is typically 'person kilometres' for people or 'tonne kilometres' for freight. MI factors – the factor by which the respective amount of materials used to produce the product or service needs to be multiplied to calculate the material intensity – range from 1.2 for natural gas, 7 for steel, 8 for PVC, 85 for aluminium, 1409 for nickel, and up to 540,000 for gold. A golden ring of about 10 g carries an invisible ecological backpack of 10 x 540,000 g, or over 5 tons. Not only is it possible to calculate the material intensity for end products, it is also possible to separately calculate for sub-components. The main advantage of MIPS is that results, although not exact ones, can be generated relatively quickly. Being exact enough to allow comparison with different alternatives can serve as a support tool for decision-making or as a basis for more detailed and sophisticated studies.[4]

Technosphere. On the INPUT side, this threshold is passed as soon as materials are actively extracted or moved with technical means. On the OUTPUT side, materials leave the Technosphere when they are translocated into a natural environment (e.g. emissions into a river) (Schmidt-Bleek et al., 1998, p. 36).

[4] Rautenstrauch, C. (1999). *Betriebliche Umweltinformationssysteme* [environmental information systems for business]. Berlin, Heidelberg: Springer.

3. Defining the Service Unit of Handheld Devices

Section 2.4 explained the basic function of the service unit. Due to its key position within the MIPS concept, the definition of the service unit is a crucial step in the analysis. It determines the data requirements as well as the applicability of the results. When defining the service unit it is important to make sure that:

1. The unit allows comparison of many different product or service alternatives. Hence it should be phrased in a generic way;

2. The unit reflects all important usage aspects of the product/service;

3. The measure of the unit is understandable and applicable for a broad audience.

Handheld computers allow users to store, access and organise information. Less sophisticated handhelds allow users to store and retrieve information such as telephone numbers and addresses, and normally offer services such as calendar management and the ability to create to-do lists and notes. However, handheld computers are following the traditional route of computers in general by becoming faster and more powerful with time. With increasing sophistication there is an increase in the number and level of services which the handheld can offer the user. More advanced handheld devices offer the user the ability to run further services such as word processing packages, spreadsheets, presentation packages and can provide access to e-mail and the Internet. This ability to access the Internet and e-mail accounts is improving as the handhelds evolve. Although handheld computers are evolving at a rapid rate, the majority are still used in conjunction with office based computer equipment. The majority of handhelds can synchronise with laptops or desktop computers and so are also used as a portable data storage unit rather than an independent computer system.

For a multifunctional computing device the service provided to the user depends on consumer behaviour and should therefore be defined based on consumer behaviour studies. As there are no consumer studies for handheld devices available within the Digital Europe project, the service unit is defined on a theoretical base. Theoretically, a handheld can fulfil different human needs. A workshop conducted with participation from HP at the Wuppertal Institute in February 2002, identified the following needs which a handheld device can potentially address.

Table 3-1: Potential needs addressed by functions of a handheld device.

Needs	Functions
Informational needs	Contact management (address book)
	Time management (calendar)
	Number processing (calculator)
	Information storage (note taker)
	Multimedia applications (image viewer)
	Working on documents & spreadsheets
Mobility needs	Portability (size, weight)
	Access to e-mail (via phone line or cellular phone)
	Internet access
	Connectivity to computer network
Kudos	Recognition by peers for having latest device

Considering the above-mentioned criteria for determining the service unit and the needs the handheld potentially addresses (informational needs, mobility needs and kudos), the service unit is therefore defined as follows:

Service unit: Convenient mobile information processing for three years

The service unit comprises aspects which depend on the user's subjective desires, e.g. a reasonable diversity of functions, appropriate time requirements and ease of use regarding specific functions, practical standby and charging times, acceptable weight, etc. The service unit also covers kudos as it can be one of the desired functions. The service unit definition takes into account that the customer is using specific services (or combinations of services) at a specific time, e.g. a customer may use the note-taking function only several minutes per day.

Considering the study scope, the service unit should allow a comparative analysis of different product configurations providing similar services. The given definition considers the provision of different services and their combinations (such as stationary note taking, mobile time management, etc.) and can be applied to other multifunctional mobile electronic devices such as the notebook.

4. Setting the System Boundaries

This chapter describes the processes involved in the life cycle of electronic equipment. In doing so, the system boundaries for the analysis of the handheld and the notebook are given. An in-depth description of figures and data is presented in chapter 5.

Material intensity analyses generally consider the entire life cycle of the product or service. This means that from raw material extraction, material processing and manufacturing to use and end-of-life, all resource consuming aspects will be reflected. The following flow chart illustrates the scope for the MIPS analyses of the notebook and the handheld.

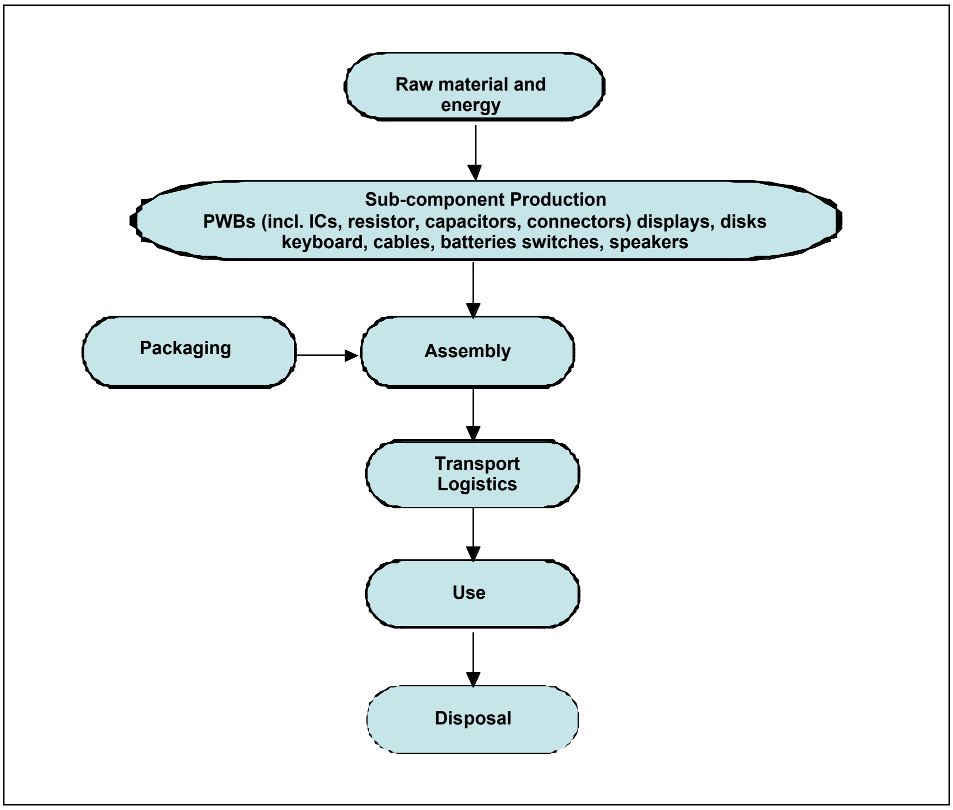

Figure 4-1: Generic process flowchart.[5]

The electronic equipment manufacturing process begins with the fabrication of the basic **electronic sub-components**. These include semiconductors, resistors, relays, capacitors, inductors and other passive components, displays, batteries, sensors, switches and cables. These sub-components are partly assembled on printed wiring boards (PWBs), which are the basic building blocks of handheld computing devices and electronics in general. In electronic equipment they are found in the main system unit, the display or the modem, as well as other peripheral components. For the production of electronic sub-components a variety of manufacturing process are needed, e.g. electroplating, etching, polishing, soldering, tinning, cutting or laminating.

[5] This flowchart is used for illustration purposes. It should be considered that it inevitably simplifies the reality.

The electronic devices are assembled by combining the electronic and non-electronic components in a casing. The non-electronic components are e.g. cables, batteries, switches, connectors, lighted diodes, sensors and keyboards. The final packed product also includes information material, supporting items such as power adapter and cables as well as the packaging.

The components and subcomponents of electronic equipment are made in different countries, often by different manufacturers, before being assembled into the finished product and sold to the end-user. Consequently, electronic devices and their constituent parts are well travelled which increases their transport intensity and thereby their material intensity. For the purposes of this study, only the fuels consumed during transportation of the assembled product to the market will be investigated. The transportation processes for the components (before assembly) are highly complex but might contribute significantly to the overall material intensity, especially if air transportation is involved.[6] Here no specific data could be made available. The transport infrastructure such as roads, harbours, truck and vessels will be assumed to be already in place and will not be accounted for.

During the **use-phase** of electronic devices the energy consumption is the most frequently mentioned environmental impact. The electricity for charging the handheld may come from different electricity grids (e.g. Europe, U.S. or charging it in the car) using different energy sources (hydropower, nuclear, fossil fuels or others). Within this study, the electricity grid of Europe and no mobile energy sources are assumed.

The **end-of-life phase** covers the takeback aswell as the end-of-life treatment. Due to the fact that currently there are almost no handheld devices being recycled, the takeback and end-of-life treatment is not covered in the study.

The geographic system boundaries for this study are worldwide. This takes the worldwide scope of HP's activities (see section 2.2) into account. However, for reasons of data availability, in some cases data with other geographic reference have been used, i.e. Brussels has been assumed as location of retailing and product use.

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[6] Considering the short innovation cycles and rapid drops in prices of some electronic components, quick transportation by plane is likely to be the economically preferred option for such components.

5. Data Inventory

This chapter provides an overview of the status quo concerning the available information and data for the material intensity analysis of both the handheld and the notebook.

5.1 Product Breakdown

In order to assess the material intensity of electronic devices it is essential to know their materials composition as well as the weight of the different parts. As this information was not available the Wuppertal Institute has done a product breakdown (employing an electronic scale) of the devices in consideration. With the help of a material scientist the different materials have been identified.

5.1.1 Handheld (Jornada 565)

The components of a handheld (Jornada 565) and related items, their material compositions and their weight are given in the following as a result of the product breakdown. Additionally an external modem was analysed in order to improve the comparability to the notebook which has an internal modem. It is the 56 K "Compact Modem" for use with pocket PCs from PRETEC.[7]

[7] For more detailes see www.pretec.com

Table 5-1: Jornada 565 product breakdown including an external modem.

Element	Component	Basic material / country of origin	Weight [g]
Handheld	Liquid Crystal Display	LCD	51
	Casing: Bottom cover	Magnesium (90%), Steel (5%), HIPS (5%)	15
	Casing: Top cover	Magnesium (60 %) HIPS (40%)	9
	Casing: Corner protection	Synthetic rubber	2
	Casing: Frame	HIPS	7
	Speaker	Steel (85%), PVC (10%), Copper (5%)	2
	Pen and shutter	HIPS	7
	Casing: Lid	HIPS	19
	Battery pack, Li-polymer	Li-Polymer (80%), HIPS (18%), 2% PP	38
	Battery, CR2032, 3V	Battery	3
	PWB, main electronics	PWB	40
	PWB	PWB	6
Modem	PWB –Modem	PWB	13
	Casing Modem	Steel (58%), PVC (42%),	14
Support Items (non-electronic)	Handheld station	Steel (60%), HIPS (25%), PVC (13%), copper (2%)	409
	Power adapter	Steel (50%), HIPS (25%), copper (15%), PVC (10%)	128
	Phone cable	PVC (88%), copper (10%), polycarbonate (2%)	24
	Modem phone cable	PVC (88%), copper (10%), polycarbonate (2%)	38
	Modem adaptor	HIPS (95%), copper (5%)	7
Packaging Items	Product instructions and info material	Paper	289
	1 CD ROM	CD	15
	CD packaging	PE	6
	PE Foil	PE	10
	Retail Box	Carton	138
	Styropor	EPS	68
	Modem product instructions	Paper	16
	Modem CD-ROM	CD	13
	Modem PE Foil	PE	5
	Modem Retail Box	Carton	123
Total:			**1515**

5.1.2 Notebook (Omnibook 500)

The following table shows the components of the notebook under investigation (HP Omnibook 500) and related items, their material compositions and their weight.

Table 5-2: Omnibook 500 product breakdown.

Element	Part	Basic material(s) /country of origin	Weight [g]
Notebook top	Liquid Crystal Display	LCD / Japan	328
	Casing: Bottom cover	HIPS	21
	Casing: Top cover	Magnesium (80 %), steel (10%), HIPS (10%)	164
	Casing: Hinge	Steel	15
	Casing: Switch	HIPS	2
Note-book bottom	Casing: Top cover	HIPS	87
	Casing: Switch board	HIPS	17
	Keyboard	Aluminium (70%), HIPS (30%) / Taiwan	97
	Battery, Li-Ion	Batteries / Taiwan	273
	Battery pack, Ni-MH	Batteries /Germany	8
	Fan	Aluminium (80%), HIPS (15%), PWB (5%) / Taiwan	19
	Heat conductor	Steel (50%), copper (30%), aluminium (20%)	45
	PWB, main electronics	PWB	194
	Memory board, 128MB	Memory board	10
	Modem board	PWB	13
	Modem cable	Steel (40%), HIPS (40%), PVC (15%), copper (5%)	10
	Hard Disk (HD)	Aluminium (60%), steel (30%), PWB (10%) / Philippines	104
	HD holders (3 parts)	Steel	58
	Metal holder for PWB	Steel	5
	PCMCIA – Slot	Steel (95%), HIPS (5%)	18
	Casing: Bottom case	Magnesium (80%), HIPS (10%), aluminium (5%), steel (5 %)	190
Expansion Base	Casing: Top Cover	Steel (40%), HIPS (40%), aluminium (20%)	336
	Casing: Metal plate	Steel	62
	Casing: Bottom cover	Steel (70%), HIPS (30 %)	263
	Floppy drive, 1.44MB	Floppy drive / China	173
	CD-ROM drive, 24X	CD ROM drive / China	231
	Switch, speaker and cables	Steel (40%), HIPS (30%), PVC (20%), copper (10%)	57
	PWB	PWB	184
	Disk holder	Steel (90%), HIPS (10%)	34
	Drive slot cover	HIPS	12
Support Items	Power adapter	Steel (50%), HIPS (25%), Copper (15%) PVC (10%)	357
	Phone cable	PVC (65%), HIPS (23%), copper (10%), Polycarbonate (2%)	37
Packaging Items	Info Paper	Paper	15
	WIN Pro Info	Paper	263
	2 CD ROM	CD	30
	CD packaging	PE	13
	Packaging foil	PE	51
	Retail box	Carton	837
	PS Foam	PS Foam	89
Total:			**4722**

5.2 Data Availability, Data Sources, Data Quality

The following table provides an overview of the data sources used to calculate the material intensity of the electronic devices.

Table 5-3: Data sources

Process		Data source
Electronic components	PWB	Atlantic Consulting, IPU (1998) US EPA (1998)
	Memory board	Wuppertal Institute (based on Siemens 1998)
	LCD	Wuppertal Institute (based on US EPA (2000)
	Hard disk	Wuppertal Institute
	CD ROM drive	No specific data could be found
	Floppy disk drive	No specific data could be found
Non-electronic components (incl. power adapter)	Batteries	No specific data could be found
	Cables	Wuppertal Institute
	Li-polymer	Wuppertal Institute (based on ENEA 2001)
	Metals	Wuppertal Institute (e.g. based on IISI 1998, EAA 2000)
	Plastics (diff. types)	Wuppertal Institute (based on APME)
Packaging	Paper	Wuppertal Institute (based on BUWAL 1996)
	Cardboard	Wuppertal Institute (based on BUWAL 1996)
	CD	Wuppertal Institute (Digital Europe Case Study with EMI)
Energy	Electricity	Wuppertal Institute
Transport	Ship and road transport	HP (personal communication), Wuppertal Institute
Use phase	Daily use of mobile devices	HP (personal communication), Roth et al. (2002), assumptions
End-of-life phase	Combustion of municipal waste	Wuppertal Institute (based on BUWAL 1996)

The data used in this study is based on the given information sources and on calculations by the Wuppertal Institute. For most materials data could be made available for the material intensity analysis. As far as the data quality is concerned, it can be said that in general the available information is appropriate. Although some studies are slightly outdated, they represent the current state of the art of accessible information.

5.3 Material Intensity of Components and their Manufacturing

This chapter describes the material intensities of the components including their manufacturing.

5.3.1 Casing

The product breakdown derived the weight and material composition of the casing (see: Table 5-1 and Table 5-2). For the handheld, the casing makes up 4% of the packed product weight (mainly magnesium and different types of plastics), whereas for the notebook, the casing represents 25% of the entire product weight (mainly of magnesium, aluminium, steel and plastic).

Box 5-1: Material intensity of the casing

	Handheld	Notebook
Abiotic raw materials	0,8 kg	19,2 kg
Biotic raw materials	-	-
water intensity	25 kg	476 kg
TMR	0,8 kg	19,2 kg

5.3.2 Electronic Components

Due to the material composition and the material intensive processing, electronic components are of major importance for the material intensity. The analysis of the electronic components covers the PWBs, the LCDs, the external modem (handheld) and the memory chip (notebook).

5.3.2.1 Printed Wiring Boards (PWBs)

Both mobile computing devices incorporate a number of PWBs. These have been covered in the material intensity analysis. The total weight of the PWB including components in the handheld is less than 60 grams (with an surface area of 97 cm^2) and in the notebook about 400 grams (with an surface area of 697 cm^2). It was not possible to get any detailed information about the material content of the specific PWB, so that generic data needed to be consulted. Based on the data given in the LCA by Atlantic Consulting, IPU (1998), the main material inputs for the PWB and its subcomponents could be identified per surface area of the PWB. For most of the material inputs (covering more than 99% of the materials) the backpack figures have been made available. For some specific materials, assumptions and estimates needed to be made.

Box 5-2: Material intensity of the PWB

	Handheld	Notebook
Abiotic raw materials	40,1 kg	286,6 kg
Biotic raw materials	-	-
Water intensity	374 kg	2680 kg
TMR	40,1 kg	286,6kg

As only generic data could be used, the given material intensity analysis is only a rough estimation. That especially the functional materials on the PWB are of major importance can be highlighted by the material intensity of a chip. First analyses for the CPU chip based on data provided by AMD in their environmental and business reports[8] found that the abiotic material intensity for the notebooks' chip die (Silicon) is more than 22 kg. The related MI factor is similar in magnitude to the MI factor of gold.

5.3.2.2 Liquid crystal displays (LCDs)

The product breakdown derived the weight of 51 g (handheld) and 328 g (notebook). The active surface area of the LCDs have been 39 cm^2 (handheld) and 632 cm^2 for the notebook. Based on a detailed LCA by the US EPA (2000) the main inputs for the LDC could be identified. For most of the material inputs (covering more than 99% of the materials) the backpack figures have been made available. For some specific materials, assumptions and estimates needed to be made.

Box 5-3: Material intensity of the LCD

	Handheld	Notebook
Abiotic raw materials	3,0 kg	48 kg
Biotic raw materials	-	-
Water intensity	93 kg	1488 kg
TMR	3,0 kg	48 kg

5.3.2.3 External Modem (handheld only)

The analysis of the material intensity of the external modem for the handheld is based on the product breakdown (PWB, HIPS, steel, polycarbonate, copper and PVC).

Box 5-4: Material intensity of the modem

	Handheld	Notebook
Abiotic raw materials	9,70 kg	-
Biotic raw materials	-	-
Water intensity	46 kg	-
TMR	9,70 kg -	-

5.3.2.4 Memory chip (notebook only)

[8] AMD (2001). Sustainability Progress Report 2000: Environment, health and safety. AMD (2001). Annual report.

The analysis of the material intensity of the memory chip in the notebook is based on information from Siemens[9].

Box 5-5: Material intensity of a memory chip

	Handheld	Notebook
Abiotic raw materials	-	29,7 kg
Biotic raw materials	-	-
Water intensity	-	885 kg
TMR	-	29,7 kg

5.3.3 Non-electronic Components

The group of non-electronic components covers parts such as power adapters, speakers, cables, switches, etc. In the case of the handheld it also includes the stylus and the docking station. For the notebook, the non-electronic components include heat conductors and the keyboard.

Box 5-6: Material intensity of non-electronic components

	Handheld	Notebook
Abiotic raw materials	18,7 kg	45,5 kg
Biotic raw materials	-	-
Water intensity	70 kg	238 kg
TMR	18,7 kg	45,5 kg

For some non-electronic components (CD-ROM and floppy drives and batteries) no relevant data for their material intensity could be made available. Thus they are excluded from the calculations. However, for both drives it is estimated that the material intensity is rather low compared to the overall material intensity figure of the notebook, even though they account for almost 9% of the product's weight (including its packaging). Reasons for this are the facts that mainly structural materials with low material intensities are used in those devices and that these drives are mass products with long product innovation cycles and therefore with rather optimised production. The batteries account for 3% (handheld) and 6% (notebook) of the product's weight (including its packaging). For the batteries, no estimations of the ecological backpack can be given due to the lack of relevant data. Here, data gaps need to be filled.

[9] Siemens (1998). Umweltbericht 1998. Der Umwelt verpflichtet: Verantwortung, Vorsorge, Erfolge. Bericht Halbleiter. [Bounded to the environment: Responsibility, foresight, success. Report Semi-conductor] Siemens (1998) Personal communication.

5.3.4 Packaging

The packaging includes information material, foil, and the carton as well as shock-absorbing materials. In the case of the handheld with its external modem, packaging makes up 45 per cent of the entire product weight whereas for the notebook this figure is about 27 per cent.

Box 5-7: Material intensity of the packaging

	Handheld/ External Modem	Notebook
Abiotic raw materials	3,7 kg / 0,95 kg	4,6 kg
Biotic raw materials	0,8 kg / 0,1 kg	1,3 kg
Water intensity	139 kg / 43 kg	189 kg
TMR	4,5 kg / 1,1 kg	5,9 kg

5.3.5 Assembly

In literature, the assembly of components in the actual consumer good is described as probably the least important step from an environmental point of view.[10] As primary data regarding the material and energy used for assembly could not be collected, this part has not been focused on within this study.

5.4 Material intensity of transport and distribution

Regarding transportation, this study covers the fuel consumption for the transport from manufacture to retailer and the transport from retailer to consumer. The transport related to the component and subcomponent manufacturing has not been included due to the lack of data. Fuel consumption is mainly determined by the volume and weight of the product, distance and mode of transport.

5.4.1 Transport from Manufacture to Retailer

Information about the location of manufacture and modes of transport (ship and road) has been provided by HP.[11] Due to the lack of specific data about average transport distances to retailers, the selling point is assumed to be in Brussels. For the analysis of the material intensity the following steps are considered.

1. First truck movement in a large lorry from the manufacturing sites to the nearest seaport in the country of manufacture. It is estimated that the distance is on average about 50 km.

[10] Kuhndt, M., Bilitewski, B., Kleijn, R., Goree, M., Clift, R., Ransome, T. (Eds.) (2002). Analytical Tools for Environmental Design and Management in a Systems Perspective. Part Two Cases and Appendices. Kluwer Academic Publishers.

[11] HP, personal communication.

2. Ship movement in vessel to Rotterdam harbour. The shipping distance is 13,000 km for the handheld and about 16,000 km for the Notebook.

3. Second truck movement (large truck) from Rotterdam harbour to Brussels retailing hub. Distance is 150 km.

4. Third truck movement from hub to retailer for which vehicles of varying size can be used. It is assumed that the transport distance is in total 30 km for which smaller trucks are used.

5. The average load per vehicle has been assumed to be

   a) for a large truck 3,000 packed handheld or 1,500 packed notebooks

   b) for a small truck 1,000 handheld or 500 notebooks

Box 5-8: Material intensity of transport from manufacture to retailer

The above figures have been used for the calculation of the material intensity of transportation from manufacture to the retailer. Key assumption that have been taken are:

- The diesel consumption for container vessels is 5.5 g/tonne-km.[12]
- Diesel consumption for a large truck is 30l/100km
- Diesel consumption for a small truck is 15l/100km

This yields to:

	Handheld	Notebook
Abiotic raw materials	0,17 kg	0,78 kg
Biotic raw materials	-	-
Water intensity	1 kg	6 kg
TMR	0,17 kg	0,78 kg

5.4.2 Transport from Retailer to Customer

For the final transportation step from retailer to consumer, consumers usually visit the sales point for information before actually buying. They usually combine more than just one shopping activity with each trip. Since shopping by car makes up the majority of shopping trips, this means of transport will need to be reviewed. For each trip, two shopping activities will be assumed. Regarding the trips for product information, one additional trip will be assumed for the handheld device, whereas for the more complex and expensive notebook two supplementary trips are assumed.

[12] The fuel consumption has been reported by Stiller, H. (1995). Materialintensitätsanalyses von Transportleistungen: Seeschiffahrt. [Material intensity analyses for transport: Ocean shipping]. Wuppertal Paper No. 40.

Box 5-9: Material intensity of transport from retailer to consumer

The key assumptions that have been taken are:

- The average distance for a shopping trip is assumed to be 10 km.
- Petrol consumption for a car is 8.5l/100km.

This yields to:

	Handheld	Notebook
Abiotic raw materials	0,83 kg	1,25 kg
Biotic raw materials	-	-
Water intensity	6 kg	9 kg
TMR	0,83 kg	1,25 kg

5.5 Material Intensity in the Use Phase

The material analysis for the use phase covers the electricity consumption and is determined by consumer behaviour and the product specifications. As shown in the figure below, the consumer behaviour of an electronic device can be described by the use characteristics, namely - time in on, standby, sleep and off modus.

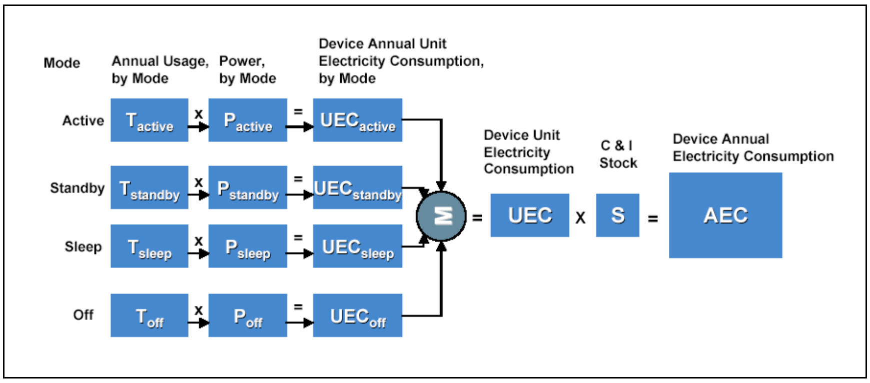

Figure 5-1: Annual electricity consumption for electrical devices[13]

The diagram shows the annual electricity consumption calculation for a larger stock of electronic equipment. For this case study the calculation can serve as a baseline with two presuppositions. First, the stock in the case study is assumed to be one single piece of equipment. Second, due to the fact that we have mobile devices connected to the power grid, charging efficiency and the standby power draw of the chargers needs to be considered. Considering this, the energy use W for mobile computing devices is described by the following equation.

[13] Taken from Roth, K., Goldstein, F., Kleinman, J. (2002). Energy Consumption by Commercial Office and Telecommunications Equipment in the U.S., Presentation for IEECB Conference, 29 May, 2002, Nice, FRANCE, p. 4.

$$W = 1/charge\_efficiency * (P_{use} *t_{use} + P_{standby} *t_{standby} + P_{sleep} *t_{sleep}+*P_{off} *t_{off}) + (P_{charger\ standby}* t_{charger\ standby})$$

This equation will be used in order to identify the electricity use of the mobile devices.

The handheld's electricity use assessment faced some difficulties, as the actual power consumption in the different modes could not be measured and needed to be estimated. In addition, according to a study by ADL, handheld device energy use can be substantially increased, e.g. by inefficient charging equipment or supplementary devices such as modems. Additional memory cards for example can be "higher in power consumption than the rest of the handheld device's electronics."[14] These give some uncertainties to the evaluation of the power consumption.

For the estimation of the Jornada's electricity consumption, the following assumptions will be made. The Jornada has three different modes: on with backlight activity, on without backlight activity and suspend. As data from HP has not been available for all the figures, assumptions have been used which are based on values sourced from generic literature and in-house estimations.

[14] Roth, K., Goldstein, F., Kleinman, J. (2002). Energy Consumption by Commercial Office and Telecommunications Equipment in the U.S., Presentation for IEECB Conference, 29 May, 2002, Nice, FRANCE, p. 4.

Table 5-4: Electricity consumption calculation for the handheld

Mode	**Power Draw** [W]	**Time/Week** [h]		**Power consumption** [Wh/week]
		Use for work[15]	**Power user**[16]	
On with backlight	1.517[17]	10	16.8[18]	15.2 – 25.5
On without backlight	0.325[19]	25	39.2[20]	8.1 – 12.7
Suspend	0.015[21]	132	112[22]	1.98 –1.87
Sum				25.3 – 40.1
1/ Charge efficiency				4.0 (1/0.25)[23]
Total Device Use				101.1 – 160.3
Charger standby consumption[24]	0.02[25]	84		1.7
Total Energy Use				102.8 - 162

For the handheld, the electricity use per year amounts then to 5.3 kWh/year for the work use and to 8.43 kWh/year for the power user.

Generally speaking, **notebooks** use more energy than handhelds. One of the main reasons is due to the bigger size of the screen which uses more energy than the comparably small screen size of a handheld. Additional components in the notebook such as larger processors or memory chips require more energy for operation. Also lithium-ion batteries that are found inside laptops require more charging energy than the small battery inside a handheld. Laptops have higher processing performance and are able to run much more complex and

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[15] This scenario assumes the use over five days a week and 9 hours per day.

[16] These data are based on literature, assessed as being high.

[17] Calculated from battery values: 3.7 V, 1.23 Ah, ≈3 h battery life (assumed)

[18] Roth et al. assume the time use in the "on" mode to be 56 hours. This time has been split into 30% with backlight and 70 % without backlight.

[19] Calculated from battery values: 3.7 V, 1.23 Ah, ≈14h battery life (Source: HP product description)

[20] Roth et al. assume the value for the on mode to be 56 hours. This time has been split into 30% with backlight and 70% without backlight.

[21] Roth, et al. (2002). Energy Consumption by Commercial Office and Telecommunications Equipment in the U.S., Presentation for IEECB Conference, 29 May, 2002, Nice, FRANCE, p. 173.

[22] Roth et al. assume the time use for the sleep mode to be 28 hours and 64 hours for the off mode. For the Jornada's suspend mode, these two values will be added up.

[23] Roth, et al. (2002). Energy Consumption by Commercial Office and Telecommunications Equipment in the U.S., Presentation for IEECB Conference, 29 May, 2002, Nice, FRANCE, p. 173.

[24] This refers to chargers being plugged into the electricity network, but not connected to the main device, here a handheld.

[25] Based on data from German EPA (2002) Online Available at http://www.umweltbundesamt.de/uba-info-daten/daten/leerlauf.htm and Griese, H. (2002). Handy – Eine Umweltbewertung aus Sicht der Wissenschaft. [Handy – An environmental assessment from a scientific point of view] in: Fraunhofer IZM, Abteilung Environmental Engineering (2002). Dauerhaft umweltgerechte IuK-Technik – Beispiel Handy – [Durable environmental IC Technoloy – An example: The Handy –]. UBA Fachgespräch Bericht, Berlin, pp. 8-10.

broad application programs, therefore it also consumes more energy in the processing phase of more complex calculations.

The estimated electricity consumption of the notebook has been calculated for each of the activity modes shown below using values from relevant literature and in-house measurements.

Table 5-5: Electricity consumption calculation for the notebook

Mode	**Power draw of notebook** [W]	**Time/Week** [h]		**Power consumption per Week** [Wh]
		Use for work	**Power user**	
Active	9.83[26]	25	35[27]	246 - 344
Suspend[28]	3[29]	15	70[30]	45 – 210
Off, connected to the grid	2[31]	58	31[32]	116 - 62
Unplugged	0[33]	70	31[34]	0
Sum				407 – 616
1/ Charge efficiency				4.0 (1/0,25)[35]
Notebook electricity				1628 – 2464
Charger standby energy	3.6[36]	84		302.4
Total Energy Use				1930 - 2766

For the notebook, the electricity use per year amounts then to 100.3 kWh/year for the work use and to 143.8 kWh/year for the power user.

The following box provides the material intensities for the use phase. The calculations are based on a European electricity mix.

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[26] Calculated from battery values: 11.1 V, 3.1 Ah, □3.5 h battery life

[27] Roth et al. assume the “on mode” value for a notebook to be 19.2 hours. This is for the scenario of a power user too little. Roth et al. assume for a PC user this value to be 99 hours, which is most probably too high. Thus, a weekly use time in the on modus of 35 hours is assumed.

[28] Please note that the suspend mode covers both the standby and the sleep mode. These two phases are assumed to have similar electricity demands.

[29] Kawamoto et al. (2001) as cited in Roth et al. (2002), p. 28.

[30] Roth et al. assume the “off mode” value for a notebook be 86.4 hours. This seems to be quite high as even a power user has a sleep modus. Thus a weekly use time in the suspend modus of 70 hours is assumed.

[31] Kawamoto et al. (2001) as cited in Roth, K.W. et al. (2002). p. 28.

[32] Roth, et al. (2002). This study bases the figure for the time use pattern on three different sources.

[33] Estimated by the Wuppertal Institute.

[34] Roth, et al. (2002). This study bases the figure for the time use pattern on three different sources.

[35] This figure is taken from Roth, et al. (2002) and based on data for handheld charging devices. The charger for the notebook might be more efficient, but no more concrete figure could be found within the time frame of the study.

[36] measured at the Wuppertal Institute.

Box 5-10: Material intensity of the electricity for a one year use phase

	Handheld	**Notebook**
Abiotic raw materials	8,5 to 13,3 kg	158,8 to 227,5 kg
Biotic raw materials	-	-
Water intensity	341 to 538 kg	6406 to 9181 kg
TMR	8,5 to 13,3 kg	158,8 to 227,5 kg

6. Material Intensity of the Product Systems

This chapter will give a summary of the material intensity analysis for both the handheld and the notebook and will provide a comparative analysis for both product systems.

6.1 Results for the handheld

The following table provides an overview of the material intensities for the handheld's life-cycle stages and components. The study of material intensities covered the manufacturing, packaging, transport and use of the handheld. As no specific data could be identified for the end-of-life phase and the batteries, these aspects are therefore not included. However, the material intensities of the available figures and their relation already enable a number of conclusions to be drawn.

Table 6-1: Results of material intensity analysis for handheld

		Material consumption [kg]			
Component/life-cycle stage	Weight [kg]	abiotic raw materials	biotic raw materials	water	TMR
Production	1.47	81.0	1.0	760	82.0
Casing	0.052	0.8	-	25	0.8
PWB with components	0.046	40.1	-	374	40.1
LCD	0.051	3.0	-	93	3.0
Non-electronics	0.570	18.7	-	70	18.7
Modem incl. PWB	0.072	13.8	-	15.4	13.8
Packaging Modem	0.157	0.95	0.1	43	1.1
Packaging Handheld	0.526	3.7	0.8	139	4.5
Transport		1.0	-	7	1.0
Use phase (3 year work use)		25.6	-	1023	25.6
Use phase (3 year power use)		40.0	-	1613	40.0
Total (work use)		107.4	1.0	1791	108.4
Total (power user)		122.0	1.0	2380	123.0

6.2 Results for the notebook

The following table provides an overview of the material intensities for the notebook's life-cycle stages and components. The study of material intensities covered the manufacturing, packaging, transport and use of the notebook. As no specific data could be identified for the disk drives, the batteries and the end-of-life phase, these aspects are not included. However, similar to the handheld device, the material intensities of the given resource consumption figures and their relation already enable a number of conclusions to be drawn.

Table 6-2: Results of material intensity analysis for notebook manufacturing

		Material consumption [kg]			
Component/life-cycle stage	Weight [kg]	abiotic raw materials	biotic raw materials	water	TMR
Production	4.04	433.6	1.3	5955	435.0
Casing	1.22	19.2	-	476	19.2
PWB with components	0.41	286.6	-	2680	286.6
LCD	0.33	48.0	-	1488	48.0
Memory chip	0.01	29.7	-	885	29.7
Non-electronics	0.78	45.5	-	238	45.5
Packaging	1.30	4.6	1.3	189	5.9
Transport		2.0	-	15	2.0
Use phase (3 year work use)		476.3	-	19218	476.3
Use phase (3 year power use)		682.6	-	27543	682.6
Total (work use)		911.9	1.3	25188	913.3
Total (power user)		1118.2	1.3	33513	1119.6

6.3 Results for the recycling scenario

During the project it turned out to be of interest to quantify the potential material savings through the use of secondary materials. For the above calculation primary material have been assumed for all materials. A potential scenario could be substitution of primary aluminium, magnesium and copper in the casing and non-electronic components. As these materials most probably cannot be fully substituted by secondary materials, a rate of 80% secondary metals should then be assumed. The following table highlights the changes in raw material consumption for the casing and non-electronic components if secondary metals are used.

Table 6-3: Resources for the casing and non-electroninc components, comparing for primary and secondary inputs

		Material consumption [kg]			
Product	Recycling scenario for aluminium, magnesium and copper	abiotic raw materials	biotic raw materials	water	TMR
Handheld	100 % primary	19.5	-	96	19.5
Handheld	20 % primary, 80% secondary	7.0	-	74	7.0
Notebook	100 % primary	50.7	-	410	50.7
Notebook	20 % primary, 80% secondary	12.5	-	273	12.5

For the handheld's casing and non-electronic components, the amount of abiotic resources used can be reduced to 36 % of the original resource consumption, the amount of water used could be reduced to 77 %. For the notebook's casing and non-electronic components, the relative savings are even higher: Abiotic raw materials could be reduced to 25 % of the previous values and the water use could be brought down to 67%. These are rough estimations, but they highlight the potentials of increased substitution. However, more practical data and research is needed to make reliable estimations regarding the efficiency of recycling.

6.4 Results for a sharing scenario

During the project the concept of sharing notebooks was discussed as mean to reduce the material intensity of a company. The question arose what raw material savings could be achieved if a company would provide handhelds to all salesmen and promote a shared use of notebooks. This could be compared to a situation where all employees are using individual notebooks. Starting from the material intensity analysis of the notebook and its assumptions, as described above, with increasing number of persons sharing a notebook the use intensities of the notebooks and the handhelds would also increase. However, with respect to the related use of abiotic raw materials, the saving of notebooks (and paper based personal organisers) is offsetting these increasing use intensities, as illustrated in the figure below.

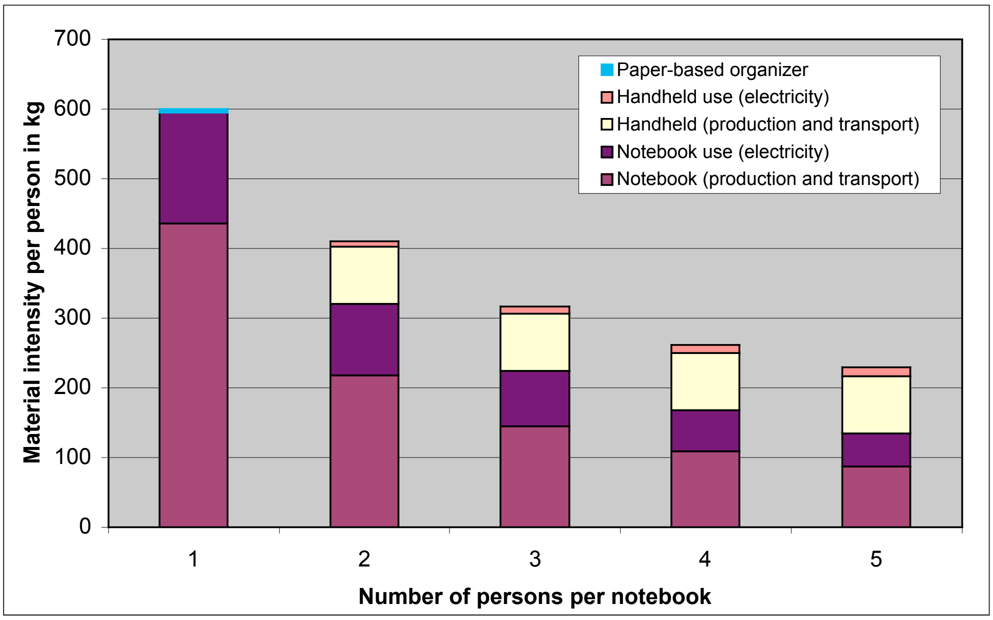

Figure 6-1: Abiotic raw material intensity for sharing notebooks and additional use of handhelds

These savings seem to be high, however, in practice there a number of barriers for the shared use of notebooks and related material saving. For example, some salesmen will need a notebook when they are travelling. The shared use of notebooks might force other salesmen to come back to the workplace when they need the notebook´s processing capacities. Also, there are a number of changes needed to create shared working places (e.g. additional office equipment), which might be related to additional material intensities. But still, the concept of sharing seems an opportunity for increased resource efficiency.

6.5 Future scenarios

Based on an Internet and literature search and interviews with HP personnel, trends and future development in the market of mobile computing have been identified. These trends were classified by their predictability. Links to risks and opportunities for resource consumption are discussed.

The following figure summarise the identified trends and examples for potential implications.

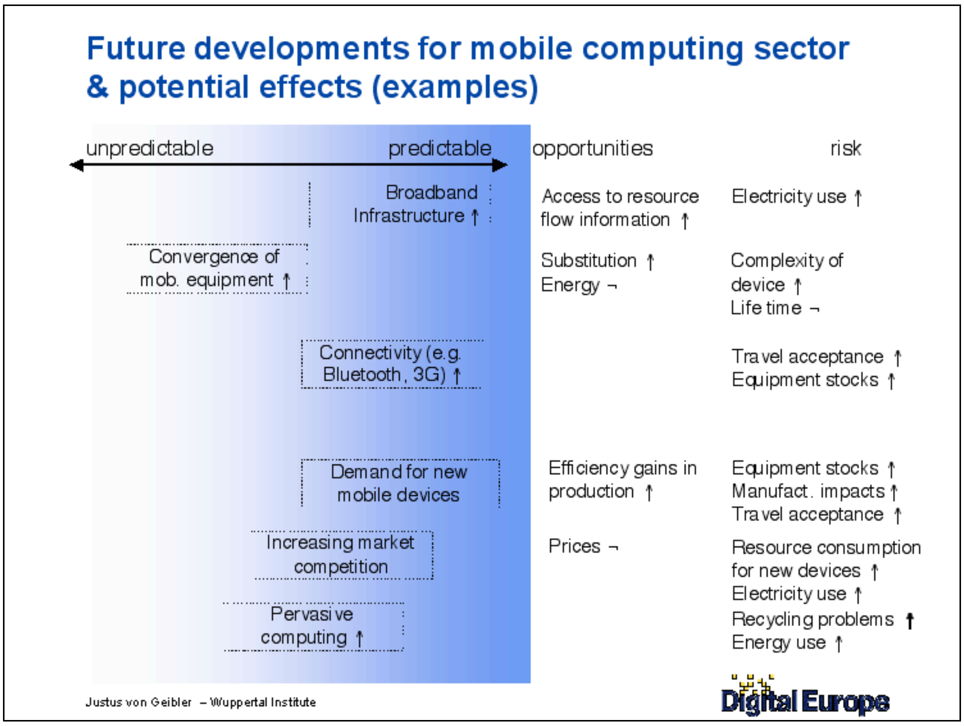

Figure 6-2: Future developments in the mobile computing sector and examples of potential effects

Broadband Infrastructure

Broadband connectivity can be defined as an Internet connection offering at least 256 Kbps downstream and 64 Kbps upstream capacities. Today, this speed is reached by DSL, cable modem, satellite and powerline connections. In OECD countries, the share of persons with access to broadband infrastructure doubled from beginning till June 2001. Growth rates in European countries are projected to reach 100 per cent. Today, we also see increased competition in flat-rate, high-speed Internet access. Between October 2000 and November 2001, the number of Internet homes that have broadband access has doubled. About six per cent of EU homes now have broadband Internet access[37]. Whereas cable modems are

[37] European Information Technology Observatory. (2002). European Information Technology Observatory 2002, p. 15.

expected to make the race in the U.S. (51 per cent share of broadband market), for Europe a predomination of DSL is projected, with an equal 51 per cent market share.[38]

In the mobile computing sector the further spread of the broadband infrastructure might lead to environmental opportunities and risks. As the mobile Internet depends partly on the broadband Internet and has some interlinkages to the broadband Internet, mobile computing is likely to be influenced. The implementation of broadband infrastructure will lead to more convenience and faster information exchange to connected equipment. This might result in a rising demand for electronic devices, including mobile devices, and their software applications, hence provoking rising material flows, also in the mobile computing sector (see section on growing demand for PDAs). Thus, the increase of resource efficiency of the single electronic device is of high importance.

Convergence of mobile equipment

With laptops and small handheld computers getting fast wireless network access and mobile phones expanding their computing capabilities and becoming more universal in their application ("smart-phones"), a debate on convergence of mobile equipment evolves – with two directions emerging. One believes in device convergence and sees the forthcoming death of pure phones and pure PDAs. The other sees smart-phones as proof of the ongoing proliferation of new device types and the trend towards users having more and more devices, sometimes with overlapping functions.[39] The view that "devices are best if they follow their primary functions"[40] competes with the vision that performing different tasks with one mobile device will offer more convenient, cheaper and easier services. Which trend will be stronger in the market place can not be seen.

Convergence could lead to a reduced number of products as users do not need to operate multiple devices for similar tasks. This could lead to reducing impacts from manufacturing, waste management, transport and packaging. Less products might also imply lower energy use, if the single device is more energy efficient than the substituted devices. On the other hand, the converged devices might have higher complexity with reduced reparability and upgradability and consequently shorter lifetime. Converged products might offer options to users they neither need nor request. In such situations, the device covers a number of product modules that are not used by consumers and creates impacts without delivering a service, e.g. if unused components stay on power while other parts are active.

Increasing wireless connectivity (e.g. Bluetooth and 3G)

The increase in connectivity between personal mobile computing devices and computing networks is predictable based on the recent developments. GSM is one of the common networks and was able to achieve almost total covering in some European countries. Even though there are different options competing for tomorrow's connectivity (standards like

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[38] For this and more numbers on broadband Internet access, consult NFO Infratest (Germany) (2002). Monitoring Informationswirtschaft – 4. Faktenbericht 2002, p. 110-143.

[39] Synchrologic: The CIO Wireless Resource Book – Information and analysis to assist with planning for wireless computing, 1-888-345-SYNC (7962), p. 19.

[40] Michael Gartenberg (2002). Conversation Trumps Convergence, August 26, 2002. http://www.computerworld.com/mobiletopics/mobile/story/0,10801,73724,00.html

Bluetooth or W-LAN are competing with UMTS as most prominent technology), the connectivity is most likely to increase within Europe.[41]

Higher speed and wider coverage of mobile network access will be a driver for wider acceptance of mobile computing, thereby leading to higher equipment stocks and consequently to higher amounts of waste products. Travel might increase due to lowered opportunity costs for travelling – due to the possibility to work more efficiently while travelling and being away from office for longer time. Another effect of increased mobile connectivity might be a higher intensity of electromagnetic fields.

Growing demand for PDAs

The PDA market is growing with growth rates slowing down at an astonishingly high level. Although times of 100 per cent growth belong to the past, Gartner Dataquest still expects a growth of 20 per cent in 2002. New or improved technological features, e.g. stronger processors and colour displays, mainly drive the growth.[42]

The increased comfort of mobile computing with PDAs is obvious; the potential ecological analysis is less visible. As often in new markets, a growth in absolute numbers can offset the efficiency gains in the production reached on a unit level, thereby leading to higher impacts from a global scale. This is definitely the case in PDA's, where the number of user devices is growing rapidly. Other effects on the material intensity can be caused by increased travel acceptance due to decreased opportunity costs through mobile computing devices, therefore worsening the material intensity through increased transportation. The benefits, e.g. though increased use of video conferencing with the mobile computing equipment, are expected to be low (see theme report, section on telework).

Increasing market competition

Due to fast technological developments, markets for mobile computing are highly volatile. Being on the market for one year, the Compaq iPAQ Pocket PC doubled its market share to 16% of worldwide unit shipments in just 3 months.[43] Even market leaders can be faced with rapid deterioration of their customer base within several months, like it happened to Palm, whose market share dropped from 50 to 32 percent in the same time span. This also illustrates how the market shifts from small, specialised companies pioneering mobile computing to established companies taking over the market. Intensity of competition is further increased by the existence of network effects in software and connection standards, forcing bigger companies to spend special efforts in overcoming the first-mover bonus of small pioneers.

Increasing market competition puts pressure on prices, which have already been reduced in the past. In anticipation of network effects, even cross-subsidised prices within companies are imaginable. This leads to equal access to mobile computing for more and more customers and the associated benefits, whereas the production of a larger stock of

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[41] Synchrologic: The CIO Wireless Resource Book – Information and analysis to assist with planning for wireless computing, 1-888-345-SYNC (7962), p. 15.

[42] ZVW-Online (2002). Studie: Weniger Wachstum bei PDA und Co. [Study: Less growth concerning PDA and Co.] online available at http://www.zvw.de/aktuell/comp/2002/15/comp07.htm

[43] Synchrologic: The CIO Wireless Resource Book – Information and analysis to assist with planning for wireless computing, 1-888-345-SYNC (7962), p. 18.

equipment is most likely to lead to absolute higher resource consumption. Increased equipment might also lead to higher energy use in the use phase. Price pressures might lead to reduced product lifespan which further increases the impact, as production impacts are dispersed over a shorter use span.

Pervasive Computing

Pervasive computing is computing power freed from the desktop – embedded in wireless handheld devices, automobile telematics systems, home appliances, and commercial tools-of-the-trade. In the future a number of everyday products will be combined with small and wireless ICT components and will also be worn in clothing. By 2006, Venture Development Corporation expects worldwide shipments of wearable computers to increase eightfold to $563 million from 2001's sales level of $70 million.[44]

In the enterprise, pervasive computing might help to manage information and reduce complexity for a mobile workforce. In society, it further increases the possibilities to exchange information.

Melting of products with different lifespans might result in the predominance of the shorter life span, thereby reducing the average lifespan of the other field: When the electronic parts are out of date, use of carrying garments will be ended and vice versa. However, this can be levelled by clever modular design solutions. Pervasive computing could result in a more complex and difficult separation and recycling process in the product's end-of-life phase. This means that recycling problems could become dominant in negative environmental impacts of ICT hardware.

[44] Albright, B. (2002). Wearable computers: the new fashion-ware for the future, December 1, 2002. Frontline Solutions, online available at http://www.frontlinetoday.com/frontline/article/articleDetail.jsp?id=38947

7. Conclusions and Recommendations

This chapter provides conclusions drawn from the case study regarding the methodology used, resource efficiency of single handheld devices and efficiency improvements in a larger communication system. Additionally, recommendations are given for improving the resource consumption of mobile computing.

Conclusions

Regarding the **methodology** used, the following conclusions can be drawn:

- The findings of the case study as well as the case study related discussions at the Expert Forum pointed out that so far existing research on resource efficiency of mobile computing devices is rare, especially with respect to qualitative research.
- The case study work confirmed that the methodology used is suitable to quantify the resource consumption of handheld devices. The methodology used is based on a life-cycle-wide approach and covers the service that the handheld is providing and the habits of the handheld user. The methodology requires sufficient data availability. However, the availability of life-cycle-wide data for handheld devices has been confirmed to be low. Even the case study partner has had considerable difficulties in obtaining data from suppliers.

Regarding the resource consumption of **a single handheld device,** the following conclusions can be drawn:

- The **production of components** of the handheld device account for a high proportion of the entire product's resource consumption (66 to 76%, depending on the user behaviour). This is a result of the components' material content with intensive upstream processing demands such as PWBs, LCDs, chips and precious metals. Most of the materials used arise from non-renewable sources. It must be assumed that the share of recycled and reused raw materials is low. A scenario for the use of recycled materials highlighted some opportunities for resource efficiencies. The material intensity analysis points also out that additional functions, here the external modem, can contribute significantly to the resource consumption.
- The **electricity consumption** in the use phase contributes significantly to the backpack of the entire life cycle of the handheld device. The electricity consumption is determined by the use characteristics (time in active, standby and sleep modus), the charging efficiency as well as the standby power drawn by the charger. The energy source (e.g. coal, oil, hydro, wind) and the technology used determines the material backpack of the handheld. Based on a European electricity mix and on specific assumptions regarding consumer behaviour, the use phase's contribution to the overall abiotic material intensity varies between 22 and 32%.
- **Transportation** both from handheld manufacturing to the retailer and from retailer to the consumer contributes little to the entire resource consumption within the device's life cycle (e.g. less than 1% for the abiotic raw materials). However, if the transport of components and subcomponents before assembly with potential air transportation would to be considered and consumer habits differ from the assumed ones, transport's contribution to resource consumption is likely to be higher.

HP has developed a recycling system to reduce impacts at the **end-of-life stage**. It offers its customers the opportunity to return their used hardware for complete recycling and only charges for the transport. However, the actual number of recycled devices is expected to be low. Considering the high efforts to produce single components, reuse and recycling as well as the extension of the use phase are important improvement options from a life-cycle perspective. A good motivation for the end-user to turn products back and efficient logistics (take back and recycling) are the basis of an efficient recycling scheme. The scenario for an increased share of secondary materials points out some improvement areas; however, for reliable evaluation of recycling schemes more practical data and research is needed. The WEEE directive is likely to have considerable influence on this issue. Additionally, the proposed directive on establishing a framework for Eco-design of End Use Equipment might also improve the conditions for enhanced design.

With a larger perspective of the **entire mobile computing system** the following conclusions can be drawn about the resource consumption and the service provision:

- The comparative analysis of the **production of the handheld** with the production of a notebook or a traditional personal organiser, shows that the handheld's resource consumption lies between both products as the following table shows.

Table 7-1: Results of material intensity analysis for production

	Handheld	Notebook	Personal organiser (paper-based)
Abiotic raw materials	81 kg	433.6 kg	3.9 kg
Biotic raw materials	1.0	1.3	0.55
Water	760 kg	5955 kg	130 kg
TMR	82 kg	435 kg	6.2 kg

- Compared to the notebook there is less resource input in most areas (casing, transport, non-electronics and electronics). However, the efficiency gains from a shift to the handheld are not proportional to the difference in weight. The handheld weighs only 200 grams (7% of the notebook's weight) but its production consumes 81 kg of abiotic raw materials (19% of the notebook's backpack). This high resource consumption is a result of a high share of functional materials in the handheld and additional items alongside the handheld such as the charging adapter or the modem.
- Both products provide the **service unit** which has been defined for the comparison of both pieces of electronic equipment: convenient mobile information processing for one year. However, there are differences in the comfort and handling of the information processing. There are mainly "mobility-related" advantages on the handheld's side, whereas there are "information processing-related" advantages for the notebook. Also the paper-based personal organiser has a limited number of functions. As the users of mobile computing devices do not need (and cannot use) all the functions at one time, the **concept of a shared use of the electronic equipment** is coming into the picture as an improvement option. The shared use of notebooks and individual use of handheld devices can increase overall efficiency as shown in the scenario. However, as most of the handhelds are currently used in combination with notebooks, the handheld today is more of an add-on device than a substitution for the notebook. As long as consumers demand a notebook or a PC in addition to the handheld substitution, an increase in resource efficiency will not take place.
- Miniaturisation – a current and potential future trend of mobile computing device – leads to difficulties regarding their end-of-life management. As the material value of smaller products is reduced and the smaller size of the device allows them to be discarded with

household waste, then the take back and recycling systems face major challenges. It is not yet clear how effective the WEEE directive will impact on this matter.

7.1 Recommendations

7.1.1 Recommendation for HP

Based on the case study, a number of recommendations can be made about environmental backpack reduction strategies at both product chain level and corporate level.

At the product chain level **Design for Environment (DfE)** is a potential way for HP to improve the environmental performance of the single handheld device. The design stage determines most of the environmental aspects of the entire life cycle and determines the number of services that can be delivered to the consumer. HP's DfE guidelines derive from evolving customer expectations and regulatory requirements, but they are also influenced by the personal commitment of its employees. A focus area for DfE, which has been identified in the case study, is the material intensity for the handheld production of specific component. Especially, the functional materials (PWB) and precious metals account for a high share of the ecological backpacks.[45] The material intensity of specific materials varies considerably.
For example, copper, a major input in the handheld, has in the primary form a material intensity of 500 kg per kg, whereas secondary copper has a material intensity of only 9.66 kg per kg. Larger improvements in resource efficiency can be obtained with material substitution.

The **charging efficiency** is another important improvement area to reduce the resource efficiency of the handheld's use phase. The development and use of intelligent chargers, which sense the battery level and automatically disconnect the equipment and the charger from the power supply once the battery is fully charged, is one such example of how resource efficiency can be increased.[46] As a consequence the unnecessary charging and standby electricity use of the charger could be reduced. This is especially important as the trends, such as increased connectivity, increasing processing capacities and increasing amounts of data, will amplify the electricity use of the single item of equipment. Handheld devices' energy use can be substantially increased by supplementary functions like Internet connectivity via modems or additional components. An additional memory card, for example, can be "higher in power consumption than the rest of the handheld's device electronic"[47].

Considering the high resource consumption of the PWB and Integrated Circuits, **lifetime extension** of the functional materials is a suitable way to increase the number of services

[45] If the producer of the PWB can be influenced through supply chain management, other areas of improvement are on-site recycling and modification of technologies as for example pointed out by the US EPA for PWB manufacturing US EPA (1998). Alternative Technologies for making Holes Conductive, Cleaner Technologies for Printed Wiring Board Manufacturers.

[46] The standby electricyty consumption of the notebook´s charger contributes significantly to the notebooks overall material intensity. If the charger is designed to shut off after disconnection, an annual amount of 16 kWh could be saved. This is equal to 25 kg of abiotic raw materials.

[47] Inhand Electronics (2001): Using BatterySmart™ to Interpret and Regulate Handheld Device Power Consumption, In: Handheld and Wireless Solutions Journal – Quarterly Publication serving the Intel Personal Internet Client Architecture, Vol. 1, fall 2001, p. 84

provided to the customer. This would increase the material intensity per service unit. The lifetime can be extended by improving the lifespan of the product (entire handheld) or by reusing the IC.[48] More research needs to be done in order to evaluate ways to improve the lifetime extension. Upgradeability by a more modular design could be one potential way to extend the lifetime of the handheld. The concept of "pay per use" as suggested for HP in a recent paper[49] might be a business model to integrate life-cycle-wide environmental aspects into the design stage and to extend the handheld's lifetime. Here further research could provide valuable insights regarding the potential of lifetime extension.

The **harmonisation** of devices is an another important area when it comes to resource efficiency opportunities. The development and use of standardised connections to other peripheral equipment is an important step to improve the connectivity between different devices from different producers. Potentially it might be possible to develop common charging devices which are suitable for a number of different mobile devices, such as mobile phones, handhelds and notebooks.

As the handheld devices are quickly changing and complex products with worldwide supply chains, the **collection of life cycle inventory data** is a major challenge. Additionally, IT manufacturing is being increasingly outsourced, which raises questions as to how continual data changes could be managed. Establishing a network of relevant research institutions and companies (including the suppliers in Asian countries) would be helpful for the efficient collection, compilation, evaluation and dissemination of life-cycle-wide resource consumption data on ICT equipment. The data disseminated by such a network could play a crucial role in the identification of improvement opportunities for the actors in the handheld's product chain. HP as a global player could contribute to and benefit from such a network. This type of network should be linked to existing environmental global initiatives, e.g. the UNEP LCA initiative.

HP encourages suppliers to analyse their manufacturing processes, identify potential environmental hazards, and take steps to eliminate them. HP may also wish to develop systems that require their suppliers to disclose further manufacturing information. Increased knowledge of components could be a valuable addition to HP, especially regarding the end-of-life treatment of the products.

At the corporate level, managing eco-efficiency also means managing related cost issues. In this respect, there is room for improvement for HP to integrate environment cost accounting into its existing management practices. The material flow information can identify significant potentials for environmental improvements and for cost reductions (see below) as compared to the direct material inputs.

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[48] Stutz, M. and Tobler, H. (2000). *Simplified LCA for Elektronikbauteile* [Simplified LCA for electronic components] IG Exact. Männedorf, Switzerland.

[49] Cambashi (2002). HP's pay-per-use drives IT investment strategies. Online. Available: Via email by Jonathan Wood.

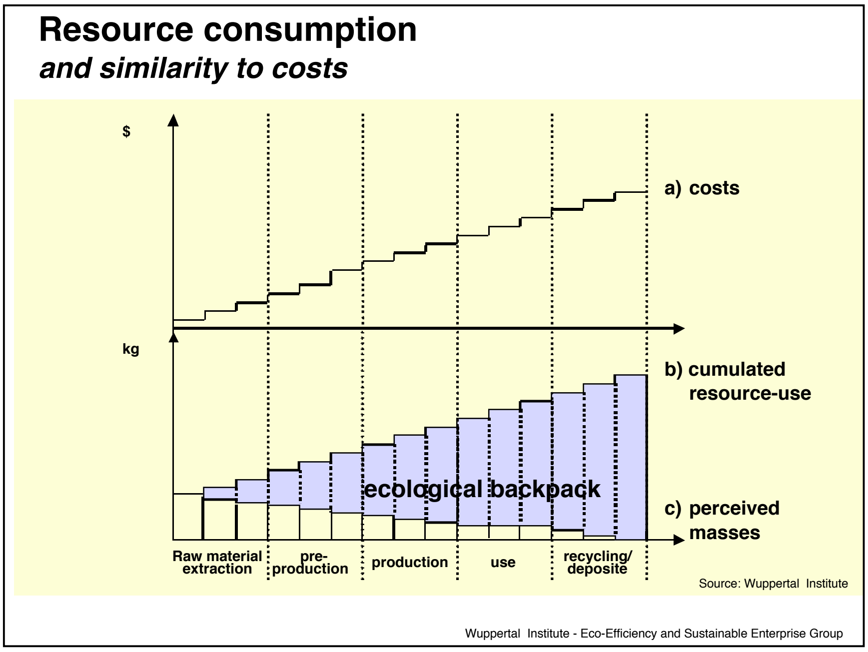

Figure 7-1: Similarity of costs and backpacks

An immediate way for HP to adapt such an approach could be to simply **combine economic information and material flow data**. Economic information at the product level can often be taken from the traditional cost accounting system, i.e. in the form of cost price of the final product or its contribution margin. Furthermore, the material intensity of processes can be allocated to the products with the aid of the company material accounting, as shown in the figure below.

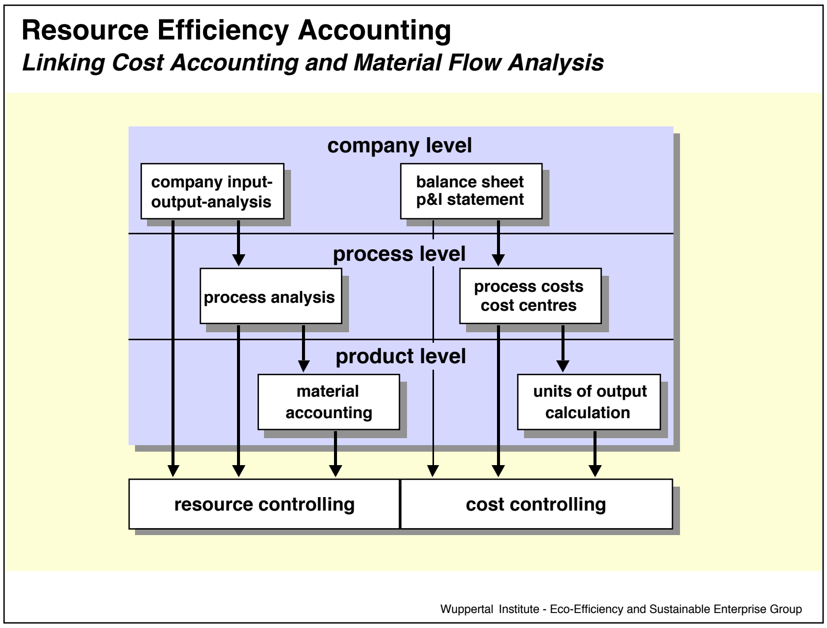

Figure 7-2: Linking conventional accounting and material flow accounting

By embracing the concept of eco-efficiency, backpack reductions can be linked to value creation and innovation. The combined accounting of cost and material flows can improve business decisions in different areas, such as product and process design, purchasing, waste management, cost allocation, product pricing and capital investments. By integrating the eco-efficiency concept into internal management, HP's reputation could be further enhanced and stakeholders' requirements more easily matched, including those of customers, retailers, employees, shareholders and investors.

Scenario techniques can be applied by decision-makers to compare the economic and environmental implications of alternative future material flow patterns at the corporate level. Aspects that significantly influence the backpack should be selected for scenario development as e.g. highlighted for the shared use of notebooks. Potential technological options e.g. the use of alternative energy sources such as solar or human power could also be analysed on the basis of scenario testing.

Customisation or standardisation is still an open question and can determine environmental impacts in the mobile computing sector. It seems that resource efficiency for multifunctional products produced in mass production is higher than for a base product with a high amount of additional peripheral equipment. Thus, basic functions, and the related electronic components, which are needed by the majority of users should be integrated for all users. This will make use of efficient mass production. Integrated functions, which are used by a limited number of users, can increase the resource consumption of the entire product system. The tipping point depends on the specific products, the material inputs needed, the number of users and user habits. Specific data on the alternatives need to be compiled and analysed in order to decide on the tipping point on a case-by-case base.

7.1.2 Recommendations for Policy Making

Based on the HP case study, a number of policy recommendations can be given in order to reduce the resource consumption caused by mobile computing.

As the products for mobile devices increasingly spread in Europe, the precautionary principle demands a timely development of policy action. The complexity of mobile computing and its environmental (and socio-economic) implications requires a balanced mix of policy measures in order to make best use of the opportunities of mobile computing technologies.

The **use phase** constitutes significantly to the resource consumption of a single mobile device. However, on the macroeconomic, e.g. national or supranational, level the electricity consumption of mobile devices is just a small part. However, if the spread of mobile devices increases in the future, the absolute electricity consumption is likely to increase and policy measures are needed. To reduce resource consumption arising from electricity use, renewable energy, such as wind or hydro power, need to be promoted by policies. This could lead to reduced CO_2 emissions but also to reductions in the environmental backpack of the electricity generation. Parallel measures should also target the demand for electricity. Setting standards for standby power consumption of the charging devices and the mobile equipment is one example of a potential measure.

A way to reduce **resource consumption for the production** is the extension of the lifetime of these devices. The devices used for mobile computing, and the technology for Internet access in general, is based on a technology which is quickly outdated. In the case study a lifetime of three years was assumed for the notebook and the handheld. Thus, the equipment needs to be exchanged within this short time. This exchange is linked to high resource consumption for the production of new devices and end-of-life problems as they are discarded after a short time. Consequently, options for lifetime extension need to be promoted by policies. Here, voluntary actions, such as design for environment or extended warranties, initiated by proactive ICT companies should be promoted. However, research on business concepts for lifetime extension and their environmental consequences is needed.

In order to promote the **demand for eco-efficient mobile computing devices**, consumer awareness needs to be raised to the benefits of longer lasting devices or alternative options for mobile computing. Here, the provision of environmental product information or the development of guidelines for mobile computing users are potential options. Additionally, public procurement could include environmental criteria such as standby power consumption and resource efficiency in purchasing guidelines.

At least since the final adoption of the EU's **waste electrical and electronic equipment** (WEEE) and substance restrictions (RoHS) directive in October 2002, ICT firms are more encouraged to tackle electroscrap recycling. Yet, a successful and efficient end-of-life treatment will only be achieved if companies bear an individual responsibility for their goods. Such a responsibility will trigger the eco-design improvements necessary to reduce the environmental effects of devices. Voluntary initiatives, such as the cooperation of leading mobile phone manufacturers with the Basle Convention[50], are promising steps towards a reduction of environmental effects for mobile devices. Additionally, other major efficiency improvement obstacles, such as the lack of communication along the supply chain, need to be overcome. Knowledge about the environmental effects along the entire product chain is a necessary precondition for the identification of efficient improvement options. Thus, the incorporation of network operators and other important stakeholders into a dialogue on improvement options is highly advisable.

In order to identify improvement options for reducing the resource consumption of handheld devices – fast-changing and complex products with worldwide supply chains – the **availability of environmental data** on ICT equipment needs to be improved. Specifically, the flows of environmental information along the supply chain should be promoted. Here, ICT itself can be used to improve the flow of environmental information. Existing data from companies and different national research institutions should be gathered, evaluated, compiled and disseminated. Thus, an institution or network of institutions with these tasks should be promoted on the European level. Improvement options can only be identified and implemented efficiently if a reliable data base is available for business and policy decision-makers. In addition, the transparency regarding the environmental performance of the ICT sector need to be improved. Thus, environmental, and also sustainability, reporting by the companies of the ICT sector should be promoted.

Considering the complexity of the product system of mobile computing devices, researching their environmental impacts is a major challenge. Due to the complexity, **more systemic evaluations** of the environmental consequences of mobile computing devices are needed in the future. To identify the resource and energy efficiency opportunities of mobile computing equipment, it is necessary to consider the entire communication system, user habits and the social importance of mobility and communication. Future evaluations should be based on methods that integrate quantitative research, to evaluate environmental effects, and qualitative research that analyses consumer demands and behaviour.

[50] UNEP. (2002): Leading Manufacturers And Basel Convention To Cooperate On The Environmentally Sound Managment Of End-of-life Mobile Phones. [Online] Available: http://www.unep.org/Documents/Default.asp?ArticleID=3189&DocumentID=274 [18 December 2002].

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