Background report for the development of an EMAS Sectoral Reference Document on Best Environmental Management Practice for the Electrical and Electronic Equipment manufacturing sector

Preparatory findings supporting the development of an EMAS Sectoral Reference Document

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Acronyms index

ABS	Acrylonitrile Butadiene Styrene
ACR	Air Change Rate
ATM	Automatic Teller Machines
BAT	Best Available Technique
BBP	Butyl Benzyl Phthalate
BEMP	Best Environmental Management Practice
BET	Business & Ecosystems Training
BFR	Brominated Flame Retardant
C_2F_6	Hexafluoroethane
C_3F_8	Octofluoropropane
$c\text{-}C_4F_8$	Octofluorocyclobutane
CD	Compact Disc
CDP	Carbon Disclosure Project
CF_4	Tetrafluoromethane
CH_4	Methane
CHF_3	Trifluoromethane
CHP	Combined Heat and Power
CLP	Classification, Labelling and Packaging (CLP Regulation)
CMOS	Complementary Metal–Oxide–Semiconductor
CMR	Carcinogenic, Mutagenic and Reprotoxic
CO_2	Carbon dioxide
CO_2e	CO_2 equivalents
CRT	Cathode Ray Tube
CVD	Chemical Vapour Deposition
CPC	Compound Parabolic Collector
dB(A)	Decibel (A-weighted)
DBP	Dibutyl phthalate
DEHP	Bis(2-ethylhexyl)phthalate
DfE	Design for Environment
DiBP	Diisobutyl Phthalate
DIDP	Di-‘isodecyl’ Phthalate
DINP	Diisononyl Phthalate
DNOP	Di-n-octyl Phthalate

DOZ	Bis(2-ethylhexyl) Azelate
DPHP	Di(2-propyl heptyl) Phthalate
ECHA	European Chemicals Agency
EECA	European Electronic Component Manufacturers Association
EEE	Electronic and Electrical Equipment
EIA	Environmental Impact Assessments
EIPE	European ICT Pole of Excellence
EMAS	Eco-Management and Audit Scheme
EMF	European Metalworkers Federation
ESIA	European Semiconductor Industry Association
EU	European Union
FEG	Finished Electronic Goods
FMD	Full Materials Declaration
FR	Flame Retardant
FY	Financial Year
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
GWP	Global Warming Potential
H_2	Hydrogen
H_2O	Water
HAP	Hazardous Air Pollutants
HBCDD	Hexabromocyclododecane
HDD	Hard Disk Drive
HDPE	High-density polyethylene
DINCH®	Diisononyl cyclohexanedicarboxylate
HF	High Frequency
HFC	Hydrofluorocarbon
HIPS	High Impact Polystyrene
HVAC	Heating, Ventilation and Air Conditioning
IAAP	Integrated Alternatives Assessment Protocol
IC	Integrated Circuit
ICT	Information and Communication Technology
IEG	Intermediate Electronic Goods
IPSO	Integrated Product Service Offerings
ISO	International Organization for Standardization

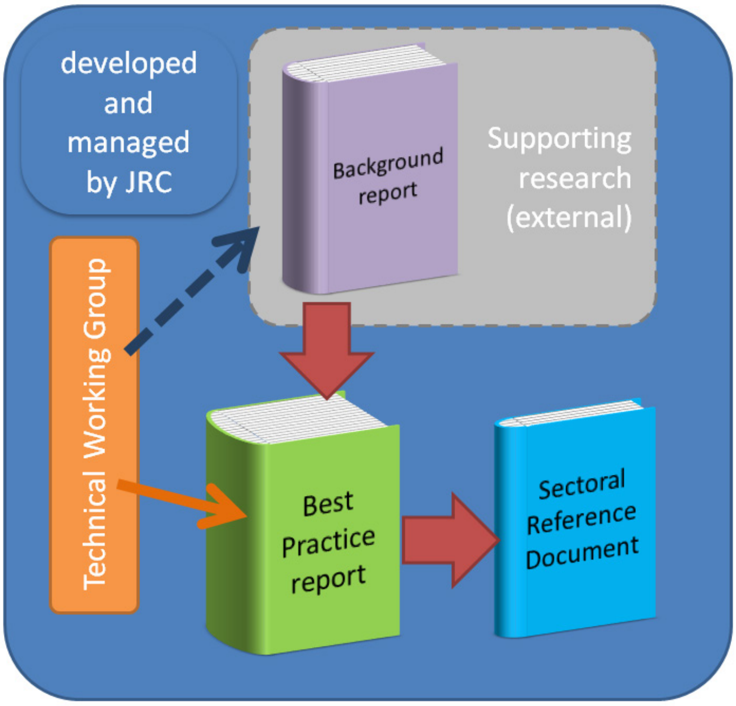
ITO	Indium-Tin-Oxide
JRC	Joint Research Centre of the European Commission
kWh	Kilowatt hour
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LED	Light Emitting Diode
LHHA	Large Household Appliances
Li-Ion	Lithium Ion
LSFI	Large Scale Fixed Installations
LSSIT	Large Scale Stationary Industrial Tools
MW	Megawatt
MW_{th}	Megawatt (thermal)
NF_3	Nitrogen Triflouride
NiMH	Nickel Metal Hydride
NWWT	North Wales Wildlife Trust
n.y.	no year
O_2	Oxygen
OEM	Original Equipment Manufacturer
OLED	Organic Light Emitting Diode
p.a.	per annum (per year)
PBB	Polybrominated Biphenyls
PBT	Persistent, Bioaccumulative and Toxic
PBX	Private Branch Exchange
PCB	Printed Circuit Board
PFC	Perfluorocompounds
PDA	Personal Digital Assistant
PET	Polyethylene Terephthalate
POP	Persistent Organic Pollutants
POS	Point Of Sale
PP	Polypropylene
PPO	Polyphenylene Oxide
PS	Polystyrene
PSU	Polysulfone
PUR	Polyurethane

PVC	Polyvinyl Chloride
QCAT	Quick Chemical Assessment Tool
R&D	Research and Development
RABS	Restricted Access Barrier System
RCD	Regulatory Compliance Declaration
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RES-E	Energy from Renewable Energy Sources
RIP	Respiratory Inorganics Potential
RoHS	Restriction of Hazardous Substances
rPET	recycled PET
rPP	recycled PP
SDoC	Supplier Declaration of Conformity
SF_6	Sulphur Hexafluoride
SMD	Surface Mounted Devices
SME	Small and Medium sized Enterprise
SRD	Sectoral Reference Document
SVHC	Substances of Very High Concern
TEHTM	Tri-(2-ethylhexyl) Trimellitate
THT	Through-Hole Technology
TOC	Total Organic Carbon
TPP	Triphenylphosphane
VFD	Variable-Frequency Drives
VOC	Volatile Organic Compounds
vPvB	very Persistent and very Bio-accumulative
WBCSD	World Business Council for Sustainable Development
WEEE	Waste from Electrical and Electronic Equipment
WSC	World Semiconductor Council

Preface

This background report provides an overview of techniques that may be considered **Best Environmental Management Practices** (BEMPs) in the electrical and electronic equipment manufacturing sector. The document was developed by Oeko-Institut under a contract with the European Commission's Joint Research Centre (JRC) on the basis of desk research, interviews with experts and site visits. This background report is intended to provide a preliminary basis for further discussions between the JRC and technical experts via the forum of a Technical Working Group (TWG). **The contents of this report therefore represent early findings that will be further developed through discussions with the TWG**, according to a structured process outlined in the guidelines on the *"Development of the EMAS Sectoral Reference Documents on Best Environmental Management Practice"* (European Commission, 2014), which are available online[1].

The final findings will be presented in a best practice report produced by the JRC and used for the development of an EMAS Sectoral Reference Document (SRD), as illustrated below.



Source: JRC

Figure I: The present background report in the overall development of the Sectoral Reference Document (SRD)

EMAS (the EU Eco-Management and Audit Scheme) is a management tool for companies and other organisations to evaluate, report and improve their environmental performance. To support this aim, and according to the provisions of Art. 46 of the EMAS Regulation (EC No. 1221/2009), the European Commission is producing SRDs to provide information and guidance on BEMPs in several priority sectors, including the electrical and electronic equipment manufacturing sector.

[1] http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf

Nevertheless, it is important to note that the guidance on BEMP is not only for EMAS participants, but rather it is intended to be a useful reference document for any relevant company that wishes to improve its environmental performance or any actor involved in promoting best environmental performance.

BEMPs encompass techniques, measures or actions that can be taken to minimise environmental impacts. These can include technologies (such as more efficient machinery) and organisational practices (such as staff training).

An important aspect of the BEMPs proposed in this document is that they are proven and practical, i.e.:

- They have been implemented at full scale by several companies (or by at least one company if replicable/applicable by others);
- They are technically feasible and economically viable.

In other words, BEMPs are demonstrated practices that have the potential to be taken up on a wide scale in the electrical and electronic equipment manufacturing sector, yet at the same time are expected to result in exceptional environmental performance compared to current mainstream practices.

A standard structure is used to outline the information concerning each BEMP, as shown in Table I.

Table I: Information gathered for each BEMP

Category	Type of information included
Description	Brief technical description of the BEMP including some background and details on how it is implemented.
Achieved environmental benefits	Main potential environmental *benefits* to be gained through implementing the BEMP.
Environmental indicators	Indicators and/or metrics used to monitor the implementation of the BEMP and its environmental benefits.
Cross-media effects	Potential *negative* impacts on other environmental pressures arising as side effects of implementing the BEMP.
Operational data	Operational data that can help understand the implementation of a BEMP, including any issues experienced. This includes actual and plant-specific performance data where possible.
Applicability	Indication of the type of plants or processes in which the technique may or may not be applied, as well as constraints to implementation in certain cases.
Economics	Information on costs (investment and operating) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, etc.).
Driving force for implementation	Factors that have driven or stimulated the implementation of the technique to date.
Reference organisations	Examples of organisations that have successfully implemented the BEMP.
Reference literature	Literature or other reference material cited in the information for each BEMP.

Sector-specific Environmental Performance Indicators and Benchmarks of Excellence are also derived from the BEMPs. These aim to provide organisations with guidance on appropriate metrics and levels of ambition when implementing the BEMPs described.

- Environmental Performance Indicators represent the metrics that are employed by organisations in the sector to monitor either the implementation of the BEMPs described or, when possible, directly their environmental performance.
- Benchmarks of Excellence represent the highest environmental standards that have been achieved by companies implementing each related BEMP. These aim to allow all actors in the sector to understand the potential for environmental improvement at the process level. Benchmarks of excellence are not targets for all organisations to reach but rather a measure of what is possible to achieve (under stated conditions) that companies can use to set priorities for action in the framework of continuous improvement of environmental performance.

Conclusions on sector-specific Environmental Performance Indicators and Benchmarks of Excellence are drawn by the TWG at the end of its interaction with the JRC. Therefore the proposals for indicators (and, eventually, for benchmarks) contained in this background report are to be considered no more than preliminary proposals from the authors of this background report.

Role and purpose of this document

The present background report provides a basis to be used by the JRC and Technical Working Group for the elaboration of the "JRC Scientific and Policy Report on Best Environmental Management Practice in the Electrical and Electronic Equipment Manufacturing Sector", or simply "Best Practice Report", containing the technical basis for the Sectoral Reference Document (SRD).

Companies from the electrical and electronic equipment sector interested in implementing best practice in the improvement of environmental performance are recommended to refer instead to the final Best Practice Report that will be available on-line[2] as soon as it is finalised and published.

[2] The Best Practice Report will be available online at http://susproc.jrc.ec.europa.eu/activities/emas/eeem.html

Executive summary

The objective of this background report is to collect technological, environmental and economic information in order to enable the European Commission's Joint Research Centre (JRC) to prepare the Sectoral Reference Documents (SRD) on Best Environmental Management Practice (BEMP) for the manufacture of Electronic and Electrical Equipment (EEE).

Altogether 21 best practice approaches were developed. The following table provides an overview of the different best environmental management practices and the respective target groups they address.

Table 1-1: Overview of Best Environmental Management Practices and the Addressed Target Groups

No.	BEMP	Target group(s)
	MANUFACTURING	
1	Energy-efficient cleanroom technology	Manufacturers of semiconductors and PCB
2	Efficient supply and substitution of compressed air	Manufacturers of EEE
3	Energy-efficient cooling technology	Manufacturers of EEE
4	Energy-efficient soldering	Manufacturers of EEE
5	Minimising the use of PFC	Manufacturers of semiconductors
6	Substitution / reuse of VOC-based solvents	Manufacturers of EEE
7	Water savings and recovery in cascade rinsing systems	Manufacturers of PCB
8	On-site recycling of metals in process chemicals	Manufacturers of PCB
9	Protecting and enhancing biodiversity	Manufacturers of EEE
10	Use of renewable energy in EEE manufacturing	Manufacturers of EEE
	SUPPLY-CHAIN MANAGEMENT	
11	Assessment tools for substitution of hazardous substances	Manufacturers of EEE
12	Elimination of certain phthalates	Manufacturers of EEE
13	Elimination of BFR and PVC	Manufacturers of EEE
14	Disclose and set targets for supply chain GHG emissions	Manufacturers of EEE
15	Conducting LCA	Manufacturers of EEE
16	Increasing the content of recycled plastics in EEE – Case study of closed -loop recycling process for PET and PP in cartridges	Manufacturers of ICT equipment
	END-OF LIFE MANAGEMENT	
17	End-of-life removability of rechargeable batteries	Manufacturers of portable EEE
18	Integrated Product Service Offerings	Manufacturers of service-intensive EEE
19	Warranted refurbishment of used products	Manufacturers of capital-intensive EEE
20	Non-destructive extraction of circuit boards	Recyclers of WEEE
21	Innovative sorting solutions for black plastics from WEEE	Recyclers of plastics from WEEE

Source: Own table

1. Introduction

The European Commission is currently developing the so-called Sectoral Reference Documents (SRD) on Best Environmental Management Practice (BEMP) for a number of sectors, one of which is the Manufacture of Electronic and Electrical Equipment (EEE). The aim is to help companies in the sector to identify relevant, proven and reliable technical information to improve their environmental performance.

This background report aims to collect technological, environmental and economic information in order to enable the European Commission's Joint Research Centre (JRC), and in particular the Institute for Prospective Technological Studies (IPTS) to prepare the SRD on BEMP for the EEE manufacturing sector.

The study shall consider the whole value chain and with specific focus on supply chain management, manufacturing and recycling of end-of-use products. It aims to identify both direct and indirect environmental aspects and describes the techniques and best practices used to improve environmental performance and the indicators and benchmarks of excellence used to measure and to compare this performance. The document will include reference to the specific applicable legal requirements relating to the environment at EU level, without prejudice to stricter legal obligations at national level.

Since industrial systems like the manufacturing of electronic and electrical equipment (EEE) are characterized by processes and activities which complexly intersect and are closely related to each other, this study will primarily apply a **process- / technology-oriented approach**.

Furthermore, the study is carried out on the basis of a **life cycle approach.** It has been derived from the methodical concept of product life cycle assessment (LCA) as described in international standards ISO 14040 and ISO 14044, presuming that each life cycle of a product or service starts with the extraction and processing of raw materials, is followed by further processing, transport and use, and finally ends with waste and waste water treatment. By virtue of the aspects taken into account, the life cycle approach is also known as cradle-to-grave approach. The use of the life cycle approach allows identification of the most important (positive as well as negative) impacts of a product system.

In particular, this approach helps to detect, where relevant, existing conflicts and shifting problems, i.e., between the individual life cycle phases (such as the environmental pollution being transferred from the manufacture to the use phase) and between different environmental impacts or media (for example, CO_2 emissions in the air and acidifying substances in water and soil).

Within this general approach, the following three perspectives are particularly relevant:

- Location-based perspective (within the “gate”):

  At this level, the life cycle approach focuses on the evaluation of alternative materials or the modification of processes, especially aiming at reducing the energy and resource consumption as well as the exposition of humans and the environment.

- Upstream perspective (towards “cradle”):

  The focus of the life cycle approach in the upstream perspective lies in the evaluation and, where relevant, in the optimization of supply chain management, directing particular attention to reducing the “ecological rucksacks” of substances and energy used.

- Downstream perspective ("from gate to grave"):

  As regards the downstream perspective, the analysis focuses on optimizing the use phase (through, e.g., reduction of energy requirements, prolongation of product lifetime, reduction of consumer exposure) and on a systematic evaluation of the processes at the end of the life cycle (such as wastewater treatment, recycling, waste incineration).

Within the context of this study, all three perspectives will be covered. However, the use phase (being part of the downstream perspective) will be out of scope in order to minimise overlap with existing studies and policy instruments concerning eco-labels, eco-design and green public procurement.

Experience gained from the development of these instruments is nevertheless considered to be beneficial for the scope of this study.

Where possible, this study even goes beyond the cradle-to-grave approach and also considers a closed-loop value chain with secondary resources derived from end-of-life treatment of EEE that can be used as input for new EEE ("cradle-to-cradle"). This refers to the vision of a circular economy that appeals particularly to EEE manufacturers that find their supply with critical raw materials increasingly constrained.

2. Scoping of the study

2.1. Scope

The focus of this study is targeted at areas of production with a high relevance for the EEE sector in the context of identifying BEMPs. Processes and technologies of high relevance are to be identified as a basis for defining frontrunners and benchmarks of excellence. A high relevance is understood to be applicable in areas where a high potential exists to contribute to the reduction of environmental impacts, either through

- a small contribution relevant for processes and technologies used for a wide range of products, therefore having a large impact potential through its total contribution; or
- through processes and technologies that have a large impact in terms of their environmental performance.

Basically, a number of aspects are relevant for the identification of areas to focus on. The scope definition is therefore performed by using three filters that assist in targeting processes and technologies with a higher potential for contribution. These filters are outlined below.

2.1.1. Component filter: Priorities regarding the scale of relevance of electronic and electrical equipment and components

An EEE product may consist of hundreds, even thousands of various components. Addressing all components is therefore a very complex process. However, not all products and components have the same potential of contributing to the reduction of environmental impacts, and thus should not all be covered in the review of BEMPs tied to production. Hence, those components must be identified which are particularly relevant with regard to the environmental aspects covered within

this study. Various components and sub-components are used in practically all EEE and thus have a strong potential for improving the environmental performance of a large range of products.

Thus, aside from identifying environmental impacts in the context of products and their various life cycle phases, it is important to screen various components and their relative contribution to the environmental performance of products.

Therefore, EEE has been screened on a component basis to identify those that are used in a wide variety of products, so as to address the EEE product range more comprehensively. This is understood as a component filter.

Since **integrated circuits** are in use in practically all EEE appliances, special attention will be given to these components. An integrated circuit (IC), also termed microchip, is an electronic circuit placed on a single semiconductor substrate. ICs are fabricated from high-grade silicon using an array of ultrapure chemicals in workrooms that must meet “cleanroom” standards. More than a hundred chips are placed simultaneously on a silicon wafer disk through a series of processes in the fabrication line. Each individual wafer consists of several hundred individual chips. ICs are complex components. A range of different technical parameters and process steps determine the material and energy input associated with IC production. Resource input needed for producing a chip depends on its use function – a processor chip for instance will entail higher resource input than a memory chip because of the increasing functionality (complexity of design). In general, the required high-purity chemicals and ultraclean production conditions (cleanroom technology) contribute to the environmental impact of these components, as larger amounts of materials and energy are required for their production / operation processes. An additional aspect of interest for environmental impacts concerns the application of perfluorocompound (PFC) emissions treatment which is not practiced in all fabrication facilities.[3]

Furthermore, regarding the highly complex and chemicals consuming print and etch processes, the content of hazardous substances, and aspects of recyclability, **printed circuit boards** (PCB) are considered to be another EEE-component of major relevance for this study. PCB based on duroplastic synthetic materials currently dominates the market. Due to their chemical characteristics, they are not recyclable at the level of materials. Moreover, they generally require brominated flame retardants such as tetrabromobisphenol A (TBBA) or the toxic substance antimony trioxide. Apart from that, duroplastic circuit boards (for example FR-4, FR-2) are usually produced using a relatively costly batch technique and have almost reached their technological limits in other areas (for example, HF characteristics).

2.1.2. Geographical filter: Priorities regarding the place of manufacturing of electronic and electrical equipment

As the availability of information is understood to limit the possibility to come across BEMPs, a further distinction is to be made between products and components that are manufactured, at least to some degree, in the EU-28, and between those produced outside the EU, for which information may be limited. Later, this will also be relevant for understanding how BEMP requirements are to be formulated towards all relevant manufacturers, as in some cases, production takes place both within and without the EU, e.g., regarding integrated circuits and circuit boards.

[3] Prakash, S.; Liu, R.; Schischke, K.; Stobbe, L. (2013): “Establishing a data base for the evaluation of ecological effects of ICT products”; study conducted within the context of the broader project entitled “Resource conservation in the field of information and communication technologies (ICT)”; Oeko-Institut e.V. in cooperation with Fraunhofer IZM; commissioned by the German Federal Environment Agency (UBA)

Addressing these aspects is understood to be a geographical filter. To further enhance the relevance of various processes and technologies for review, attention shall be given to distribution of manufacturing facilities throughout the EU, regarding areas where manufacturing is mainly done by SMEs as compared to areas where production by large enterprises is dominant. Likewise, in some cases it may be relevant to review if production facilities are evenly distributed throughout the EU or more concentrated in countries in which specific characteristics or conditions apply.

2.1.3. Environmental filter: Priorities regarding the environmental performance of EEE in various life cycle phases

The environmental impacts associated with a process or technology are a key aspect for the identification of potential BEMP candidates to be reviewed in the course of the project. BEMPs that are relevant for being applied across industry should have the potential of addressing environmental impacts in various life cycle stages. It is thus particularly important to identify the improvement potential in various life cycle stages of EEE appliances. In this context, the scoping sets priorities regarding the environmental performance of EEE in various life cycle phases.

Thus, components with a high relevance identified by means of the component filter are thoroughly screened during each of their life cycle stages in order to determine processes and manufacturing techniques with higher contributions towards environmental impacts. This information is the basis of identifying BEMPs, methods for benchmarking and performance indicators.

Finally, the environmental filter ensures that all environmental aspects considered relevant for the EEE sector (see section 3.3) are covered.

3. General information about the EEE sector

3.1. Definition and structural overview

The term electronic and electrical equipment (EEE) covers a wide variety of products and devices, including, but not limited to, information and communication technology (ICT) appliances, household appliances, lighting equipment, electrical tools, medical devices, etc.

NACE is the European standard classification of productive economic activities.[4] The NACE codes relevant for activities tied with the EEE manufacturing sector are understood to be as follows:

- **26 Manufacture of computer, electronic and optical products**
  - 26.1 Manufacture of electronic components and boards
    - 26.11 Manufacture of electronic components
    - 26.12 Manufacture of loaded electronic boards
  - 26.2 Manufacture of computers and peripheral equipment
  - 26.30 Manufacture of communication equipment
  - 26.4 Manufacture of consumer electronics

[4] Regulation (EC) No 1893/2006 of the European Parliament and of the Council of 20 December 2006 establishing the statistical classification of economic activities NACE Revision 2 and amending Council Regulation (EEC) No 3037/90 as well as certain EC Regulations on specific statistical domains Text with EEA relevance, imposes the use of the NACE classification uniformly within all the Member States. For legal text see: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006R1893

- 26.5 Manufacture of instruments and appliances for measuring, testing and navigation, watches and clocks
  - 26.51 Manufacture of instruments and appliances for measuring, testing and navigation
  - 26.52 Manufacture of watches and clocks
- 26.6 Manufacture of irradiation, electromedical and electrotherapeutic equipment
- 26.7 Manufacture of optical instruments and photographic equipment
- 26.8 Manufacture of magnetic and optical media

- **27 Manufacture of electrical equipment**
  - 27.1 Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
  - 27.11 Manufacture of electric motors, generators and transformers
  - 27.12 Manufacture of electricity distribution and control apparatus
  - 27.2 Manufacture of batteries and accumulators
  - 27.3 Manufacture of wiring and wiring devices
    - 27.31 Manufacture of fibre optic cables
    - 27.32 Manufacture of other electronic and electric wires and cables
    - 27.33 Manufacture of wiring devices
  - 27.4 Manufacture of electric lighting equipment
  - 27.5 Manufacture of domestic appliances
    - 27.51 Manufacture of electric domestic appliances
  - 27.9 Manufacture of other electrical equipment

- **28 Manufacture of machinery and equipment n.e.c.**
  - 28.1 Manufacture of general-purpose machinery
    - 28.11 Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
    - 28.12 Manufacture of fluid power equipment
    - 28.13 Manufacture of other pumps and compressors
    - 28.14 Manufacture of other taps and valves
    - 28.15 Manufacture of bearings, gears, gearing and driving elements
  - 28.2 Manufacture of other general-purpose machinery
    - 28.21 Manufacture of ovens, furnaces and furnace burners
    - 28.22 Manufacture of lifting and handling equipment
    - 28.23 Manufacture of office machinery and equipment (except computers and peripheral equipment)
    - 28.24 Manufacture of power-driven hand tools
    - 28.25 Manufacture of non-domestic cooling and ventilation equipment
    - 28.29 Manufacture of other general-purpose machinery n.e.c.
  - 28.3 Manufacture of agricultural and forestry machinery
  - 28.4 Manufacture of metal forming machinery and machine tools
    - 28.41 Manufacture of metal forming machinery
    - 28.49 Manufacture of other machine tools

- 28.9 Manufacture of other special-purpose machinery
- 28.91 Manufacture of machinery for metallurgy
- 28.92 Manufacture of machinery for mining, quarrying and construction
- 28.93 Manufacture of machinery for food, beverage and tobacco processing
- 28.94 Manufacture of machinery for textile, apparel and leather production
- 28.95 Manufacture of machinery for paper and paperboard production
- 28.96 Manufacture of plastics and rubber machinery
- 28.99 Manufacture of other special-purpose machinery n.e.c.

In this context, it should be noted that the **target group** of this report are clearly companies belonging to **NACE codes 26 and 27**. However, it cannot be excluded that the BEMPs developed in this document might also be relevant for some companies belonging to NACE code 28. Within this context, especially the following product groups are considered to be relevant:

- fluid power equipment and of other pumps and compressors (NACE code 28.12 and 28.13)
- lifting and handling equipment (NACE code 28.22)
- office machinery and equipment (NACE code 28.23)

Furthermore, it can be seen that the Directives developed in the EU to handle EEE provide a definition that excludes some of the products and components that otherwise fall under NACE classes 26 through 28.

According to Directive 2012/19 (WEEE) and Directive 2011/65/EU (RoHS),[5] EEE is defined as follows:

> "*Electrical and electronic equipment' or 'EEE' means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current*;" (RoHS 2 (2011))[6]

Both of these Directives link their scope of applicability to the voltage rating of equipment, and thus exclude larger installations and machinery. This aspect is further reflected in the exclusions that the RoHS Directive makes, which provides for the exclusion of some of the machinery relevant for the "28" classes from its scope. These exclusions refer to Large Scale Fixed Installations (LSFI) and Large Scale Stationary Industrial Tools (LSSIT) and are embodied in Article 2(d) and Article 2(e) of the RoHS Directive, respectively.

5 Recognising the potential of inadequately treated waste to have adverse impacts on the environment and on health, in 14.11.1996, the European Commission was asked by Parliament to propose directives on a number of priority waste streams, including electrical and electronic equipment (EEE). In 2003, EU legislation promoting the collection and recycling of such equipment (WEEE Directive 2002/96/EC) and restricting the use of hazardous substances in EEE (RoHS Directive 2002/95/EC) came into force. The EU's major trading partners have also brought into force similar legislation (e.g. China, Korea, Japan, some US states). In light of some implementation deficiencies, in December 2008 the European Commission proposed to recast both Directives to tackle the fast increasing waste stream of such products, and to strengthen the enforceability of this legislation (European Commission, 2009). Thus, both the RoHS and WEEE Directives were amended in 2011 and 2012 respectively and provide the main legal framework at present for EEE in the EU member states.

6 RoHS 2 (2011), Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32011L0065:EN:NOT

Furthermore, as these Directives lay forth various requirements that are obligatory for products placed and made available on the EU market, their categorisation is product or device based, whereas as components; spare parts and cables are dealt with indirectly in light of their being part of these products. In this sense both directives lack categorisations parallel to the NACE classifications available for components (e.g. class 26.10. for electronic components and boards) The product categories are specified in Annex I of Directive 2012/19/EU (WEEE)[7] as follows.[8]

- Large household appliances;
- Small household appliances;
- IT and telecommunications equipment;
- Consumer equipment and photovoltaic panels;
- Lighting equipment;
- Electrical and electronic tools (with the exception of large-scale stationary industrial tools);
- Toys, leisure and sports equipment;
- Medical devices (with the exception of all implanted and infected products);
- Monitoring and control instruments;
- Automatic dispensers.

Directive 2011/65/EU (RoHS) specifies very similar product categories under Annex I, which are thus not further detailed.

The ICT subsector with its IT and telecommunication equipment is regarded to be both most relevant and most innovative concerning environmental issues. For example, in many sectors of the economy and realms of society, ICT can make an important contribution to mitigating climate change. The estimates of mitigation potential cited most frequently in the technical literature and by experts anticipate that intelligent deployment of ICT solutions[9] could deliver emissions reductions totalling around 7.8 billion t CO_2e worldwide in the year 2020. This amounts to around 15% of the global emissions expected in 2020, which totals 51.9 billion t CO_2e (Climate Group 2008). Beside this potential climate benefit, ICT is also a source of emissions amounting to 830 million t CO_2e worldwide in 2007 (Climate Group 2008).[10] These emissions are expected to rise to 1.4 billion tonnes CO_2e by 2020 (Climate Group 2008).

However, the present debate on the environmental impacts attributable to ICT in particular and EEE in general focuses strongly on the use phase of devices and infrastructures. This focus is driven by the current discourse on climate change and by sharply rising energy costs (UBA 2009). As a result, insufficient attention is often given to the environmental impacts arising during the

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7 Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast), http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0019

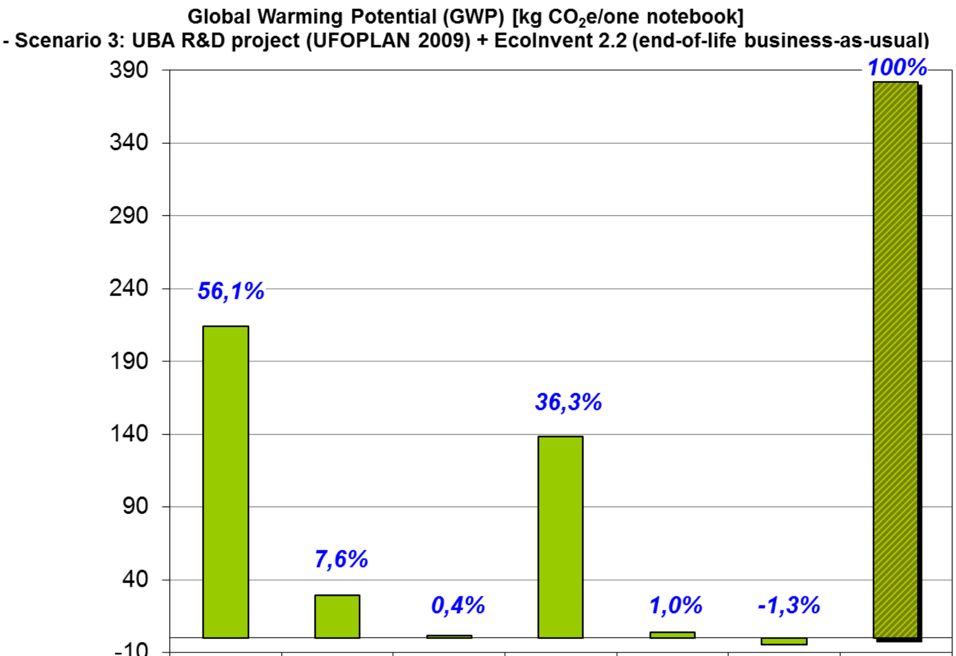
8 It should be noted that under the WEEE Directive, the categories specified in Annex I, which are very similar to the RoHS categories, are regarded as transitional categories, whereas Annex II specifies categories that shall be regarded in the WEEE context starting August 2018. Annex II contains fewer categories, however is assumed to include the various products falling under the Annex I category scope. In light of their present applicability, the Annex I categories are therefore further used for this demonstration.

9 Examples: Intelligent control of buildings and electricity grids, traffic prevention through telephone and video conferencing systems, substitution of physical by digital goods (e-mails, photos etc.) (UBA 2009)

10 In the present study, ICT comprises computers, telecommunication networks and devices, printers and computer centres. Other studies estimate the global emissions attributable to the electricity consumption alone of ICT equipment and infrastructures in their use phase as amounting to around 2.1 billion t (Climate Group 2008).

production phase. This is due in part to the absence of economic incentives – in contrast to the price signals that steer the use phase – and in part to the poor availability of data on production processes. For example, a study performed by Oeko-Institut has found that more than 60 percent of the environmental impact of notebook computers is attributable to their production and distribution (cf. following figure).

Figure 3-1: Absolute GWP values and percentage proportions of life cycle phases

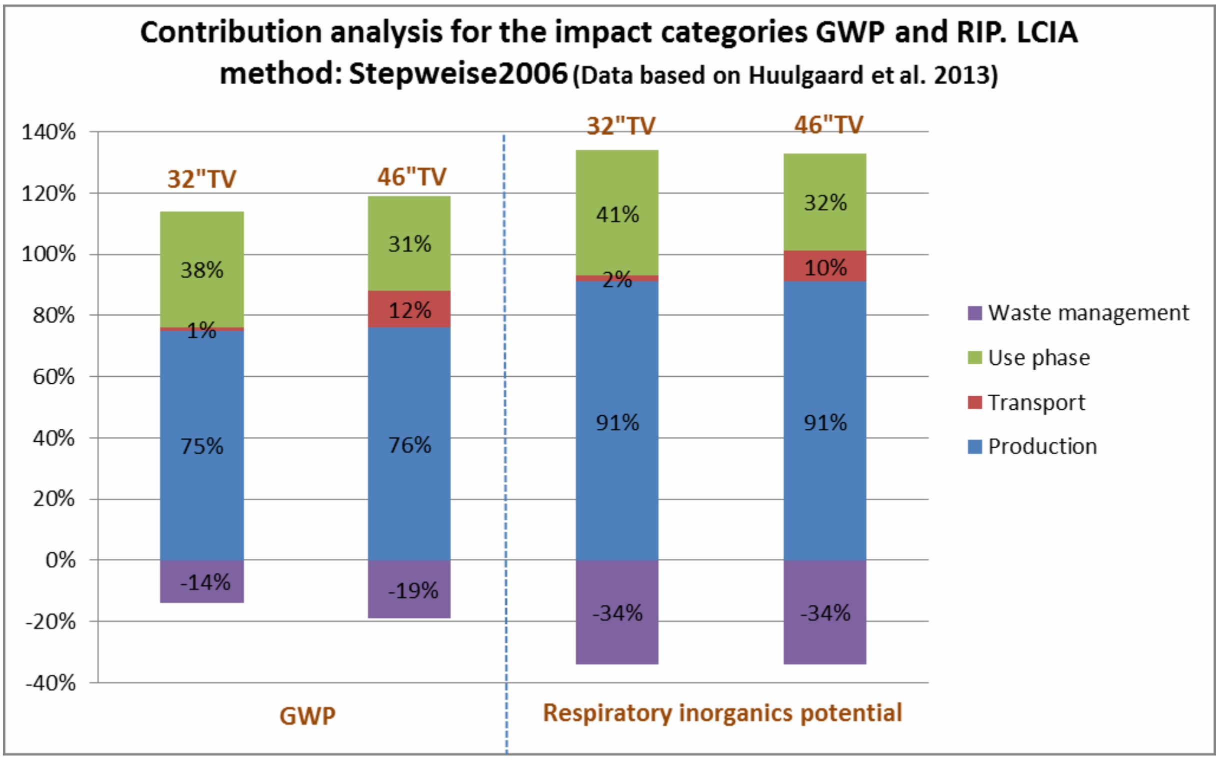


	Production	Distribution	Shopping trip	Use	Disposal	Credit	Total (with credit)
UBA R&D project (UFOPLAN 2009) + EcoInvent 2.2 (end-of-life business-as-usual)	214	29	1	138	4	-5	382

Source: Prakash et al. (2011b)

This is especially applicable for mobile applications, but not necessarily limited to them. Other studies even estimate that the share of the production phase in the total greenhouse gas emissions of a notebook amounts to over 90% (Andrae & Anderson 2010; Huulgaard et al. 2013). The following figure demonstrates this development by showing the contribution of the different life cycle stages of television sets (both 32'' and 46'' diameter) concerning the environmental pressures Global Warming Potential (GWP) and Respiratory Inorganics Potential (RIP).

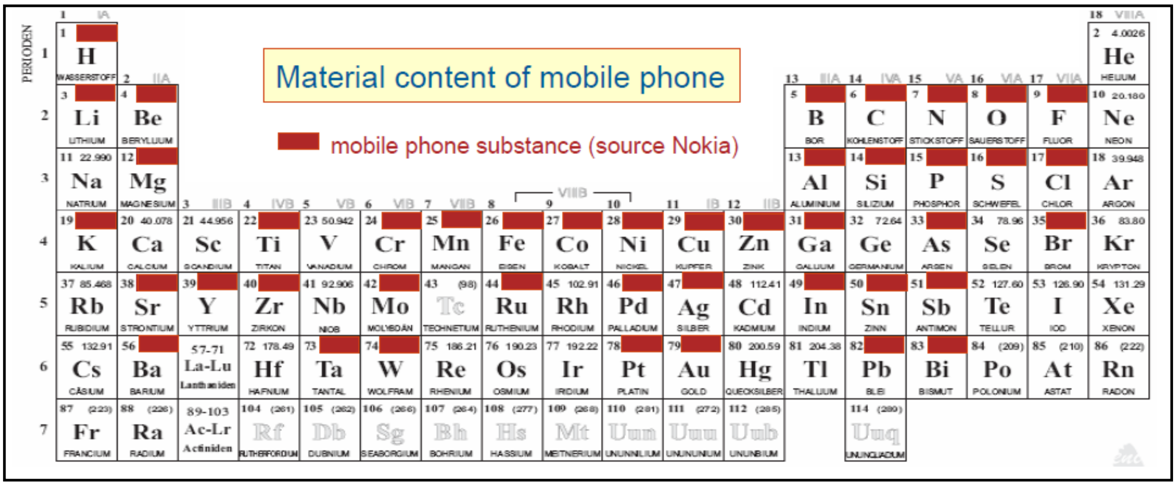
Figure 3-2: Contribution analysis for the impact categories GWP and RIP



Source: Data based on Huulgaard et al. (2013)

Concerning their supply chain, EEE devices often contain a great number of important metals such as gold, silver, platinum group metals, indium, tantalum, gallium etc. A mobile phone, for instance, can consist of 43 different elements (cf. following figure).

Figure 3-3: Metals in a mobile phone



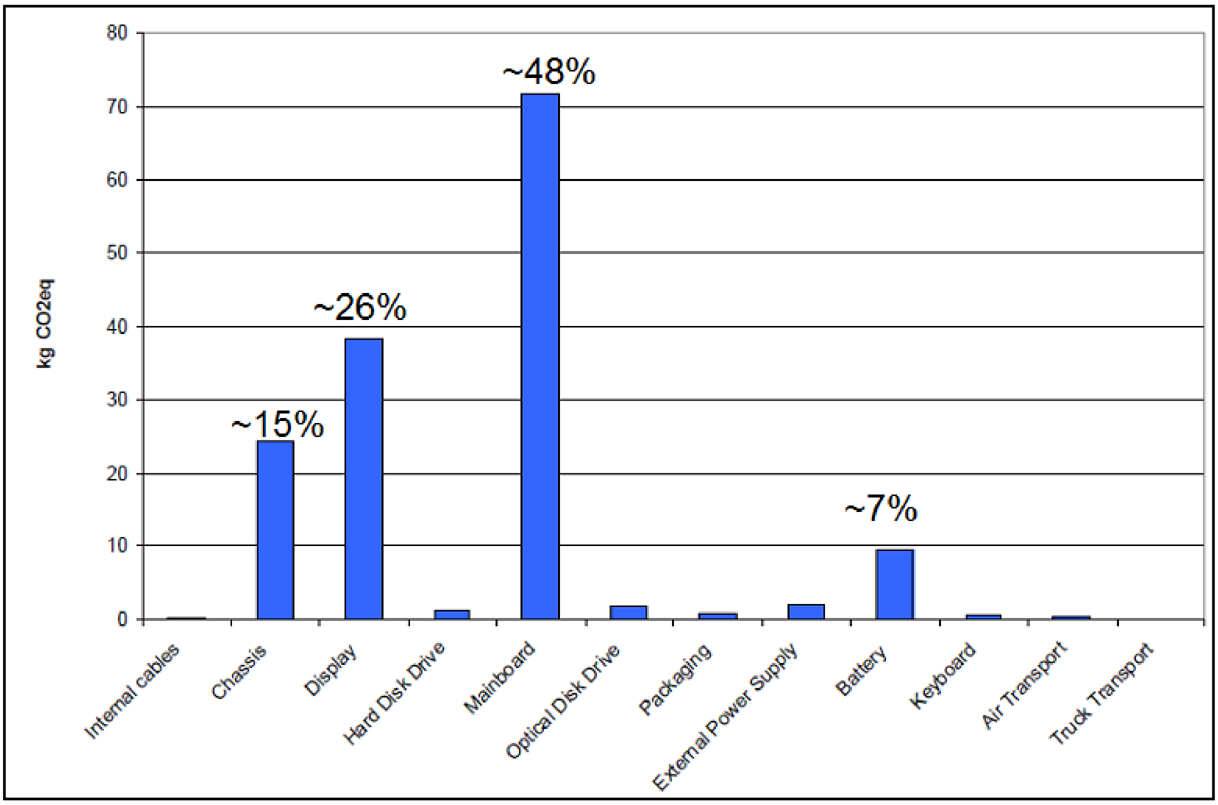
Source: Hagelüken & Buchert (2008)

The extraction and processing of these elements is associated with major material requirements, appropriation of land and consumption of energy, and causes severe environmental impacts. For instance, in many places around the world, the mining of gold and silver incurs high ecological and

social costs. Broad-scale excavation of rock, energy-intensive comminution, cyanide leaching and amalgamation with mercury are just a few typical causes of the far-reaching impacts on humans and the environment. The production of one tonne of gold generates emissions of approx. 18,000 t CO_2e and has a cumulative resource requirement[11] of almost 740,000 t (IFEU 2011).

With regards to their manufacturing processes, it has to be considered that EEE devices often contain components that cause a high energy and/or material consumption. For example, the energy and material consumption of a notebook's mainboard results in a GWP of approx. 70 kg CO_2e, representing almost 50% of the overall emissions of the production phase. Other relevant components in this respect are display, chassis and battery (cf. following figure).

Figure 3-4: Breakdown of component-specific greenhouse gas emissions (CO_2e) from the production phase of a Dell notebook



Source: O'Connell & Stutz (2010)

Regarding the manufacturing processes of the mentioned components, it is important to note that, for example, chemicals of high purity and with highly diversified functionalities as well as important peripheral processes such as clean-room technology are required in more and more cases. These circumstances tighten the trend of a manufacturing phase with an increasing impact on the environment.

Furthermore, the extremely high speed of innovation as well as the specialisation and globalisation of supply chains make it necessary to transport components and EEE products often several times

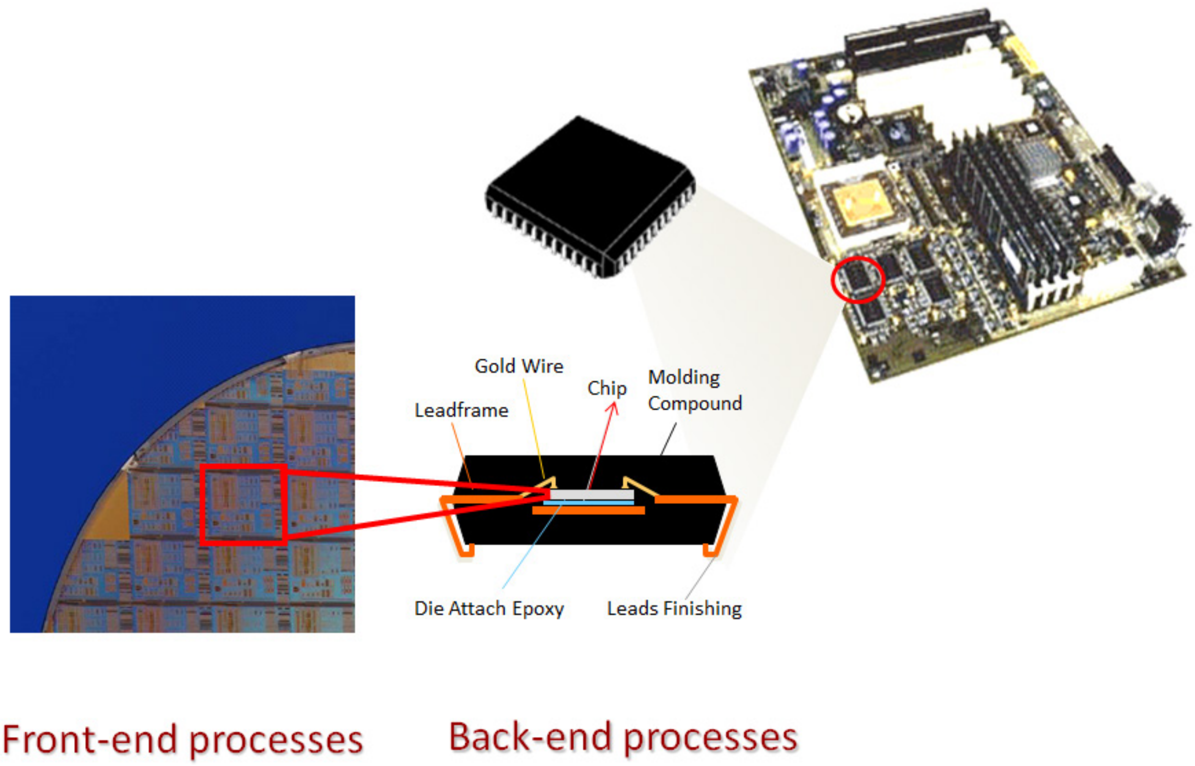
11 "Cumulative resource requirement" comprises energy and metal resources, earths and stones, and other mineral resources.

over long distances during their manufacturing, with air transportation becoming increasingly important.

The individual contributions of these aspects related to EEE manufacturing to the overall environmental performance of EEE appliances or components can be illustrated on the basis of the more than 300 different processes during the manufacturing of integrated circuits (IC). Generally speaking, these processes can be clustered into two groups (see Figure 3-5):

- Front-end processes comprising the formation of the individual devices (transistors, capacitors, resistors, etc.) directly in the silicon and interconnecting them with the wiring on the wafer;
- Back-end processes that refer to the assembly and to the testing of the individual semiconductors.

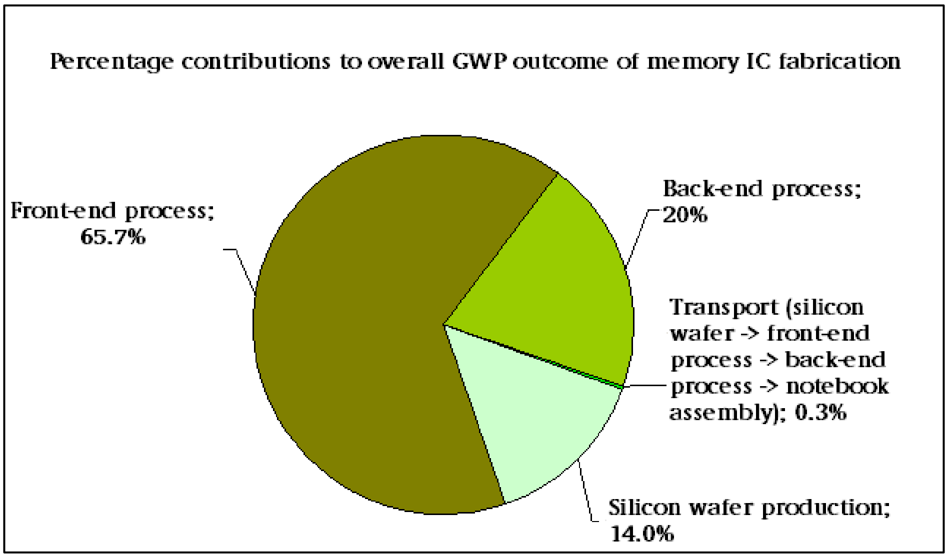
Figure 3-5: Front-end Processes and Back-end Processes of IC Manufacturing



Source: Prakash et al. (2011a)

The analysis of the contributions of the above mentioned process clusters shows that the overall greenhouse gas emissions (GWP) of IC fabrication are mainly caused by the front-end processes (approx. two thirds), whereas in the back-end processes, the manufacturing of the used base material (silicon wafer production) and the various transport processes account for the remaining third of greenhouse gas emissions (see Figure 3-6 below).

Figure 3-6: Percentage Contributions to Overall GWP Outcome of Memory IC fabrication



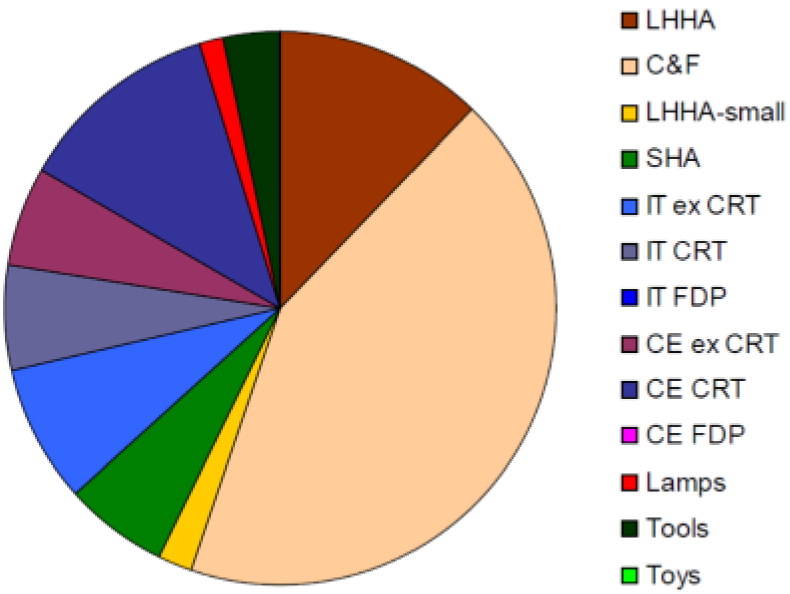
Source: Prakash et al. (2011b)

UNU (2008),[12] which reviewed several aspects of the WEEE Directive, attributed differing weights to the various EEE categories outlined above in light of their contribution to the environmental impacts of waste from EEE (see Figure 3-7). The impacts examined included cumulative energy demand; abiotic depletion; global warming; ozone layer depletion; human toxicity; fresh water and marine aquatic eco-toxicity; terrestrial eco-toxicity; photochemical oxidation; acidification; and eutrophication. The collected data identifies the main contributors of EEE during the end of life stage: household appliances of various sizes (with a large contribution associated with cooling and freezing appliances[13]) and the various equipment falling under the definition of ICT.

12 UNU (2008); Review of Directive 2002/96 on Waste Electrical and Electronic Equipment – Study No. 07010401/ 2006/442493/ETU/G4, page iii; available at http://ec.europa.eu/environment/waste/weee/pdf/final_rep_unu.pdf

13 Regarding large household appliances, an important aspect is ozone-layer depletion and global warming potential of cooling and freezing devices. However, in this report it is emphasized that this impact may change over time in light of the phase out of CFCs in such appliances, whereas the data available at the time did not allow understanding how this would be reflected in products reaching the end-of-life phase. The study mentions the shift from CRT screens to flat panel displays as well as the phase out of CFC's from fridges, NiCd from battery packs and PCBs in capacitors as areas where the composition of the analysed waste stream differed from the composition of products put on the market at the time.

Figure 3-7: Contribution of categories to environmental impacts of WEEE total (Eco Indicator '99 H/A)



Abbreviations:

- LHHA: Large Household Appliances
- C&F: Cooling and freezing
- LHHA-small: Large Household Appliances (smaller items)
- SHA: Small Household Appliances
- IT ex CRT: IT & Telecom excluding CRT's
- IT CRT: CRT monitors
- IT FDP: LCD monitors
- CE ex CRT: Consumer Electronics excluding CRTs
- CE CRT: CRT TVs
- CE FDP: Flat Panel TVs
- Lamps: Lighting equipment – Lamps
- Tools: Electrical and electronic tools
- Toys: Toys, leisure & sports equipment

Source: UNU (2008)

Due to their importance within the different life cycle stages, the EEE sub-sectors of household appliances and ICT equipment will be examined more closely throughout this project.

In the NACE[14] codes, domestic appliances fall under electric equipment. Example products are provided, distinguished between the following two sub-categories:

- Manufacture of domestic electric appliances: refrigerators; freezers; dishwashers; washing and drying machines; vacuum cleaners; floor polishers; waste disposers; grinders, blenders, juice squeezers; tin openers; electric shavers, electric toothbrushes, and other electric personal care device; knife sharpeners; ventilating or recycling hoods.
- Manufacture of domestic electrothermic appliances: electric water heaters; electric blankets; electric dryers, combs, brushes, curlers; electric smoothing irons; space heaters and household-type fans, portable; electric ovens; microwave ovens; cookers, hotplates; toasters; coffee or tea makers; fry pans, roasters, grills, hoods; electric heating resistors etc.

14 See details under: http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_NOM_DTL_VIEW&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=18504194&IntKey=18504224&StrLayoutCode=HIERARCHIC&IntCurrentPage=1

In the NACE codes, ICT[15] is represented by the following sub-categories:[16]

- 26.1 Manufacture of electronic components and boards – This class includes manufacture of capacitors; resistors; microprocessors; electron tubes; electronic connectors; bare printed circuit boards; integrated circuits (analog, digital or hybrid); diodes, transistors and related discrete devices; inductors (e.g. chokes, coils, transformers), electronic component type; electronic crystals and crystal assemblies; solenoids, switches and transducers for electronic applications; dice or wafers, semi-conductor, finished or semi-finished; display components (plasma, polymer, LCD); light emitting diodes (LED); loaded printed circuit boards; loading of components onto printed circuit boards; and interface cards (e.g. sound, video, controllers, network, modems)
- 26.2 Manufacture of computers and peripheral equipment - This class includes manufacture of desktop computers; laptop computers; main frame computers; hand-held computers (e.g. PDA); magnetic disk drives, flash drives and other storage devices; optical (e.g. CD-RW, CD-ROM, DVD-ROM, DVD-RW) disk drives; printers; monitors; keyboards; all types of mice, joysticks, and trackball accessories; dedicated computer terminals; computer servers; scanners, including bar code scanners; smart card readers; virtual reality helmets; computer projectors (video beamers); computer terminals, like automatic teller machines (ATM's), point-of-sale (POS) terminals, not mechanically operated; and multi-function office equipment performing two or more of following functions: printing, scanning, copying, faxing.
- 26.30 Manufacture of communication equipment - This class includes manufacture of central office switching equipment; cordless telephones; private branch exchange (PBX) equipment; telephone and facsimile equipment, including telephone answering machines; data communications equipment, such as bridges, routers, and gateways; transmitting and receiving antenna; cable television equipment; pagers; cellular phones; mobile communication equipment; radio and television studio and broadcasting equipment, including television cameras; modems, carrier equipment; burglar and fire alarm systems, sending signals to a control station; radio and television transmitters; and communication devices using infrared signal (e.g. remote controls)
- 26.4 Manufacture of consumer electronics – This class covers manufacture of video cassette recorders and duplicating equipment, televisions; television monitors and displays; audio recording and duplicating systems; stereo equipment; radio receivers; speaker systems; household-type video cameras; jukeboxes; amplifiers for musical instruments and public address systems; microphones; CD and DVD players; karaoke machines; headphones (e.g. radio, stereo, computer); and video game consoles.
- 26.8 Manufacture of magnetic and optical media This class includes manufacture of blank magnetic audio and video tapes; blank magnetic audio and video cassettes; blank diskettes; blank optical discs and hard drive media

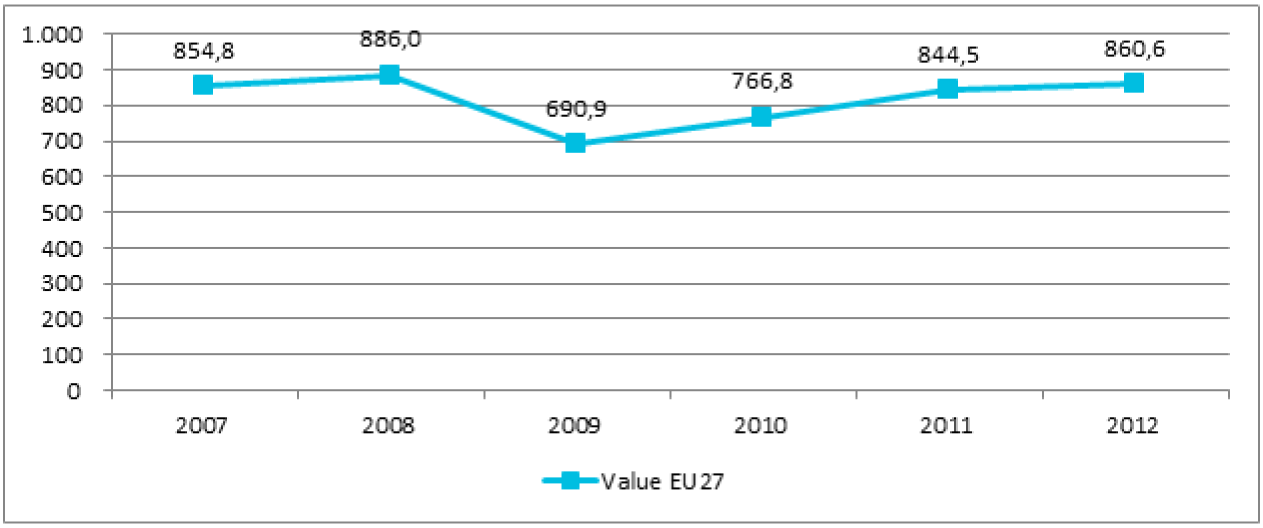
15 Based on the classification provided under: http://www.google.de/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&cad=rja&uact=8&ved=0CCkQFjAA&url=http%3A%2F%2Fis.jrc.ec.europa.eu%2Fpages%2FISG%2FPREDICT%2F2da%2Fdocuments%2F06ICT_TUR_27APR.xlsx&ei=9EdyU6v5GYa3yQPWuIHYBQ&usg=AFQjCNEhWLC6CgfJcd-ZF9onRmnVWMFBfg

16 See details under: http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=18503264&StrLayoutCode=HIERARCHIC

3.2. Economic relevance

Statistical data from Eurostat,[17] concerning the value of production, was collected for the NACE code groups 26, 27 and 28 that are understood to be of relevance for the EEE sector. Data for the period between 2007 and 2012 shows that the value of production has remained similar, whereas in 2009 a significant decrease in production was observed, both for the EU 27 and in most individual countries. This reduction is understood to be the result of the financial crisis and its impact on the economy in general and more specifically on the demand for EEE products (see Figure 3-8 below). To provide insight as to the contribution of the EEE sector to the economy, the value of production can be analysed in terms of its share from the GDP for the EU 27 in Figure 3-9, as well as for specific countries in Figure 3-11 and Figure 3-13 below. From this demonstration it can be understood that the 2009 crisis did not only impact the absolute value of production but rather had a slightly more significant impact on the EEE sector's activity in relation the GDP. This demonstration however also shows that the sector has almost regained its significance in this regard in the EU.

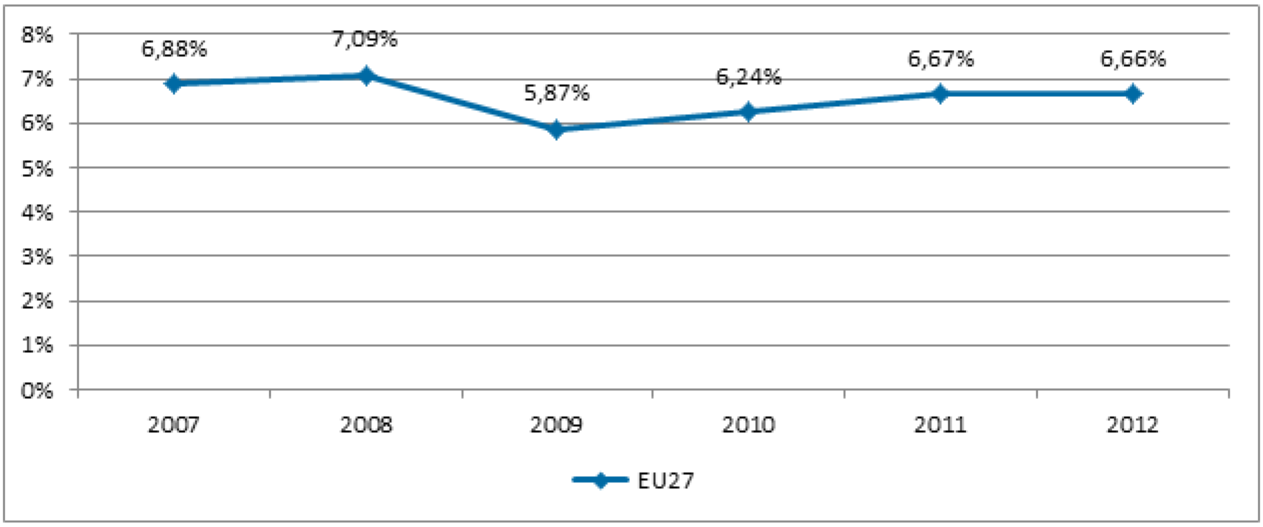
Figure 3-8: Value of EEE production between 2007-2012, EU 27 (in billion €)



Source: Own compilation, data based on EUROSTAT Statistics on the production of manufactured goods for the years 2007-2012

[17] EUROSTAT statistics on the production of manufactured goods for the years 2007-2012; available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/tables_excel

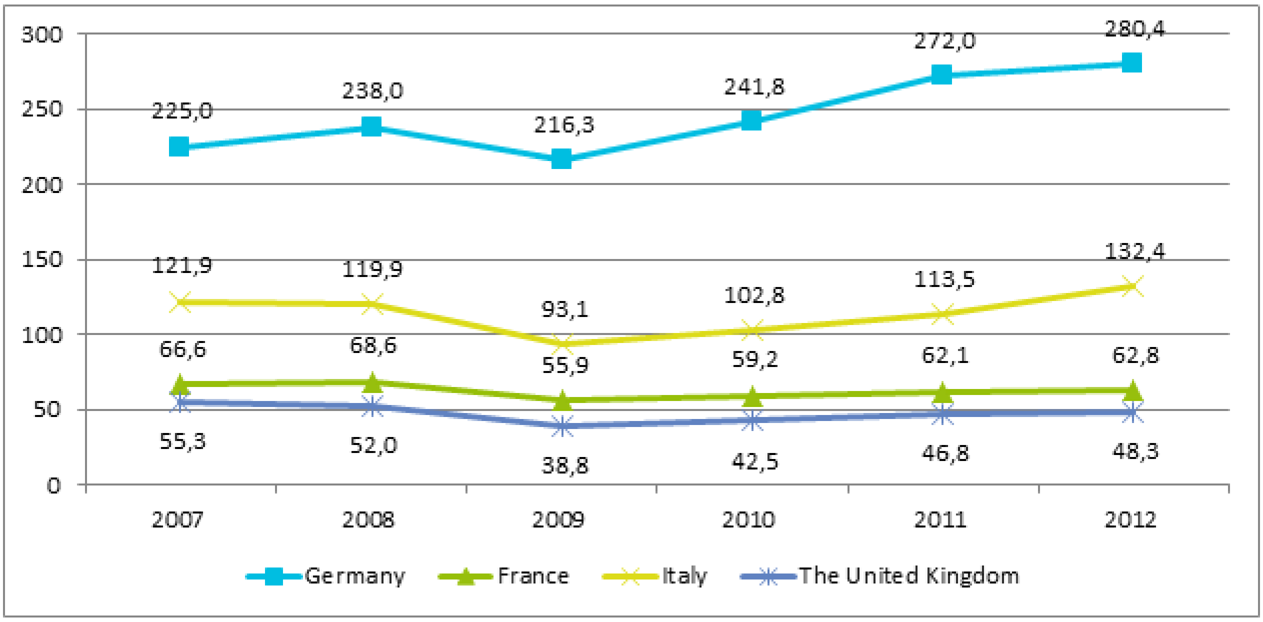
Figure 3-9: Contribution of EEE Production Value to GDP, EU27 (%)



Source: Own compilation, data based on EUROSTAT Statistics on the production of manufactured goods for the years 2007-2012 and EUROSTAT „GDP and main components – Current prices [nama_gdp_c]" for the years 2007-2012

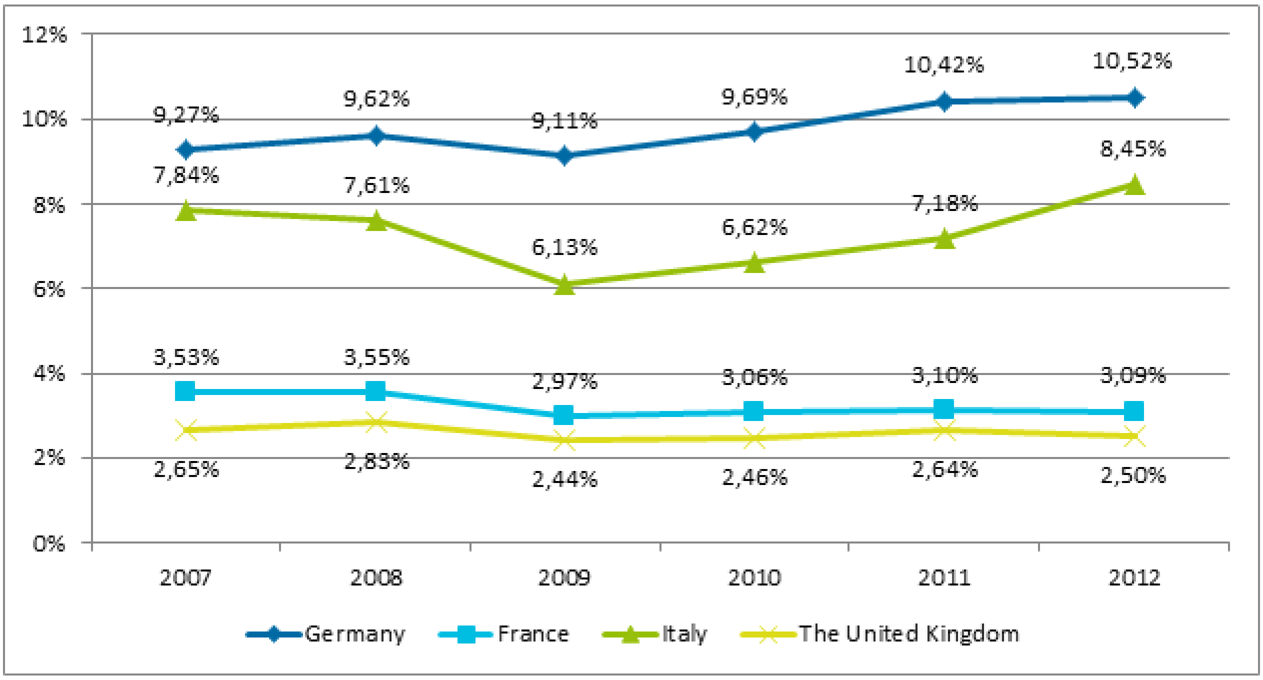
Data for the various European countries shows that the main countries contributing to production throughout this period were Germany, Italy, France and the UK, with production values having decreased since 2007 in both France and the UK (see Figure 3-10 below). This decrease is also reflected in Figure 3-11, which also shows that activity in Germany and Italy has increased beyond the pre-crisis levels.

Figure 3-10: Contribution of EEE Production Value to GDP for Germany, Italy, France, and the UK (in billion €)



Source: Own compilation, data based on EUROSTAT Statistics on the production of manufactured goods for the years 2007-2012 and EUROSTAT „GDP and main components – Current prices [nama_gdp_c]" for the years 2007-2012

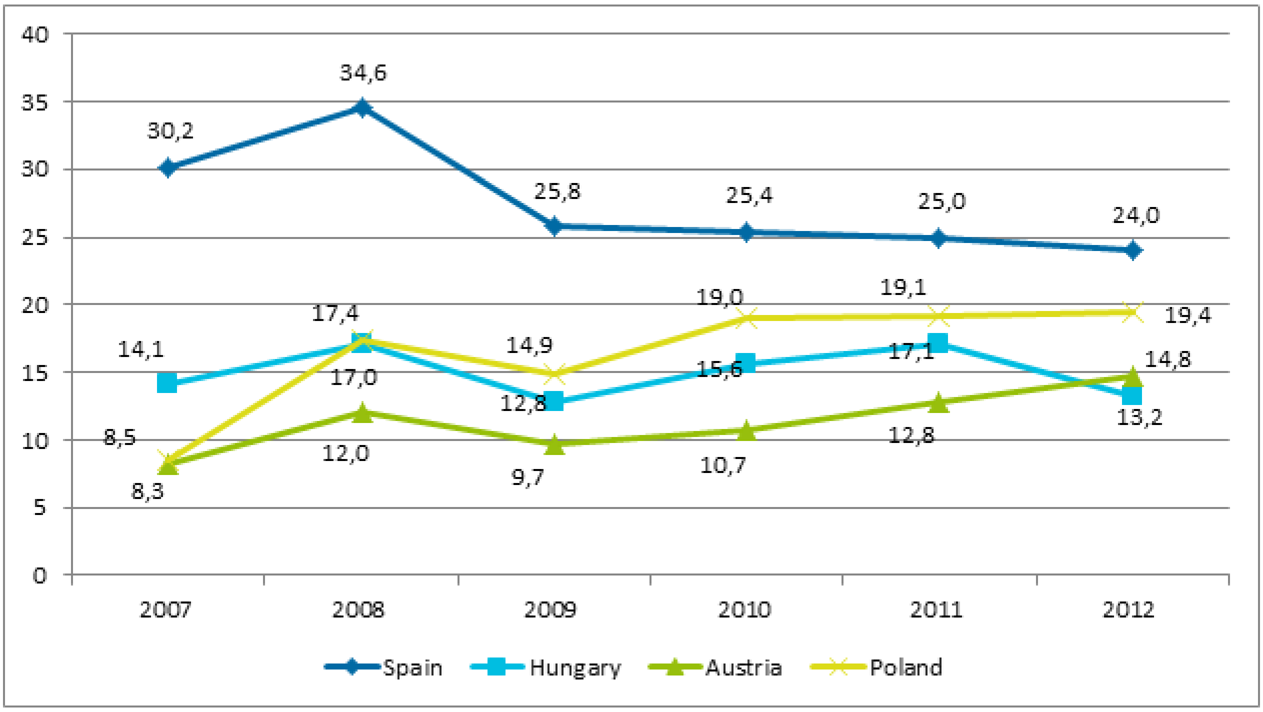
Figure 3-11: Contribution of EEE Production Value to GDP for Germany, Italy, France, and the UK (%)



Source: Own compilation, data based on EUROSTAT Statistics on the production of manufactured goods for the years 2007-2012 and EUROSTAT „GDP and main components – Current prices [nama_gdp_c]" for the years 2007-2012

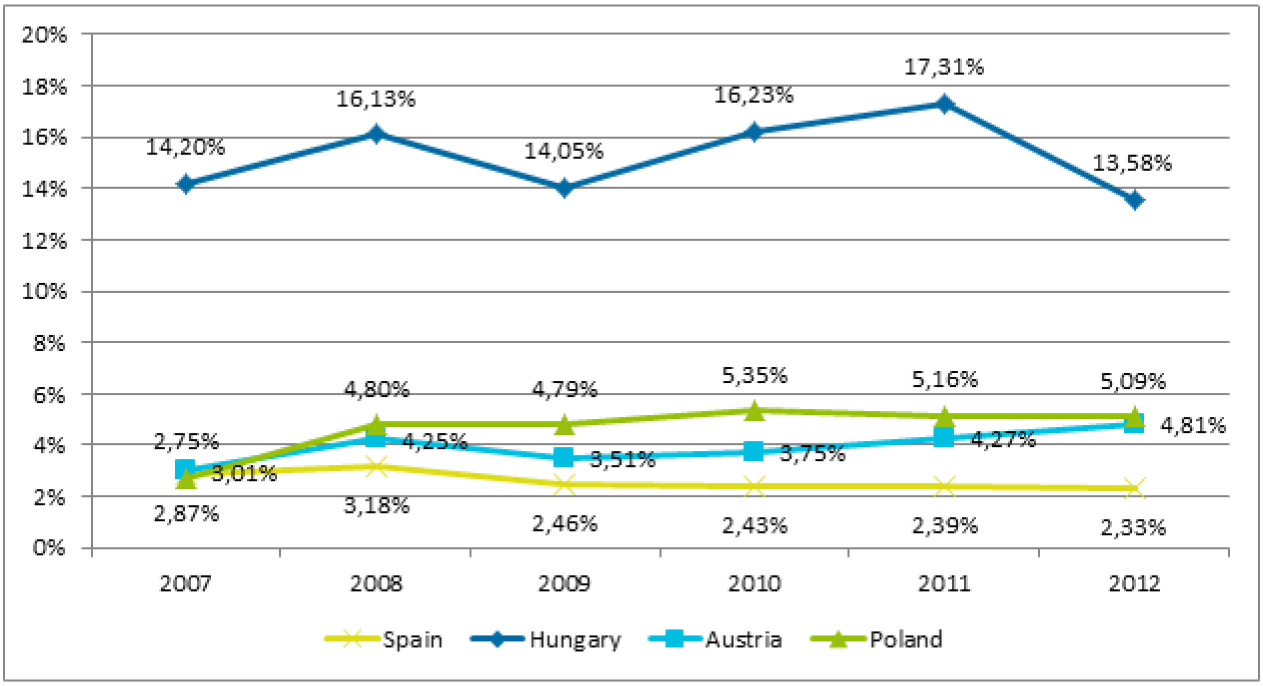
From EU 15, Spain and Austria are also of interest, Spain showing a significant decrease in production value throughout this period compared to Austria, showing a significant growth. In the eastern European countries, Hungary and Poland are observed to be the largest contributors, whereas in this concern Poland more than doubled its production volume in this period (see Figure 3-12 below). This trend is also reflected in the contribution to GDP, where Austria and Poland show a rising trend, in comparison to Spain and Hungary, where activity seems to be decreasing in relation to GDP (see Figure 3-13).

Figure 3-12: Value of EEE Production Between 2007 and 2012, for Spain, Austria, Hungary, and Poland (in billion €)



Source: Own compilation, data based on EUROSTAT Statistics on the production of manufactured goods for the years 2007-2012

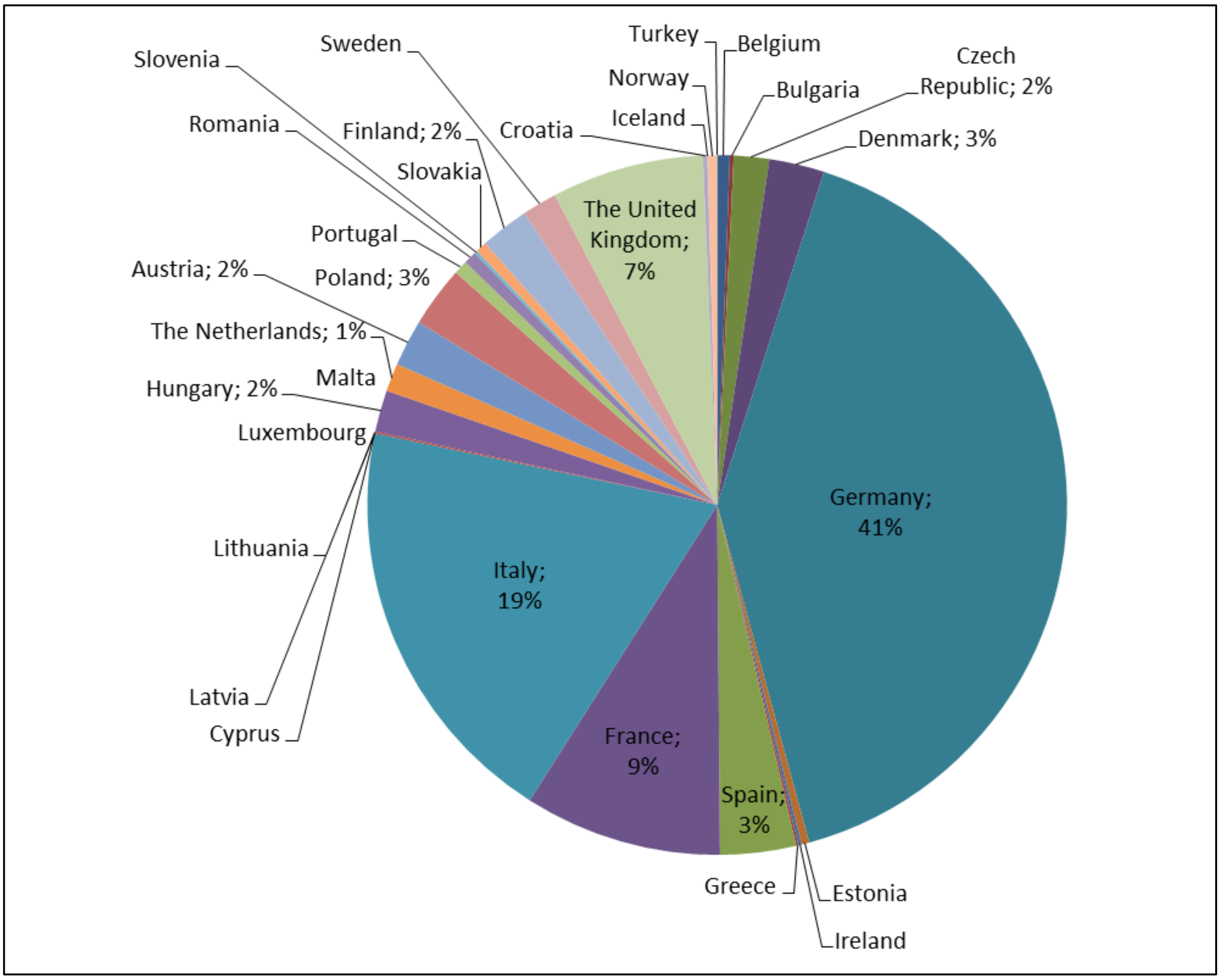
Figure 3-13: Contribution of EEE Production Value to GDP for Spain, Austria, Hungary, and Poland (%)



Source: Own compilation, data based on EUROSTAT Statistics on the production of manufactured goods for the years 2007-2012 and EUROSTAT „GDP and main components – Current prices [nama_gdp_c]" for the years 2007-2012

To further illustrate the distribution of EEE manufacture in the EU, this data has been processed into the pie chart in Figure 3-14. In this figure, manufacturing shares are detailed only for the larger manufacturing countries.

Figure 3-14: EU Country Shares of EEE Production Value Between 2007 and 2012 (%)



Source: Based on data from the EUROSTAT Statistics on the production of manufactured goods for the years 2007-2012

According to Eurostat data for 2011, there are over 190,000 enterprises in the EU who manufacture products or components of EEE. More than 90% of these enterprises are defined as small enterprises, with less than 50 employees. It is further worth mentioning that 51% of these enterprises manufacture machinery and equipment, whereas the 22% manufacture computer, electronic and optical products and the remaining 27% manufacturing other electrical equipment. Of the various countries in the EU, here too it is clear that most enterprises are located in Italy, Germany and the Czech Republic, followed by the UK, Spain, France and Poland. It is interesting in this regard to see that the number of enterprises does not always correspond to the value of production. In this regard the large number of enterprises located in the Czech Republic and performing EEE manufacture related activities as defined by the NACE code groups, is surprising in relation to the value of production related with these activities. Spain is also of interest in this regard, with a larger number of enterprises as compared to France, despite a significantly lower production value.

Table 3-1: Eurostat Data for 2011, Concerning the Number of Enterprises in the EEE Sector and its Sub-sectors in the Various EU Countries

Geographical area	Total number of enterprises (all EEE)	Total no. of small enterprises (below 50 employees) (all EEE)	Total no. of enterprises (Manufacture of computer, electronic and optical products)	Total no. of enterprises (Manufacture of electrical equipment)	Total no. of enterprises (Manufacture of machinery and equipment n.e.c.)
European Union (28 countries)	**190,319**	**173,098**	**42,700**	**51,000**	**96,619**
Belgium	2,576	2,364	518	562	1,496
Bulgaria	1,697	1,481	348	472	877
Czech Republic	24,768	23,908	3,390	15,213	6,165
Denmark*	n,i,a.	n,i,a.	n,i,a.	n,i,a.	n,i,a.
Germany	30,371	24,941	7,933	6,026	16,412
Estonia	325	264	102	95	128
Ireland	530	433	120	106	304
Greece*	n,i,a.	n,i,a.	n,i,a.	n,i,a.	n,i,a.
Spain	10,821	10,164	2,600	2,439	5,782
France	10,568	9,308	2,776	2,438	5,354
Croatia	1,950	1,858	711	449	790
Italy	39,605	37,191	5,759	9,162	24,684
Cyprus	65	n,i,a.	n,i,a.	n,i,a.	65
Latvia	309	274	110	69	130
Lithuania	379	319	133	96	150
Luxembourg	48	31	10	14	24
Hungary	5,210	4,813	1,603	902	2,705
Netherlands	5,608	5,145	1,454	1,190	2,964
Austria	2,352	1,912	561	469	1,322
Poland	9,736	8,782	2,812	2,101	4,823
Portugal	2,785	2,612	333	773	1,679
Romania	2,722	2,365	834	618	1,270
Slovenia	1,451	1,315	303	397	751
Slovakia	3,866	3,598	804	1,537	1,525
Finland	2,507	2,247	567	418	1,522
Sweden	5,918	5,523	1,704	1,001	3,213
United Kingdom	17,331	15,800	6,119	2,953	8,259
Norway**	1,988	1,866	296	402	1,290
Switzerland**	3,814	2,968	1,517	577	1,720

Notes:

n.i.a. – no information available

* It should be noted that according to the Eurostat 2012 Data available at Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2], extracted 20.03.2014, 2.708 enterprises were listed for Denmark and 4.269 were listed for Greece. This SBS source was not used here as data was missing for other countries such as Ireland and Italy and information concerning enterprise size was not detailed.

** Shaded countries not part of the EU

Source: Eurostat: Industry by employment size class (NACE Rev. 2, B-E) [sbs_sc_ind_r2], extracted 20.03.2014

Regarding the employment situation in the EEE sector, Eurostat data shows that in 2011 there were over 5.5 million individuals employed in the manufacture of EEE in EU countries. For detailed data see Table 3-2 below. Around 53% of these were employed in the manufacture of machinery and equipment with 27% being employed in the manufacture of electrical equipment and the remaining 20% being employed in the manufacture of computer, electronic and optical products.

Of the various countries in the EU, here too Germany is a leader in the sector with almost 2 million employed persons in the various sub-sectors. Italy, France and the UK are also significant players, with Italy having over 700,000 persons employed in the sector and France and the UK both with over 400,000 employed persons. This is followed by Poland, the Czech Republic and Spain who all employ over 200,000 persons in the EEE sector. In all of these countries the manufacture of machinery and equipment has the largest share, though the distribution differs from country to country, as can be seen in the data above.

The number of persons employed shows a better correspondence with the data concerning the value of production, in terms of the ranking of the main contributing countries (Germany, Italy, France and the UK). Data for the more moderate players however shows that more individuals are involved in EEE manufacture than expected from the production value data in Poland and in the Czech Republic, with Spain following closely and other moderate contributors such as Austria and Hungary having lower employment numbers in the EEE sector.

Table 3-2: Eurostat Data for 2011, Concerning the Number of Persons Employed in the EEE Sector and its Sub-sectors in the Various EU Countries
(**Employment variables are expressed in *units* for individual countries, but in *hundreds* for European aggregates**)

Country	Total* Number of Persons Employed in the EEE Manufacturing Sector	Manufacture of computer, electronic and optical products	Manufacture of electrical equipment	Manufacture of machinery and equipment n.e.c.
European Union (28 countries)	**54,972**	**11,000**	**14,907**	**29,065**
European Union (27 countries)	**54,789**	**11,000**	**14,827**	**28,962**
Belgium	67,037	11,577	18,610	36,850
Bulgaria	57,235	8,718	18,603	29,914
Czech Republic	256,733	40,066	97,326	119,341
Denmark	107,524	21,910	13,516	72,098
Germany	1,870,615	311,314	502,546	1,056,755
Estonia	14,027	5,789	4,780	3,458
Ireland	28,779	14,793	3,602	10,384
Greece	27,757	3,058	8,454	16,245
Spain	201,912	30,442	69,825	101,645
France	439,602	136,433	120,088	183,081
Croatia	24,892	5,406	8,435	11,051
Italy	738,709	112,296	168,176	458,237
Cyprus	640	n.i.a.	n.i.a.	640
Latvia	6,846	1,246	2,522	3,078
Lithuania	12,506	3,316	3,780	5,410
Luxembourg	n.i.a.	n.i.a.	n.i.a.	n.i.a.
Hungary	157,643	60,037	37,551	60,055

Country	Total* Number of Persons Employed in the EEE Manu-facturing Sector	Manufacture of computer, electronic and optical products	Manufacture of electrical equipment	Manufacture of machinery and equipment n.e.c.
Malta	n.i.a.	n.i.a.	n.i.a.	n.i.a.
Netherlands	125,785	27,485	21,652	76,648
Austria	137,817	19,557	45,360	72,900
Poland	283,010	61,792	95,788	125,430
Portugal	48,486	8,887	18,856	20,743
Romania	119,793	27,265	37,503	55,025
Slovenia	39,828	5,435	20,087	14,306
Slovakia	83,369	17,632	28,675	37,062
Finland	101,513	32,886	18,605	50,022
Sweden	112,213	n.i.a.	28,939	83,274
United Kingdom	422,361	128,303	95,402	198,656
Iceland	n.i.a.	n.i.a.	n.i.a.	n.i.a.
Liechtenstein	n.i.a.	n.i.a.	n.i.a.	n.i.a.
Norway**	34,462	8,074	6,449	19,939
Switzerland**	238,392	113,994	38,602	85,796

Notes:
n.i.a. – no information available
* Own compilation, based on data for NACE classifications 26, 27 and 28 – see section 3.1 for detail.
* *Shaded countries not part of the EU.

Source: Eurostat: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2] extracted 13.05.2014

In a 2005 working paper prepared by the European Metalworkers Federation (EMF), in the scope of which larger household appliances fall, it is explained that the manufacture of white-goods shows a shift of production (from EU 15 counties) to the new member states of the European Union, and in some cases directly to the Far East, respectively China. The paper names a number of enterprises dominating the sector, including three key manufacturers in Sweden (Electrolux), Germany (BSH) and Italy (Indesit).[18]

European Commission (2013)[19] presents a strategy to strengthen the competitiveness and growth capacity of the micro- and nano-electronics industry in Europe, which is also relevant for the manufacture of EEE components. It is explained that the industry is expected to develop in two main directions driving business transformation. On the one side the miniaturisation of components at the nano scale, following an international roadmap for technology development established by industry, is expected to progress. This is often termed the “More Moore[20]” development, aiming at higher performance, lower costs and less energy consumption. In parallel, the diversifying of the

18 EMF (2005); Trends and developments in the white goods sector in Europe A working paper of the EMF; available at: http://www.emf-fem.org/Industrial-Sectors/White-Goods/Background-documents-and-studies-on-the-white-goods-sector

19 European Commission (2013); European Commission Communication: A European Strategy for micro- and nanoelectronic components and systems, published on the 23rd of May 2013, reference: COM(2013) 298 final; available at: http://ec.europa.eu/digital-agenda/en/news/communication-european-strategy-micro-and-nanoelectronic-components-and-systems

20 This expression refers to "Moore's law", which consists of the observation that the number of transistors in a dense integrated circuit can be doubled approximately every two years.

functions of a chip by integrating micro-scale elements such as power transistors and electro-mechanical switches is also expected. This is referred to as the "more than Moore" development and forms the basis of innovations in many important fields such as energy-efficient buildings, smart cities and intelligent transport systems. In addition, totally new, disruptive technologies and architectures are being researched, often referred to as the "*beyond CMOS"*.

> *"Europe's micro- and nanoelectronics industry is concentrated around major regional production and design sites. The regions around Dresden (DE), Grenoble (FR) and Eindhoven-Leuven (NL-BE) host three main research and production centres with increased specialisation in one of the three areas of "more Moore", "more than Moore" and equipment and materials. In addition, the region of Dublin (IE) hosts a large European manufacturing site of microprocessors, and Cambridge (UK) e.g. is home to the leading company in the design of low power consumption microprocessors that equip most of today's mobile devices and tablets. Europe is relatively absent in the production of computer and consumer related components that represent a large part of the total market. It is leading though in electronics for automotive (~50% of global production), for energy applications (~40%) and industrial automation (~35%). Europe is also still strong in designing electronics for mobile tele-communications. European companies, including a large number of SMEs, are world leaders in smart microsystems like health implants and sensing technologies. Although these are currently niche markets, they are areas of high growth (typically more than 10% per year). Another key asset is the European leadership in the high growth market of low power consumption components*."(European Commission (2013, p. 4-5)).

The strategy outlined by European Commission (2013, p. 8) is to support and strengthen areas in which the EU already excels. In this regard, three specific areas are named:

- *"The development of the "More than Moore" technology track on wafer sizes of 200 mm and 300 mm. This will enable Europe to maintain and expand its leadership in a market that represents roughly €60 billion per year and has a 13% yearly growth. It will have a direct impact on high-value jobs creation including notably in SMEs.*
- *The further progression of "More Moore" technologies for ultimate miniaturisation on wafer sizes of 300 mm. The investment should enable Europe to gradually increase production in this market that represents more than €200 billion.*

The development of new manufacturing technology on 450 mm wafers. The investment will initially benefit equipment and material manufacturers in Europe who are today world leaders on a market of around €40 billion per year and will provide a clear competitive edge to the whole industry, in a five to ten years range."

Within the EU strategy to reinforce Europe's industrial and technology leadership in ICT, an atlas of a European ICT Pole of Excellence (EIPE) has been compiled (Nepelski & De Prato 2014). This study gives an overview of geographical areas in the EU with best performing activities in ICT production as well as research & development. Munich, Inner London and Paris are within the 1st tier of this ranking, whereas in the 2nd tier the following cities and regions are mentioned: Karlsruhe, Cambridgeshire CC, Stockholms lan, Darmstadt, Uusimaa, Zuidoost-Noord-Brabant, Groot-Amsterdam and Leuven.

3.3. Environmental aspects in the EEE sector

EEE are of significant relevance in terms of environmental impacts. Though the type and magnitude of impacts may vary, this sector has various relevant aspects throughout the complete product life cycle, which shall be detailed shortly in this section. Aspects relevant for the use phase, such as energy consumption and GHG emissions, have been the focus of various studies initiated by the European Commission. Further aspects are addressed through additional EU regulative framework, such as schemes developed for the labelling of products with higher environmental performance, or for promoting public procurement of such products. Additionally, various guidelines and regulations exist to promote design for dismantling and recycling as well as other practices viewed as beneficial in terms of environmental impacts. As has been mentioned above, the impact of EEE relevant at the end-of-life phase, when products turn into waste, is also integrated into EU legislation.

The following both figures show the main flows of materials and wastes in the various life cycle phases of EEE products, both from the EEE manufacturers' perspective (Figure 3-15) and the EEE recyclers' perspective (Figure 3-16). The use phase is not detailed as it is not in the scope of this study.

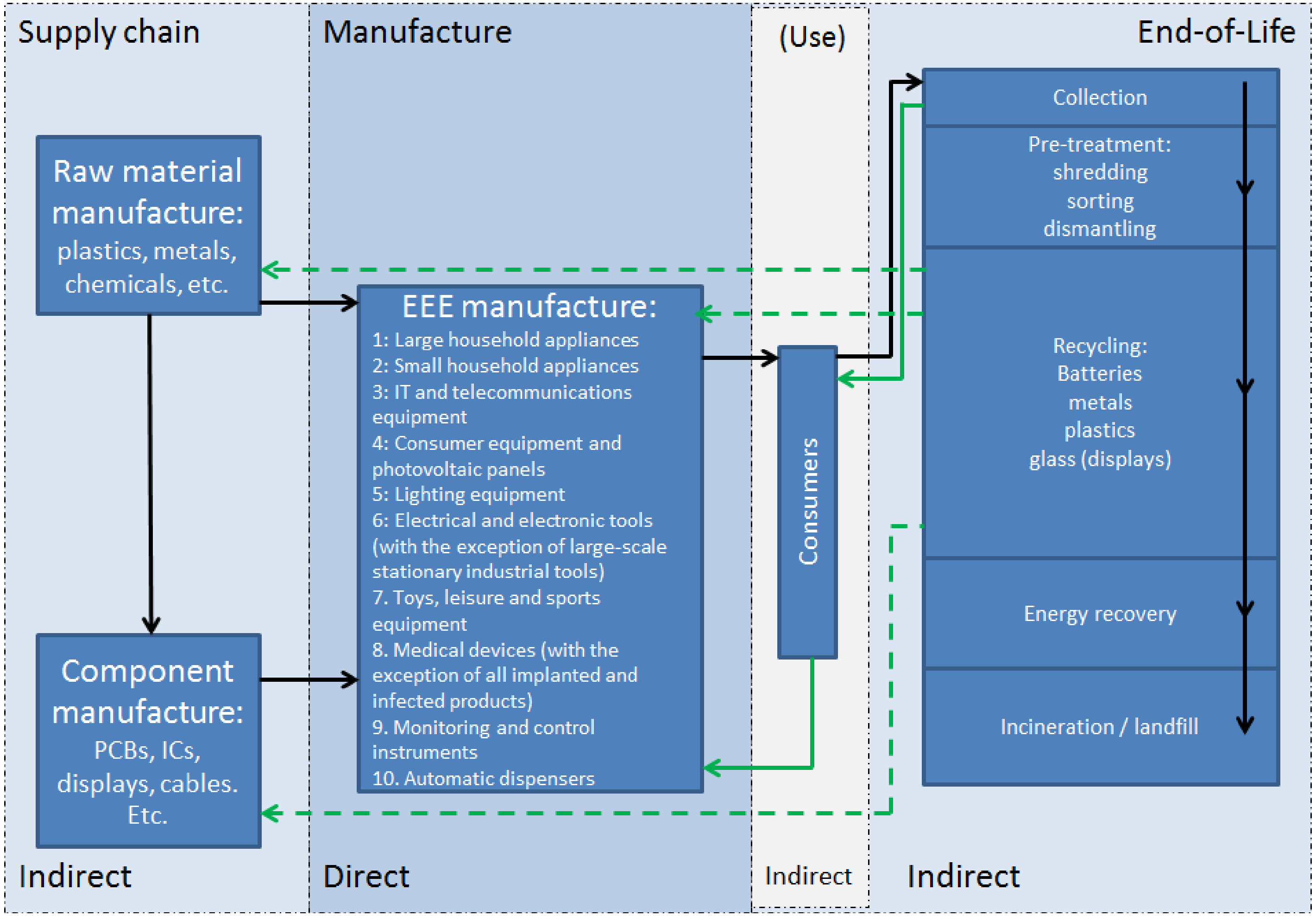
Within EEE manufacture, the **environmental aspects** (i.e. manufacturers' activities that have / can have an impact on the environment) depicted in Table 3-3 could be identified. They refer not only to direct environmental aspects[21] (e.g. component manufacturing), but also indirect environmental aspects[22] (e.g. supply chain management). The environmental pressures (i.e. potential environmental impacts) that can be associated with the different environmental aspects are also included in this overview and will be described in sections 3.3.1 to 3.3.7.

An analogous overview of relevant environmental aspects and associated environmental pressures can be found in Table 3-4 for the EEE recyclers' perspective.

[21] Direct environmental impacts refer to environmental aspects associated with activities, products and services of the EEE manufacturer itself over which it has direct management control (adapted according to EMAS (2009)).

[22] Indirect environmental impacts refer to environmental aspects which can result from the interaction of EEE manufacturer with third parties (e.g. suppliers) and which can to a reason able degree be influenced by the EEE manufacturer (adapted according to EMAS (2009)).

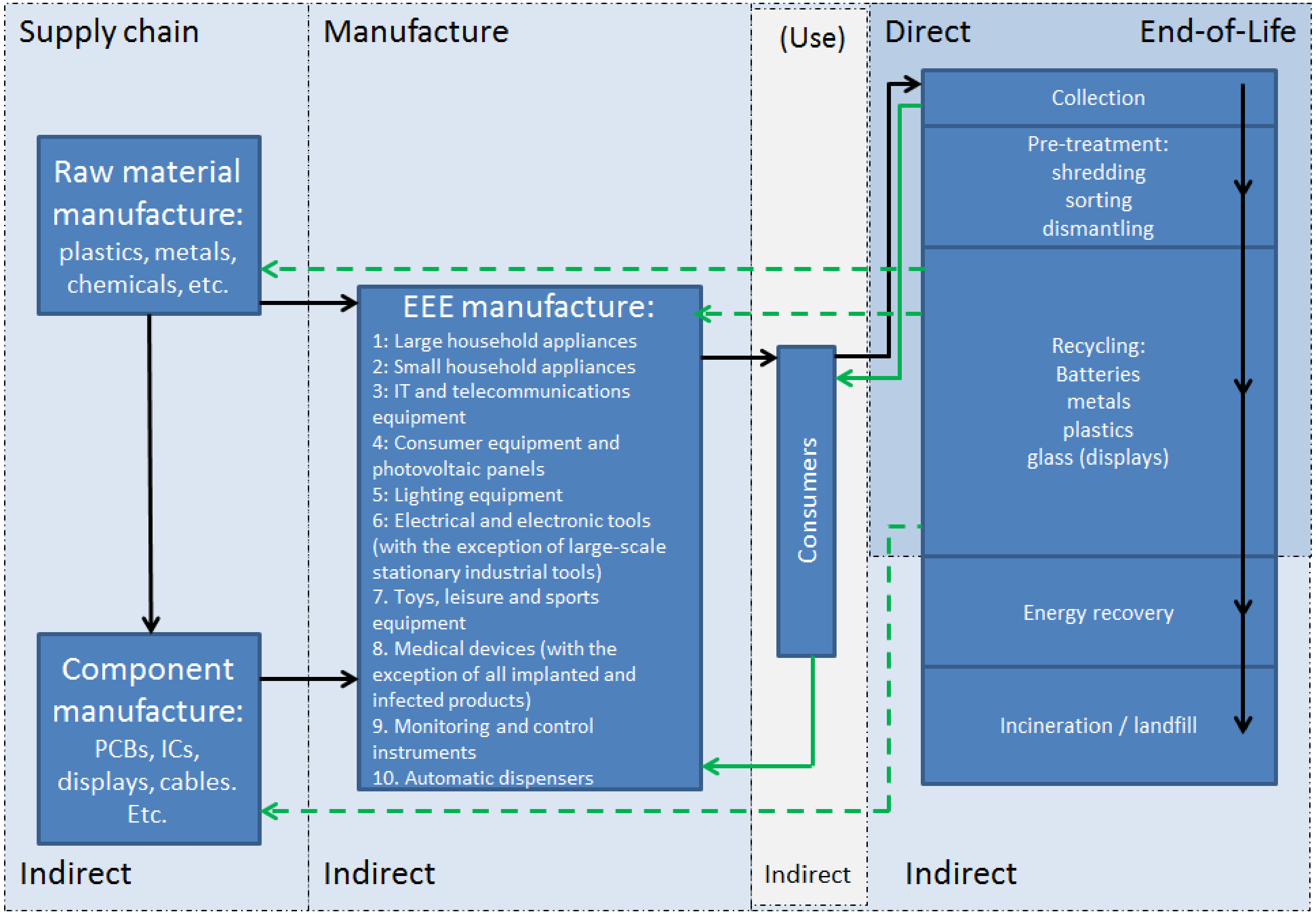
Figure 3-15: Overview of Input and Output Flows of EEE Sector Activities (EEE Manufacturers' Perspective)



Note: 'Indirect' and 'direct' are used to distinguish between input and output flows of the manufacturing sector and of other sectors up and down the EEE supply chain.

Source: Own illustration

Figure 3-16: Overview of Input and Output Flows of EEE Sector Activities (EEE Recyclers' Perspective)



Note: 'Indirect' and 'direct' are used to distinguish between input and output flows of the manufacturing sector and of other sectors up and down the EEE supply chain.

Source: Own illustration

Table 3-3: Environmental Aspects and Associated Environmental Pressures (EEE Manufacturers' Perspective)

	Environmental pressures addressed						
Environmental aspects (activities)	Resource efficiency	Water	Waste	Emissi-ons to air	Energy & climate change	Bio-diversity	Hazar-dous sub-stances
Product design (e.g. LCA, design for recycling)	X	X	X	X	X		X
Supply chain management	X				X		X
Support functions (e.g. cleanroom conditions, ecosystem)	X				X	X	X
Plant utilities (e.g. electricity, heat, cooling energy, compressed air, chemicals)	X	X	X	X	X	X	
Component manufacturing (especially, IC and PCB)	X	X	X	X	X		X
Component assembly (e.g. soldering)	X			X	X		
Final assembly					X		
Quality control			X				
Logistics, storage and transportation				X	X		X
Extended producer responsibility (e.g. IPSO, refurbishment)	X		X		X		

Source: Own table

Table 3-4: Environmental Aspects and Associated Environmental Pressures (EEE Recyclers' Perspective)

	Environmental pressures addressed						
Environmental aspects (activities)	Resource efficiency	Water	Waste	Emissi-ons to air	Energy & climate change	Bio-diversity	Hazar-dous sub-stances
Collection, transportation and storage				X	X		X
Pre-treatment (e.g. removal of batteries)	X		X				X
Shredding			X	X	X		X
Sorting (e.g. sorting of plastics)	X		X				
Dismantling (e.g. extraction of PCB)	X		X				X
Recycling of components and materials (e.g. batteries, plastics, metals, glass)	X	X	X	X	X		X
Plant utilities (e.g. electricity, heat, chemicals)	X	X	X	X	X	X	
Quality control			X				

Source: Own table

The following sections detail some of the main **environmental pressures** tied to the identified environmental aspects in the EEE sector. To clarify the key areas of impact of the EEE sector, a review of declarations of environmental performance and sustainability was performed for manufacturers understood to be key enterprises in light of environmental performance and/or market share. Companies for both the ICT and the household appliance industries were reviewed as well as manufacturers of electronic components (i.e., the semi-conductor industry). Based on the information available in public reporting and websites, the following sections have been formulated, detailing environmental pressures understood to be of importance.

3.3.1. Resource efficiency

In the manufacturing of products in general and of EEE products specifically, resource efficiency is addressed either through design of products or through planning and management of the manufacturing process and of abatement processes. Though product design is in part oriented at making a product more efficient during use or easier to disassemble and recycle at the end-of-use, it also impacts the choice of materials and the quantities used for production. In this sense, it can lead to the use of materials for which manufacturing as well as other life cycle impacts may be easier to mitigate or to prevent. A number of impacts that at present are understood to be of key concern in this regard include:

- EEE manufacture, such as the semi-conductor industry. It can be seen that the reduction of hazardous waste and waste water effluents has often resulted in solutions that recycle various substances back into the process. This will result in reduced costs for raw materials while reducing the various emissions tied with production. Some of the key targets include reducing the amount of solvents.
- Concerning polymers used in EEE appliances, a growing trend is the shift away from primary materials to recycled materials where possible, with frontrunning manufacturers quoting the share of recycled content within specific products or throughout their portfolio. A shift towards more sustainable materials or environmentally friendly materials is also observed as a key focus in R&D and design.
- Indium-tin-oxide (ITO) sputtering processes, applied in the manufacturing of thin films for displays, are quite inefficient. According to Goonan (2012) *„Only about 30 percent of an ITO sputtering target is effectively deposited as quality substrate material".*[23] Though some efforts for decreasing the demand of indium aim at increasing the efficiency of the manufacturing method, a main practice concerns the recovery of indium from the sputtering chambers used in these processes. In the past, recovery rates were around 60-65%. Though efficiencies are improving, they are still an important focus of further development efforts.

3.3.2. Water

Though it is sometimes assumed that the use of water is only a concern in countries where water resources are insufficient, in the EEE industry, the costs tied with the treatment of water and waste water motivate manufacturers to reduce consumption and increase recycling of certain streams where this is economically feasible. Particularly in the production of electronics, water is often treated before being directed to production processes, to remove substances that may interfere with specific reactions or impact the longevity of equipment. Where consumption can be reduced,

[23] Goonan, T.G. (2012); Materials flow of indium in the United States in 2008 and 2009: U.S. Geological Survey Circular 1377, p. 8; available at: http://pubs.usgs.gov/circ/1377/.

this results in savings not only in water costs but also in the costs tied with lower energy consumption and resources required for such pre-treatment. In parallel, the need to treat wastewaters before they can be discharged back to the environment or to municipal treatment plants provides a further motivation for the net consumption of water by various processes. To make waste water treatment more efficient, manufacturers often adopt practices where various waste water streams are pre-treated before being merged with other streams. This is also motivated by the possibility of filtering certain substances or solutions that can be recycled back into production or sold to external recyclers. As this results in lower quantities of discharged effluents, it also introduces cost savings in terms of discharge fees for effluents and wastewaters directed to municipal facilities. Though not always a practical solution and thus not as common, in industrial areas, further potential for reducing impacts exists where adjacent industries can cooperate in the use of certain streams. In some cases, certain wastewater or effluent streams of one factory can be used in production processes of another, reducing the amount of „wastes“ that need further treatment of the former and the costs of raw materials of the latter.

3.3.3. Waste

Once products reach the end-of-life phase, a few stages can be distinguished regarding how waste is processed:

- Collection and transport;
- Pre-treatment – shredding, sorting and dismantling;
- Recycling and recovery processes;
- Incineration and landfill.

Though all stages are relevant regarding WEEE, the focus in this report concerns the production of waste during manufacturing, as well as the recycling of waste at the end-of-life of EEE.

Concerning production, the treatment of different waste fractions incurring from the manufacture of components and products is tied with different costs. Fees for landfilling or recovery of wastes in national facilities are often devised to create an economic incentive for manufacturers to either recycle certain fractions back into production processes or to collect certain fractions that can be sent to external recyclers or other industries that can use the waste as a resource. Though this also concerns the collection and treatment of fractions common in municipal waste, such as paper, packaging, glass, etc., and construction wastes at times of site development and expansion, the main focus of waste from production is hazardous waste resulting from the various processes as well as sludge and filter dust resulting from the treatment of other emissions (water, air). Here too, manufacturers focus efforts at more efficient design of processes so that wastes are either reduced or treated to allow the recycling of materials to processes or their reuse. In some cases, the development of a product is also focused on a shift from materials tied with substantial quantities of waste or waste of a particularly hazardous type to alternatives that can reduce or eliminate such impacts.

As a further aspect of waste in the scope of this study is in which way EEE waste is treated at the end-of-use, it is also important to mention the efforts of manufacturers in the design of products that influence the collection and treatment at this stage. This includes design efforts focusing on:

- Enabling easier dismantling of product components and materials;
- Preferring the use of materials that can be recycled more easily or with fewer negative environmental impacts (energy and resource consumption / emissions);

- Shifting towards the use of fewer kinds of materials in the end-product (mainly in household appliances).

In 2009, the European Commission[24] estimated the annual amount of waste from electrical and electronic equipment (WEEE) in the EU at 8.3–9.1 million tonnes. It was further estimated that this would increase to about 12.3 million tonnes by 2020. The main motivation for the controlled management of WEEE lies in the quantities and the often hazardous nature of this waste stream, but also in its potential as a source for valuable resources. According to the European Commission report,[24] in 2009, only one third of e-waste in the Community was reported as appropriately treated. The other two thirds were sent to landfills and potentially to sub-standard treatment sites in, or outside the EU. In this regard, illegal trade of electrical and electronic waste to non-EU countries was estimated to be widespread, explaining that a significant number of illegal shipments of e-waste are notified to the Commission each year. As for the various recycling and recovery targets set out in the original WEEE Directive, these were met by only five and four Member States respectively.

A 2008 report by UNU[25] provides some data as to the collection rate of WEEE in the various EU 25 countries. It concludes that at the time, the WEEE Directive collection target could easily be met by EU15 Member States, but was a very challenging target for the new Member States.

The study also provides some data as to the collection rates relevant for various WEEE categories and sub-categories:

Table 3-5: Collection Rates for various WEEE Categories and Sub-categories

#	Treatment category	Estimated amount of WEEE collected and treated*
1A	Large Household Appliances (LHHA)	16.3%
1B	Cooling and freezing (C&F)	27.3%
1C	Large Household Appliances (smaller items) (LHHA – small)	40.0%
2,5A,8	Small Household Appliances (SHA), Lighting equipment – Luminaires and 'domestic' Medical devices	26.6%
3A	IT and Telecom excl. CRT's (IT ex. CRT)	27.8%
3B	CRT monitors (IT CRT)	35.3%
3C	LCD monitors (IT FDP)	40.5%
4A	Consumer Electronics excl. CRT's (CE ex. CRT)	40.1%
4B	CRT TV's (CE CRT)	29.9%
4C	Flat Panel TV's (CE FDP)	40.5%
5B	Lighting equipment – Lamps (Lamps)	27.9%
6	Electrical and electronic tools (Tools)	20.8%
7	Toys, leisure and sports equipment (Toys)	24.3%
8	Medical devices	49.7%
9	Monitoring and control instruments	65.2%
10	Automatic dispensers	59.4%

* (as a % of the amounts arising for the EU 27 in 2005)

Source: UNU (2008)

[24] European Commission (2009), Report on Implementation of the Community Waste Legislation, pp. 8 and 11, available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0633:FIN:EN:PDF

[25] UNU (2008); Review of Directive 2002/96 on Waste Electrical and Electronic Equipment – Study No. 07010401/2006/442493/ETU/G4, page iii; available at http://ec.europa.eu/environment/waste/weee/pdf/final_rep_unu.pdf

3.3.4. Emissions to air

Emissions to air relevant for manufacturing can be divided into a number of groups:

The first regards greenhouse gases emissions. Where these are more relevant to the production of electricity or heat for production, they shall be shortly regarded in the energy and climate change section below. This group also concerns the phase-out or reduction of ozone-depleting substances, including some refrigerants as well as Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF6) and Nitrogen trifluoride (NF3) used in the manufacturing phase of ICT components, such as LCD screens and semiconductors (Prakash et al. (2014)).[26] Reporting companies often refer to absolute emissions along with emissions normalised to production volumes.

Manufacturers are also required to treat or prevent emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) to reduce toxicity and flammability risks, as well as transportation of such elements into the environment. A main origin of VOCs, for example, are solvents in use in various processes or in the cleaning of equipment, for which recovery, reuse and reduction practices are of interest, as well as the application of less hazardous substitutes where this is relevant.

A further sub-group concerns dust from various processes or from the storage of raw materials. In the semi-conductor sector such emissions are of additional concern, as many processes are very sensitive, performed in clean-rooms and require elaborate filtration of air to ensure productivity. In this regard, filtration technologies as well as practices for avoiding entrance of particles into manufacturing areas are of particular interest.

3.3.5. Energy and climate change

Energy and climate impacts tied with the manufacturing of EEE originate either from the direct (on-site) or indirect (purchased) production of energy or from the consumption of energy associated with production and supporting processes.

The larger EEE manufacturers often have a mix in terms of sources of energy and process heating/cooling. Though some energy will usually come from the grid, especially where enterprises purchase energy from renewable sources, most of the larger manufacturers will have some type of electricity production facility on site, either to supply general demand or for times of power supply shortages. Production sites will also usually have various facilities for supplying heat and cooling demands of processes. To cut energy costs (and costs of resources needed for combustion and cooling), manufacturers may identify areas where waste heat can be used to reduce heating demand. External air flows (in winter months or in the colder countries) or water flows (when the site has its own access to groundwater to supply its consumption) may also be integrated into production and support facilities in order to reduce cooling costs with the use of heat transfer systems.

As for reducing the consumption of energy demands in manufacturing facilities, besides efforts directed at specific processes, efficient operation of equipment and machinery, such as pumps, compressed air devices, conveyors, heating and lighting, can also reduce consumption.

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[26] Prakash et al. (2014); Prakash, S.; Baron, Y.; Liu, R.; Proske, M.; Schlösser, A.; Study on the practical application of the new framework methodology for measuring the environmental impact of ICT – cost/benefit analysis (SMART 2012/0064); Oeko-Institut e.V. in cooperation with Technische Universität (TU), Berlin.

3.3.6. Biodiversity

For the manufacturing industry, it seems that the main concern with biodiversity is tied with the possible impacts that a site can have on its environment. These concerns are of more importance at the initial stages of acquiring and planning of new manufacturing facilities as well as with the extension of existing ones. They are addressed to some degree by Environmental Impact Assessments (EIA) and statements prepared for such activities. At later stages, impacts of manufacturing facilities on biodiversity are mitigated indirectly through the abatement of various emissions and thus rarely the target of specific actions of EEE manufacturers. Some manufacturers further initiate voluntary projects to enhance biodiversity in natural areas in their area; however these are usually not tied directly to manufacture.

3.3.7. Hazardous substances

An impact assessment prepared in 2008[27] concerning the 2008 RoHS recast proposal provides some insight as to the quantities of hazardous substance presence in EEE. Among others, it mentions that there are uncertainties about the quantities of the substances banned under RoHS in EEE, with manufacturers explaining that it is very difficult to know exactly the product composition, in particular when it incorporates thousands of components from a long supply chain stretching around the world. A study by Arcadis[28] is cited as a source of estimations of the savings of RoHS-regulated substances that have been enabled through the implementation of RoHS 1. The study calculated quantities of the banned substances avoided being present in EEE due to RoHS as: 130,605 tonnes of lead, 6,251 tonnes of cadmium, 760 tonnes of hexavalent chromium, 31 tonnes of mercury and 18,468 tonnes of Octa-BDE. This information provides good insight as to the potential of eliminating the use of certain substances, however, at present, the RoHS Directive restricts only 6 substances. As these substances have been the focus of substitution efforts of most EEE manufacturers since the Directive was first casted in 2002, it is assumed that in most cases, substitution or elimination practices shall already be relatively widespread or shall only concern a very narrow range of products. However, in parallel, the European Commission is considering the restriction of additional substances. Decisions are expected during 2014 concerning di-(2-ethylhexyl)phthalate (DEHP), di-n-butyl phthalate (DBP), butyl benzyl phthalate (BBP), diisobutyl phthalate (DiBP) and hexabromocyclododecane (HBCDD), whereas a further shortlist[29] of substances is under review to decide upon substances that may be assessed and discussed in the future in this regard.

In parallel, the number of substances identified under the REACH legislation as Substances of Very High Concern (SVHC) suggests additional substances that may be a focus of substitution and elimination efforts in the EEE sector. Industry has started to understand that substance restrictions targeting end-products can have significant impacts on business, and that restrictions for additional substances are likely to develop. This is part of the motivation of some companies to voluntarily look into substitution of some additional hazardous substances. Sustainability reports and other

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27 European Commission (2008); Commission Staff Working Paper accompanying the Proposal for a Directive of the European Parliament and of the Council on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Recast – Impact Assessment, pg. 60; available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2008:2930:FIN:EN:PDF

28 Cited as Arcadis study ("Study on RoHS and WEEE Directives", No30CE-0095296/00-09, March 2008), carried out for the Commission services (Directorate General Enterprise and Industry).

29 For further details, see the priority list of substances under review on the consultation website: http://rohs.exemptions.oeko.info/index.php?id=213

documentation of some manufacturers suggest that the following substances are in the focus of such efforts in the EEE industry:

- The use of brominated flame retardants, especially in laminates for PCBs;
- The use of PVC in various components and especially in cables;
- The use of tetrabromobisphenol A in plastic enclosures;
- The use of arsenic in display glass.

3.4. Implementation of environmental management systems

3.4.1. EU Eco-Management and Audit Scheme (EMAS)

The EU Eco-Management and Audit Scheme (EMAS) is a management instrument developed by the EU for companies and other organisations to evaluate, report, and improve their environmental performance. EMAS is open to every type of organisation committed to these goals. It spans all economic and service sectors and is applicable worldwide. Currently, more than 4,500 organisations and approximately 8,150 sites are EMAS-registered worldwide, including many multinational enterprises and smaller companies as well as public authorities.[30]

It needs to be mentioned in this context that this study as well as the Sectoral Reference Document (SRD) to be developed by the European Commission on the basis of this study are carried out under the EMAS regulation.

According to the EMAS registration data base,[31] in February 2014, 134 companies were registered under the NACE codes relevant for the EEE (NACE codes 26 through 28).[32] In this regard it is worth mentioning the following activity groups (NACE codes) for which larger numbers of enterprises are EMAS-registered:

- 26.11 Manufacture of electronic components (21 enterprises);
- 28.95 Manufacture of machinery for paper and paperboard production; 28.99 Manufacture of other special-purpose machinery n.e.c. (20 enterprises);
- 28.96 Manufacture of plastics and rubber machinery (19 enterprises);
- 28.29 Manufacture of other general-purpose machinery n.e.c; 28.91 Manufacture of machinery for metallurgy; 28.93 Manufacture of machinery for food, beverage and tobacco processing (17 enterprises);
- 26.51 Manufacture of instruments and appliances for measuring, testing and navigation; 28.11 Manufacture of engines and turbines, except aircraft, vehicle and cycle engines; 28.12 Manufacture of fluid power equipment; 28.25 Manufacture of non-domestic cooling and ventilation equipment; 28.92 Manufacture of machinery for mining, quarrying and construction; Manufacture of machinery for textile, apparel and leather production (16 enterprises);
- 28.13 Manufacture of other pumps and compressors (15 enterprises);

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[30] See EU EMAS website: http://ec.europa.eu/environment/emas/index_en.htm

[31] See EMAS Register: http://ec.europa.eu/environment/emas/register/

[32] Compiled from data collected from the EU EMAS registry; available at: http://ec.europa.eu/environment/emas/register/search/search.do, March 2014

- 27.12 Manufacture of electricity distribution and control apparatus; 28.14 Manufacture of other taps and valves; 28.15 Manufacture of bearings, gears, gearing and driving elements (14 enterprises).

Additionally, it should be clarified that many companies are registered for more than one activity.

According to the EMAS registration data base, in February 2014, 179 companies were registered under the industrial sector "treatment and disposal of hazardous wastes" (NACE code 38.22), understood to include operations of relevance for the treatment of EEE waste.

3.4.2. ISO 14000 family of standards

The **ISO 14000** family addresses various aspects of environmental management. It provides practical tools for companies and organisations looking to identify and control their environmental impact and constantly improve their environmental performance. ISO 14001:2004 and ISO 14004:2004 focus on environmental management systems. The other standards in the family focus on specific environmental aspects such as life cycle analysis, communication and auditing.[33]

Though many companies have declarations on their websites as well as in public environmental reports as to the various standards that they apply (including ISO standards), there is no public registry of companies certified with ISO 14001. Therefore, it could not be clarified how common this practice effectively is.

Though it is difficult to conclude as to how common environmental management is in practice, reports of the larger firms show that many of these recognize the importance of applying such schemes, declaring how wide ISO certification is in their facilities and often publishing certification under environmental sections of websites. From the companies reviewed, some reported on having at least one of the above mentioned environmental management schemes in place, some having both.

3.5. Chapter references

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[33] See http://www.iso.org/iso/iso14000

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4. Manufacturing of EEE

4.1. Scope

As mentioned in section 2.1.1, an EEE product may consist of hundreds, even thousands of various components. The same is considered to be applicable for the portfolio of EEE manufacturing processes and techniques that will be addressed in this section.

In order to provide meaningful recommendations concerning best environmental management practice in this field, a selection of the most relevant processes / techniques and corresponding approaches is deemed to be necessary. In order to identify the most relevant issues, the three filters described in section 2.1 were set for this purpose. When taking these considerations into account, the following fundamental conclusions can be drawn:

- Firstly, the application of the **component filter** implies a clear focus on all manufacturing processes that are relevant within the context of IC and PCB manufacturing; however, the scope needs to cover also relevant processes in the EEE sector beyond the production of these components, whereas especially peripheral processes are considered to be relevant.
- Secondly, the **geographical filter** requires a clear focus on manufacturing processes that take place in EU-28. Due to the enormous cost pressure that arises from the competition especially with companies in Asia, economic feasibility of the proposed best environmental management practice is regarded to be a vital aspect for the framework of this report.
- Finally, when considering the **environmental filter,** it has to be ensured that the scope of the best management practices sufficiently addresses all relevant environmental aspects that are associated with EEE production (see section 3.3 for more details). Within this context, an extensive review of existing environmental reports and declarations of EEE companies ensures that the most relevant aspects of the current debate in terms of continuous improvement potential and corresponding measures will be adequately addressed.

Against the background of these basic findings, ten issues with high priority were identified for the process / technique portfolio that makes up the scope of this background report. In the following abstracts, the selection will be briefly justified.

The first element covers **energy-efficient cleanroom technology**, since cleanrooms constitute the most important energy consuming system within a typical semiconductor production site, causing almost as much electricity consumption as the complete manufacturing equipment.[34] Besides the traditionally high relevance during production of integrated circuit, cleanrooms also becomes more and more important in the production process of advanced printed circuit boards with ultrafine structures as well as of electrical components and accessories. Their increasing use thus makes them a high-priority object of coverage within a continuous improvement process in the EEE sector, in particular since energy savings potentials of 50% can be achieved.

Similarly important is the supply of the manufacturing processes with **compressed air** and **cooling energy** representing two other peripheral processes that are used throughout the EEE sector. Their production is considered to be the least efficient and thus most expensive of all energy carriers, making them the most sumptuous and thus polluting form of energy in the manufacturing process of EEE. For example, compressed air needs approx. ten times of the provided final energy

[34] Cf. http://seshaonline.org/proceedings00/naughtonphilip.pdf

during its production, accounting for 10% of total electricity consumption of EEE production sites; savings in the range of 50% are possible. While demand for compressed air is rather stagnant, **cooling systems** are becoming increasingly important in the EEE sector. The most common application is the removal of process heat that accumulates in the production processes, but also in the production halls. In particular, the continuing trend towards increasingly fine structures, both in the production of integrated circuits and of printed circuit boards increases the demand for this technology.

When looking at the core manufacturing processes of EEE, **soldering** needs to be considered. This process causes 70% of the energy demand within the production process of surface-mounted devices, and can also cause emissions to air. Best practice soldering systems are characterized by at least 20% lower electricity consumption; besides investment in new lines which involves relatively high investment cost, however, also interesting retrofit solutions and simple measures are possible.

When moving the focus to emissions to air and hazardous substances, gaseous emissions containing **perflourocompounds** (PFC) need to be in scope: On the one hand, because, besides energy use, they are the most relevant contribution to a semiconductor´s fab global warming potential beyond energy use; on the other hand, because a best practice abatement technology for emission reductions of more than 90% already exists. Regardless of this aspect, PCF emissions control is a valuable element of the scope of this report, since it can be considered as a good example how best practice can be initiated and pushed forward by effective voluntary agreements. Regarding **VOC-based solvents**, representing the most relevant airborne pollutant of EEE manufacturing besides greenhouse gas emissions, harmful toxicological impacts on human health as well as on the environment and their minimization are in the focus of attention. However, when solvents are recovered and recycled back into the process, also environmental benefits concerning resource and waste aspects can be created.

Best environmental management practice in the EEE sector certainly also has to address water use and **water savings**, since the management and protection of water resources is another cornerstone of environmental protection. Concerning its specific relevance in the EEE sector it has to be reminded that especially during the manufacture of printed circuit boards, wet processes play an important role. Against the background of the substantial water demand in this sub-sector, elaborated cascade rinsing systems have been developed that enable water savings of more than 80%. Closely connected to the measurements of enhanced efficiency in terms of water use is **on-site recycling of metals in process chemicals**, since this approach also addresses wet processes of PCB manufacturing. This clearly needs to be considered in an integrated approach covering all relevant environmental pressures of EEE manufacturing, because it addresses a major lever regarding resource efficiency, especially when considering the environmental impacts, economic relevance as well as social issues that are associated with the use of metal resources.

Against the background of the rising relevance of biodiversity within the general environmental debate, approaches to **protect and enhance biodiversity** adjacent to EEE production sites are deemed to be another important part of the scope. While EEE manufacturing sites usually impact biodiversity, in particular through land use and soil sealing, they can also benefit from the well-being of natural environments through the services provided by the latter. For example, in built areas with higher densities, vegetation has been shown to regulate extreme temperatures by 2-3°C, often allowing savings in terms of cooling energy, but also contributing to the well-being of the site's employees. This aspect is regarded to be an excellent example of the systemic approach that characterizes the scope of this background report. Within this context, also the **use of renewable energy**, both in terms of electricity and heat energy will be covered. Even though it

plays only a minor role in today's energy supply, the potentials are substantial and need to be developed in order to make EEE manufacture more sustainable.

The following table summarizes the developed best environmental management practices for EEE manufacturing and provides an overview of the addressed environmental pressures.

Table 4-1: Overview of the Developed BEMPs for EEE Manufacturing and the Addressed Environmental Pressures

No.	Title of BEMPs	Environmental pressures addressed						
		Resource efficiency	Water	Waste	Emis-sions to air	Energy & climate change	Bio-diversity	Hazar-dous sub-stances
	MANUFACTURING							
1	Energy-efficient cleanroom technology	X				X		
2	Efficient supply and substitution of compressed air	X				X		
3	Energy-efficient cooling technology	X				X		
4	Energy-efficient soldering	X			X	X		
5	Minimising the use of PFC				X	X		X
6	Substitution / reuse of VOC-based solvents	X		X	X			X
7	Water savings and recovery in cascade rinsing systems		X	X				
8	On-site recycling of metals in process chemicals	X	X	X				
9	Protecting and enhancing biodiversity						X	
10	Use of renewable energy in EEE manufacturing	X				X		

Source: Own table

4.2. Description of best environmental management practice

4.2.1. Energy-efficient cleanroom technology

4.2.1.1. Description

The purpose of a cleanroom is to ensure a controlled low level of pollutants, such as dust, airborne microbes, aerosol particles and chemical vapours (Rumsey 2010).

Cleanrooms are classified according to their cleanliness level, i.e. the number of particles per unit of air volume. In order to define the different cleanliness levels, two standards are used: the “US cleanroom class” as well as the “ISO standard” (ISO 14644-1). The following table gives an overview of the correlation of these two cleanroom classifications which are used the most frequently:

Table 4-2: Cleanroom classifications

US cleanroom class	ISO standard
Class 1	ISO 3
Class 10	ISO 4
Class 100	ISO 5
Class 1,000	ISO 6
Class 10,000	ISO 7
Class 100,000	ISO 8

Source: Own table according to data from Rumsey (2010)

A “class 1” / “ISO 3” cleanroom is defined as a contamination by only one particle larger than 0.5 micrometre per cubic foot[35] of air, whereas a “class 2” / “ISO 4” cleanroom will contain 10 particles per cubic foot of air, and so on (Rumsey 2010).

Within the EEE sector, ultra-clean production conditions are considered to be essential for the quality of many electronic components and devices. This is especially applicable in the field of manufacturing of integrated circuits (IC), but also becomes more and more relevant in the production process of advanced printed circuit boards (PCB) with ultrafine structures as well as electrical components and accessories.

Cleanroom facilities encompass heating, ventilation and air conditioning (HVAC) systems, these processes accounting for 36–67% of the total facility energy (Tschudi & Xu 2001). Since cleanrooms are cooling dominated[36], the air conditioning systems represent another main driver for cleanroom energy consumption (Lowell et al. 1999).

Although the HVAC units are decisive for energy consumption, it should be noted that energy intensity also heavily depends on the system design, the cleanliness level to be achieved, specific

[35] 1 cubic foot equals 28.3 litres.

[36] In contrast to cooling, only little or no heating is required, e.g. preheat of supply air after dehumidification.

cleanroom functions (e.g. airflow type), and critical parameters such as temperature, humidity, etc. (Xu n.y.).

Against this background, significant energy savings potential exists in many cleanroom facilities, especially fan motors and air conditioning as the most important single consumers of electricity bear a significant optimization potential. Moreover, the design of cleanroom facilities can contribute to energy savings and reduced life cycle costs. Hence, a strategic approach for best environmental management practice in the field of cleanroom technology should consider both technology-related and design-oriented measures and encompass the following elements:

1. Optimized sizing of cleanrooms;
2. Reducing heat load;
3. Use of high efficiency components (e.g. through premium-efficiency fan motors, variable-frequency drives for chillers and upsize passive components).

When improving the systems design of cleanrooms, the actual particle generation in the real operation of the cleanroom should be investigated in order to determine the lowest possible air change rate. The air change rate (ACR) is a metric for maintaining cleanliness or particle count, and is a vital determinant for the cleanroom's recirculation air-handling-system fan and the corresponding size of the motor. ACR of far lower than recommended practice have proven to be feasible without affecting the cleanliness of production. Another important approach is to reduce the pressure difference between the cleanroom and its surroundings, since this also helps to adapt the air volume to the demand and thus to significantly reduce the electricity consumption of cleanroom fans. In terms of optimized system design, the so-called “low face velocity design” is another relevant approach. Face velocity is the speed at which air passes over the filters or heating / cooling coils in an air handler unit. A lower face velocity can be achieved when using larger air handlers but smaller fans that allow air circulation to be maintained at lower velocity. Moreover, energy savings in the context of optimized systems can also be achieved by taking into account the option of selective cleanroom environment. This means a local protection / encapsulation of equipment or plants where a higher cleanliness class is maintained in a limited area and as required by a process.

Besides optimized sizing of cleanrooms, it is considered to be important to pay attention to cases where the removal of heat load results in an increased ACR and thus to additional electricity consumption at the level of the ventilator and HVAC. In particular, the heat load from processes consuming electricity has a major influence on the design and operation of the cooling system. Most electricity used by these processes converts directly into heat load for removal by the HVAC unit. Thus, the reduction of heat load, e.g. through heat recovery and minimising the number of personnel in the cleanroom environment, is considered to be another important measure in terms of energy-efficient cleanroom technology.

Finally, the use of high efficiency components is regarded as another key measure in order to improve cleanroom energy-efficiency. Especially premium-efficiency fan motors, variable-frequency drives for chillers and upsizing passive components are important components to be addressed within this context.

It has to be noted that the elements mentioned above can be applied separately. However, best results will be achieved through an integrated approach implementing all or most of these measures.

4.2.1.2. Environmental benefits

As has been described above, the operation of cleanroom is a very energy intensive process and causes substantial consumption of electricity.

It is estimated that an electricity consumption reduction potential of 50% can be achieved, primarily through improved integrated design, commissioning, and operations (Lowell et al. 1999). Since the consumption of electricity is a main driver for global warming, also the correspondent CO_2 emissions can be cut by half, if the measures described in section 4.2.1.5 are implemented.

As the most important approach, the reduction of air change rate[37] is mentioned. For example, a 50% reduction in air change rate can reduce power consumption by up to 88%. However, this figure is indicative, since the energy consumption is heavily dependent on other determinants, such as outdoor air temperature, compensation of local exhausts, pressure difference and heat loads (Cleanroomtechnology 2014).

4.2.1.3. Appropriate environmental performance indicators

The environmental performance of a cleanroom used in the EEE sector should be based on its overall energy productivity. Since there is a concrete output measure for the most important fields of application – semiconductor / IC facilities as well as PCB facilities – the environmental performance indicator should be defined as kilowatt hours of electricity needed per surface unit of output (Mathew et al. 2010; Tschudi & Xu 2001):

- In the case of semiconductor / IC facilities, the output is usually specified in square centimetres of processed silicon wafers. Thus, the environmental performance indicator should be defined as kWh/cm²
- Regarding PCB, however, the output is measured predominantly in square meters, resulting in an environmental performance indicator defined as kWh/m²

Another useful metric is the air change rate, which can serve as a first step in order to identify efficiency potentials. The air change rate is a measure of how many times the air within a defined cleanroom space needs to be replaced in order to meet the cleanliness requirements. Usually, this metric is indicated as a number per hour.

4.2.1.4. Cross-media effects

Cross-media effects are considered to be irrelevant for most of the approaches mentioned in section 4.2.1.1. Even in cases where additional equipment is needed for the implementation of a measure (e.g. plate heat exchanger in the case of waste heat recovery) the environmental impacts caused by the additional equipment will be more than offset by the substantial savings of electricity enabled by the respective equipment.

One exception could be the installation of energy-efficient fan motors. Here, it has to be taken into account that electric motors that enable the highest possible degree of efficiency usually require the use of critical metals in their magnets, especially neodymium. Neodymium is regarded as “critical raw material” in the EU, which means that it is considered to have a high economic importance to the EU combined with a high risk associated with its supply (EU 2014). Furthermore,

[37] For more details concerning the definition of the air change rate and corresponding optimization potentials, see sections 4.2.1.3 and 4.2.1.5, respectively.

the extraction of rare earths such as neodymium is characterized by imposing a heavy burden on the local environment and by high technical complexity. Especially, large amounts of toxic or radioactive chemicals (thorium, uranium, heavy metals, acids, etc.) are required or released during production when insufficient security measures to the purification process were taken (Schüler et al. 2011).

4.2.1.5. Operational data

According to the different approaches mentioned in section 4.2.1.1, the corresponding details for implementation and operational data are given below.

Optimized sizing of cleanrooms

Due to normative documents (such as ISO 14644) and their poor interpretation, over-specification and over-design of cleanroom facilities is still quite common. It has to be noted that the normative documents cover mostly general aspects and do not address the specific features of cleanrooms in a sufficient manner. Guidance in terms of optimization of energy consumptions exists in form of British Standard BS 8568:2013 and German Standard VDI 2082, however, the underlying determinants and mechanisms of cleanroom energy consumption are not sufficiently covered (Cleanroomtechnology 2014).

In terms of determining the lowest possible air-change rate it has to be noted that current recommendations concerning ACR are not based on scientific findings. For example, for ISO Class 5 (US cleanroom class 100) cleanrooms, air change rates of 250 to 700 air changes per hour are recommended. According to benchmarking studies, however, most facilities operate effectively at or below the low end of this range (Mathew et al. 2010; Rumsey et al. 2004; Tschudi & Rumsey n.y.). Reducing the air change rate can yield substantial energy savings (see section 4.2.1.2). Concerning pressure difference, due to safety reasons, ISO 14644 recommends pressure differences (between a cleanroom and its surroundings) in the range between 5 to 20 Pascal. The air quantities required for this, however, account for a substantial proportion of the energy consumption. As fans have been identified as the most important electricity consumer within cleanrooms, measures to adapt the air volume to the demand open up the greatest energy saving potential. Hence, the air pressure should be brought down as close as possible to the minimum requirements of the standard and finely regulated.

Moreover, narrow operating ranges for space temperature and relative humidity should also be avoided, because they can lead to an additional energy consumption to cool, preheat and humidify the supply airflow. Therefore, it should be checked whether the processes within the cleanroom actually require these narrow operation ranges or whether it makes sense to allow wider operating ranges that are able to contribute to a reduction of energy use (Cleanroomtechnology 2014, Mathew et al. 2010).

Regarding “low face velocity design” larger air handlers in the combination with smaller fans decrease the pressure drop of the air handler units, which allows the installation of smaller fans and motors and thus ultimately leads to energy savings. For example, 20% lower face velocity results in 36% reduction of pressure drop. Optimal face velocities should be in the range of 1.3 – 2.3 m/s, instead of 2.5 m/s which used to be the traditional design rule of thumb (Cleanroom-technology 2014; Rumsey 2010).

Reducing heat load

Within the context of optimizing the heat load of cleanrooms, the heat load during normal operation needs to be assessed at first. Especially, over-estimation of heat load (e.g. using figures for the heat load during start-up of equipment component as the basis for systems design) should be avoided.

Based on these fundamental considerations, the removal of excess heat load from process equipment by local in-built means (e.g. heat exchanger, preheat coils, separate high temperature chillers for process cooling) needs to be taken into account. Recovered heat can be used for outside air preheat, supply air preheat, and other purposes. Preheat coils can be used in order to recuperate waste heat from air compressors or chiller condenser return water, which can contribute to reducing both chiller energy and boiler fuel (Rumsey et al. 2004).

Further information concerning the energy-efficient supply of cooling energy is provided within section 4.2.2).

Reducing the heat load of cleanrooms also implies minimising the number of personnel present inside cleanrooms, because people also cause a considerable heat load (besides their contribution to particle contamination). Minimization of personnel inside cleanrooms can be achieved through automation technology, such as closed systems, physical barriers between workers and production areas (Restricted Access Barrier System – RABS) as well as by means of isolator technology.

Use of high efficiency components

Since the continuous duty fan motors consume most of the cleanroom facility energy, special attention needs to be given to increasing the efficiency of these system components. Against this background, premium-efficiency fan motors should be installed, which is especially interesting for retrofits (see also economic perspective in section 4.2.1.7).

Utilizing variable-frequency drives (VFD) can be an interesting option in this respect in order to realise operational savings from oversized fans, but is also worth considering with respect to pumps, cooling towers, and some types of chillers. When turning down the drive speed, not only energy can be saved; this measure also contributes to expanding the lifetime of the equipment and will lower the noise level.

Another relevant aspect within this context can be the approach to upsize passive components (such as filters, ducts and pipes), which allow the use of smaller fans and pumps.

4.2.1.6. Applicability

Basically, the approaches for improving the energy efficiency of cleanroom facilities can be applied by all companies that operate or are planning to invest in such a system. They are feasible for cleanroom space to be rebuilt, but are also suitable for retrofits.

However, it has to be noted that downsizing the ACR might require efforts regarding insuring and adjusting the quality requirements of the cleanroom. As already mentioned in section 4.2.1.1, the cleanliness level is not necessarily affected in a negative way by a reduced ACR. The reason for this can be seen in the fact that turning down the fan speed (as a prerequisite for a lower ACR) may actually improve cleanliness through less turbulence in the room (Tschudi & Rumsey n.y.).

4.2.1.7. Economics

A review of studies on cleanroom costs has shown that electricity costs account for 65-75% of the total costs associated with cleanroom operation and maintenance in Europe (Whyte 1999). Thus, since energy clearly exceeds the operating cost incurred for cleanroom facilities the improvement of energy efficiency can contribute to significant cost savings.

Concerning the installation of premium-efficiency fan motors, it has to be taken into account that these components consume their capital equipment cost value in electricity roughly every month. Hence, efficiency improvements make most retro-fit solutions cost-effective. Chillers with variable speed drives are characterized by payback times of about one year[38] (Rumsey et al. 2004).

4.2.1.8. Driving force for implementation

Due to the very high costs for the operation of cleanrooms and the substantial cost saving potentials at the various levels of cleanroom facilities, costs are considered to be the most important driver for the implementation of the best management practices and techniques described in section 4.2.1.5.

Another important aspect for successful approaches in order to increase energy efficiency are standards available at the national level (especially BS 8568:2013 in the UK and VDI 2083 in Germany), which generally increase the attention for the implementation of energy saving measures and provide valuable information for this purpose.

4.2.1.9. Reference organisations

- Globalfoundries: Launched in March 2009, Globalfoundries is the world's first full-service semiconductor foundry with a global footprint. With operations in Singapore, Germany and the United States, Globalfoundries is represented in three continents. Globalfoundries is owned by Mubadala Technology. Globalfoundries operates Europe's largest production site for 300mm wafers in Dresden (Germany). Globalfoundries has constructed 110,000 square feet of new cleanroom space (Hermanns 2012).

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38 Based on chiller manufacturing data and 0.05$/kWh consumed electricity. Due to the generally higher energy prices in Europe even shorter payback periods can be expected for most European countries.

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4.2.2. Efficient supply and substitution of compressed air

4.2.2.1. Description

Compressed air is a very versatile operation media and thus widely used in EEE manufacturing. The advantages of compressed air applications lie in the safety of this energy source, the speed and precision as well as the low weight of air tools. For example, it is an effective way to clean EEE components without damaging them, as no liquids are used which could cause harm to the components or leave behind a residue. Compressed air can also be used to clean machinery involved in the manufacturing process, such as the air knives that are used to produce LCD panels. Furthermore, compressed air technology is often used to power manufacturing equipment, e.g. assembly tools, such as air driven machinery that is used to hold, position, and assemble EEE components (LCD panels, printed circuit boards, memory chips, etc.).

Although compressed air technology is highly useful for manufacture, and nearly all companies make use of it, it is the least efficient and the most expensive energy carrier. Since compressed air is usually supplied by electrical compressors and has to be distributed by distribution networks that are vulnerable to leaks, at least ten times of the final energy stored within compressed air is consumed during its production (Diemer & Feihl 2011).

Against this background, a strategic approach for best environmental management practice in the field of compressed air systems should consider the following elements:

1. Assess the potential to reduce the use of compressed air through substitution of compressed air tools by electrically driven devices;
2. Identify and eliminate leaks using appropriate control technology;
3. Increase the overall energy efficiency of the compressed air system;
4. Increase the specific energy efficiency of major compressed air system components;
5. Install waste heat recovery.

Before dealing with the issue of rational use of compressed air, the fundamental question should be answered whether it is feasible to do without this expensive energy carrier as far as possible. Substitution of compressed air can be achieved especially at the level of tools (like drillers and screwdrivers) that are still driven by compressed air, but could also be replaced by electrically driven tools.

The single most important as well as the easiest measure in terms of rational use of compressed air is the identification and elimination of air leaks. It can be shown that air leaks with even very small diameters (e.g. 1 mm) can cause substantial losses in terms of both energy and costs. Their detection is possible by simple methods of sensory perception in many cases, but also air leaks that are hidden or difficult to access can be easily located with ultrasound measuring instruments.

In terms of increasing the overall energy efficiency of the compressed air system, it has to be taken into account that the specific electricity consumption of the system is directly correlated with its pressure level. For example, if the pressure level can be lowered by 1 bar, the energy demand will decrease by about 6% to 10%. Furthermore, possible losses through air leakages are also proportional to the pressure level (Dena 2012; Diemer & Feihl 2011). Hence, optimization of the system design is very important prior to the installation of technical solutions.

Concerning the installation of energy-efficient components for an optimized compressed air system, especially compressors should be taken into account, since they represent the system´s most important as well as most energy-consuming component. In the selection of compressors, attention should be paid to the highest possible efficiency. One of the key factors in this respect is the installation of drives with variable speed. Besides compressors, also dryers that are necessary for compressed air systems in order to avoid corrosion can be enhanced in terms of energy efficiency. In this respect, dryers with integrated cold storage are an interesting option.

Finally, the recovery of waste heat from the compressor(s) is considered to be a powerful measure in order increase the overall energy efficiency of a compressed air system. When installing appropriate facilities (like plate heat exchanger), large amounts of previously unused heat energy can me made accessible for the EEE manufacturing process.

It has to be noted that the elements mentioned above can be applied separately. However, best results will be achieved through an integrated approach implementing all or most of these measures.

4.2.2.2. Environmental benefits

As mentioned above, the supply of compressed air requires a specifically high amount of electric energy. As a result, it is estimated that up to 10 % of total electricity consumption of EEE production sites has to be allocated to compressed air production (Radgen & Blaustein 2001).

When implementing the measures mentioned in section 4.2.2.1, especially concerning heat recovery, savings in the range of 50% are possible (Radgen & Blaustein 2001), other assessments showing savings potentials of up to 66% (VDMA 2005).

Also the correspondent CO_2 emissions can be cut by half. For example, a compressed air system with best available management practice can save approx. 0.05 kg CO_2e per cubic meter of compressed air.[39]

Finally, more than 90% savings can be achieved in case compressed air operated tools can be substituted by motor-driven tools (Niermeier 2013b). However, important circumstances for the realisation of these savings potentials are the costs that are associated with the investment of the motor-driven tools as well as the corresponding payback times (see section 4.2.2.7 for more details).

4.2.2.3. Appropriate environmental performance indicators

The measurement of the environmental performance of a compressed air system should be based on the Energy Performance Indicator according to ISO 50001[40].

When calculating this indicator, the following aspects need to be taken into account:

- The indicator should refer to the entire compressed air system, meaning that not only the compressors and dryers are evaluated, but also the secondary drives such as fan motors and

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[39] Own calculations based on data of EcoInvent (2014) for a compressed air system operating with a capacity above 30 kW and at 6 bar gauge.

[40] ISO 50001 requires that in the procurement of compressed air systems, energy efficiency is taken into account. Any additional requirements specific to compressed air systems do not exist.

pumps for the operation of heat recovery. It is therefore not enough to assess the key figures of the manufacturer and test values;

- The unit of Energy Performance Indicator is defined as kilowatt hours of electricity needed per cubic meter of compressed air (kWh/m³);
- The calculated values should refer to standard cubic meters (calculated on the basis of standard conditions: at a pressure of 1.01325 bars and at a temperature of 20°C);
- As reference value for the calculated values, the pressure level of the compressed air system has to be indicated.

Besides the Energy Performance Indicator for the compressed air system, also the energy demand of important individual components of the compressed air system (especially compressor and dryers) can be taken into account for decisions at the component level. Within this context, besides taking into account the performance at full load, special consideration should be given to the energy efficiency at partial load (e.g. 33%, 50%, 75%).

4.2.2.4. Cross-media effects

Cross-media effects are considered to be not relevant for most of the approaches mentioned in section 4.2.2.1. Even in cases where additional equipment is needed for the implementation of the measure (e.g. plate heat exchanger in the case of waste heat recovery), the environmental impacts caused by the additional equipment will be more than offset by the substantial savings of electricity enabled by the respective equipment.

One exception could be the installation of energy-efficient compressors. Here it has to be taken into account that electric motors that enable highest possible efficiency usually require the use of critical metals in their magnets, especially neodymium. As described in section 4.2.1.4, Neodymium is regarded as “critical raw material” in the EU; furthermore, its extraction is associated with heavy burden on the local environment (EU 2014; Schüler et al. 2011).

4.2.2.5. Operational data

According to the different approaches mentioned in section 4.2.2.1, the corresponding details for implementation and operational data are given.

Assess the potential to reduce the use of compressed air through substitution of compressed air tools by electrically driven devices

In general, compressed air should only be used in application fields where the corresponding equipment has clear advantages when powered by compressed air instead of electricity. Relevant examples for such reasonable uses are e.g.:

- Control air, for example for valve control;
- Positioning of materials;
- Packaging machines (control & drive)
- Material handling and blending.

However, for other devices such as screwdrivers or drillers it should be carefully checked, whether the respective functionality can be provided with electrical tools at a much higher efficiency. For screwdrivers and random orbit sanders, for example, it can be shown that electrical tools require about 95% less energy than the respective compressed air devices (Niermeier 2013b).

Identify and eliminate leaks using appropriate control technology

As shown in the following table, the losses in terms of both energy and costs increase exponentially with the diameter of the leakages. For example, a 10 mm air leak in a network operating at 6 bars causes energy losses of more than 30 kW (or more than 18,000 EUR). However, also relatively small leakages of only 1 mm in diameter should not be neglected.

Table 4-3: Energy losses and costs caused by air leaks

Diameter of air leak (mm)	Air losses (l/s)		Energy losses (kW)		Costs(€/a)	
	6 bars	12 bars	6 bars	12 bars	6 bars	12 bars
1	1.2	1.8	0.3	1.0	168	580
3	11.1	20.8	3.1	12.7	1,763	7,112
5	30.9	58.5	8.3	33.7	4,648	18,872
10	123.8	235.5	33.0	132.0	18,480	73,920

Source: Own table according to data from Dena 2012

Many leaks can be located even by simple methods of sensory perception. For example, when machines are not operating, a hiss can be noticed at the place where compressed air is escaping. Leakages at valve terminals can be identified by moving the hand across the valves (Niermeier 2013a).

In order to detect the network leaks in inaccessible areas and within production equipment, an ultrasonic testing device is recommended. This measurement device detects the ultrasonic noise that is caused by the mechanical friction of the escaping gas. This test method has the advantage that it can be used even during operation. Special sensors make it easier to reach the faulty components. With a flexible rod microphone localised hose connections and valves can be reached in running systems. A parabolic microphone is also available for testing of pipes in the ceiling area (Niermeier 2013a).

Figure 4-1: Ultrasonic testing device with rod and parabolic microphone

Source: Miele

Increase the overall energy efficiency of the compressed air system

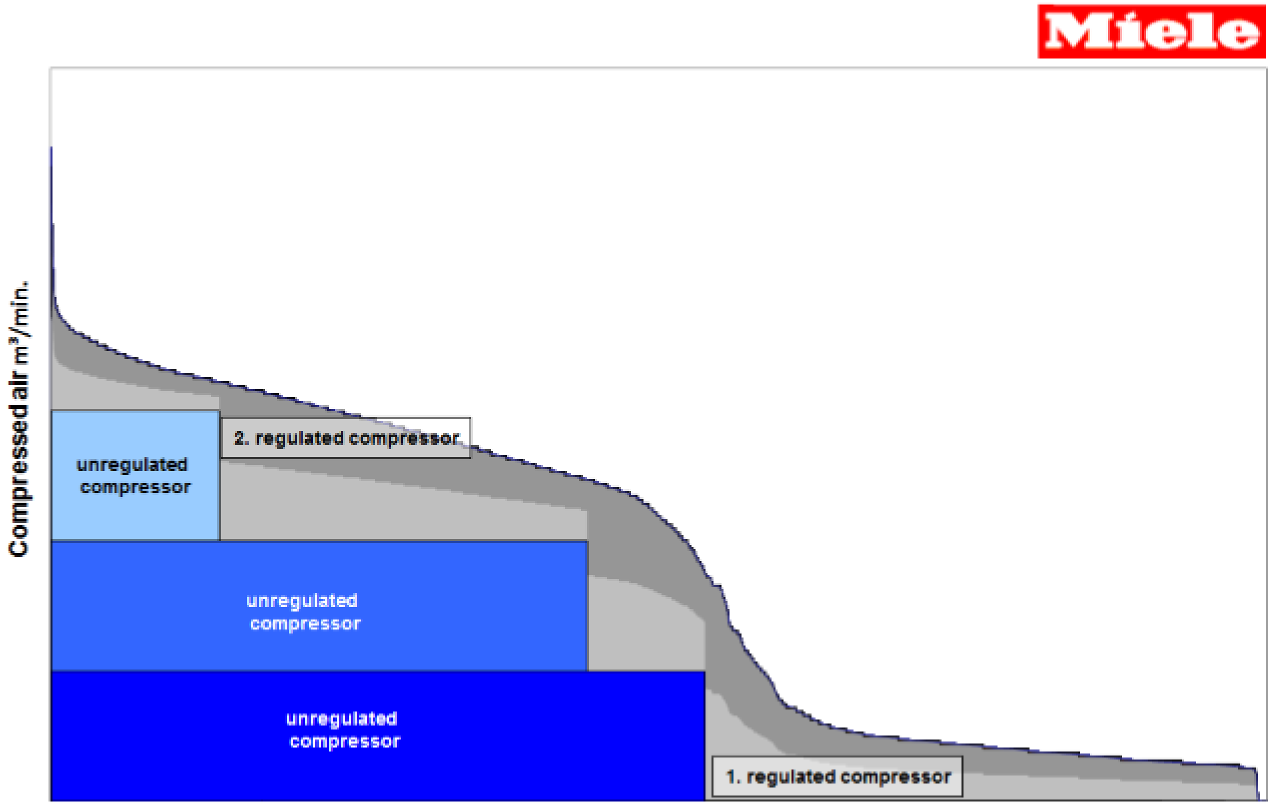
It is recommended to check the existing compressed air system in terms of possible improvements concerning overall energy efficiency, especially if the following reasons for pressure losses exist (Diemer & Feihl 2011):

- Too small cable cross-sections (bottlenecks);
- Added filters or coolers;
- Unsuitable fittings or hose couplings;
- Too long (spiral) hoses, too many couplings.

Furthermore, one of the fundamental objectives of an energy-efficient system design is to match the air pressure, volume and quality to the needs of the various end use devices. Within this context it has to be decided whether a centralized compressor station is more suitable than two or more decentralized units. In any case, the supply should be close to the consumptions centres. Furthermore, it is recommended to prefer a system delivering a lower pressure (applicable for most applications) and add pressure boosters for devices that require higher pressure (Radgen & Blaustein 2001).

In addition to this, the system design should be based on the annual load duration curve. As shown in the following table, this implies that large, unregulated compressors run base load, whereas the peaks are covered by the smaller, regulated devices. The latter can also ensure supply during minimal load periods. As a result, compressor running times (operation hours) of the individual compressors decrease, thus reducing both energy consumption and wear of the compressors (Diemer & Feihl 2011).

Figure 4-2: System design according to annual load duration curve



Source: Miele

Increase the specific energy efficiency of major compressed air system components

In terms of compressor technology, the market in the relevant segment is dominated (75% of sales) by screw compressors, mainly due to their simplicity and reliability (Radgen & Blaustein 2001).

Within this segment, however, differences concerning the specific energy-efficiency can be significant. For example, Miele decided to install 2-stage screw compressors with hybrid permanent magnet motors that are characterized by constantly high efficiency also at partial load (Hermelingmeier 2014a).

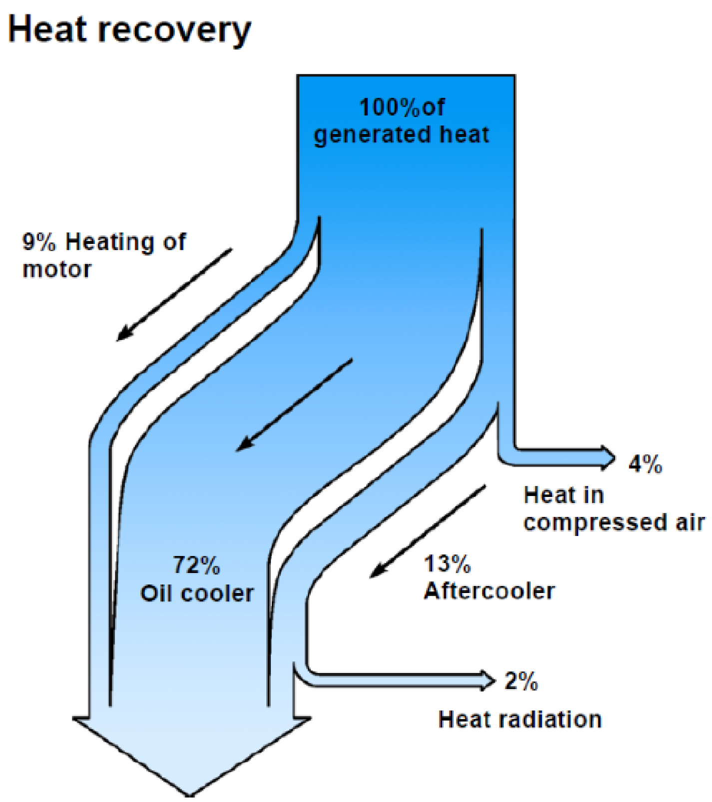
However, centrifugal compressors can be an interesting option as they are more efficient than screw compressors; however, they are inefficient during partial loads and have been used so far only very rarely. Therefore, it can be an interesting solution to combine centrifugal and screw compressors, with centrifugal units used for providing the base load, and smaller screw compressors added during the peak loads.

In terms of dryers, efficiency gains can be achieved through units with integrated cold storage. This functionality can be provided by a system based on glycol-water mixture and makes it possible that the dryer will run only if the compressor is running. Hence, no continuous operation of the dryer is necessary, whereas the cold storage provides cooling until the dryer has reached the operating point (Hermelingmeier 2014a).

Install waste heat recovery

As illustrated by the following figure, the potential of compressed air systems for waste heat recovery is substantial: Theoretically, up to 94% of electrical power consumption can be exploited for heat recovery.

Figure 4-3: Potentials for waste heat recovery



Source: BOGE (2008)

In terms of technology, waste heat recovery can be achieved through the installation of a plate heat exchanger within the oil circuit of the compressors. The heat exchanger provides hot water with a temperature between 60 and 80°C (Diemer & Feihl 2011; Hermelingmeier 2014a) that can be used for the heating of buildings, drying of products, regenerating the desiccant dryer and other similar purposes.

Another very interesting utilization of waste heat recuperated from compressed air systems is the operation of an absorption chiller for air conditioning (cf. section 4.2.2).

4.2.2.6. Applicability

Basically, the approaches for improving the energy efficiency of compressed airs systems can be applied by all companies that have such a system at their disposal.

The substitution of compressed air devices as well as the elimination of leakages is applicable for almost all systems, independent of their age and current state.

Concerning the optimization of systems design, the innovation cycle has to be taken into account. Thus, the recommendations are especially relevant for systems that have “grown” over decades

(with implementation of extensions that have originally not been planned) and that need revision. However, it is estimated that this approach is applicable for at least 50% of all compressed air systems (Radgen & Blaustein 2001). In case a centralized system seems to be favourable, enough space is required for all important components, such as compressors, dryer, oil deposition, slitting as well as cooling air supply and noise abatement.

Regarding the use of waste heat a continuous demand for process heat is necessary in order to realise the existing energy and cost savings potentials.

4.2.2.7. Economics

Due to the relative inefficiency of compressed air production, the electricity required to generate compressed air / vacuum accounts for 20% to 80% of the overall energy costs in a factory[41].

When analysing the cost structure of compressed air systems, it can be shown that 78% of all costs are caused by the energy demand, where the remaining costs are caused by maintenance and investments (Diemer & Feihl 2011).

Thus, when optimizing inefficient compressed air processes, companies could save significant amounts of their overall energy demand (between 5% and 50%). In Germany, compressed air systems from 59 firms were analysed by measurement, whereas an average potential energy and cost savings rate of 34% could be detected (Diemer & Feihl 2011). Payback times for the different measures implemented in German companies typically range between two and four years, depending on the individual age, size and state of the system (VDMA 2005).

The following table shows typical payback times[42] for selected measures applicable for the European scope:

Table 4-4: Payback times for selected measures

Measure	Payback time (months)
Optimizing end use devices	18
Reducing air leaks	6
Overall system design	18
Drives with high efficiency motors	12
Drives with speed control	9
Recovering waste heat	6

Source: Own table with selected data from Radgen & Blaustein 2001

41 Cf. http://www.efficiency-from-germany.info/EIE/Navigation/EN/Technologies/industry,did=356360.html?view=renderPrint

42 It needs to be taken into account that the study was published in 2001, and that financial constraints for the calculated payback times might have changed since then.

4.2.2.8. Driving force for implementation

The major driving forces behind the vast majority of the approaches described in section 4.2.2.5 clearly are the corresponding savings potentials (see details in the section above). This is particularly applicable to the elimination of leakages. Against this background, it is highly recommended to establish an own cost centre for compressed air, which is currently the practice in only very few companies. Such a measure would enable the management to identify the costs that are associated with the production of compressed air, as well as to monitor the success of already implemented measures.

Furthermore, an energy management system according to ISO 50001 with its correspondent audits is regarded to be another important driving force for the identification and implementation of measures for improved efficiency of the compressed air system of a company.

4.2.2.9. Reference organisations

- Miele: Miele has improved the efficiency of their compressed air system in a few stages. Among others this included:
  - Identification of weaknesses of the existing system and application of measures for system optimization (e.g. decrease of system pressure, exchange of pipings);
  - Shift from a decentralised compressed air production (see following figure) adjacent to areas of use to a centralised manufacture station which supplies all of the Gütersloh facilities with compressed air for various purposes;
  - Installation of screw compressors with energy-efficient hybrid permanent magnet motors and dryers with an integrated cooling storage;
  - Use of waste heat associated with the system (e.g. within the manufacturing process of enamel coatings);
  - Replacement of devices that formerly used compressed air for tools powered by electricity.

Figure 4-4: Centralized compressed air station at Miele manufacturing site in Gütersloh

Source: Miele

4.2.2.10. Chapter references

BOGE (2008)	BOGE Kompressoren – Otto Boge GmbH & Co. KG; BOGE Compressed Air Compendium; Technical Paper „Efficient compressed air production"; Bielefeld 2008
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Diemer & Feihl (2011)	Diemer, R.; Feihl, M.; Energieeinsparpotentiale bei der Druckluftversorgung; Vortrag am 17.05.2011 bei der IHK Region Mannheim im Netzwerkdialog Süd (German only)
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EU (2014)	European Commission; Report on critical raw materials for the EU. Report of the Ad hoc Working Group on defining critical raw materials. Brussels, May 2014.
ISO 50001	International Organization for Standardization (ISO) (eds.); ISO 50001:2011; Energy management systems -- Requirements with guidance for use, 2011
Hermelingmeier (2014a)	Hermelingmeier, H.; Effiziente Drucklufterzeugung bei Miele. In: VIK Mitteilungen 1/2014, pp. 14-16
Hermelingmeier (2014b)	Hermelingmeier, H. (Miele & Cie. KG); personal communication; Gütersloh 17.10.2014
Niermeier (2013a)	Niermeier, A.; Energiesparvorschläge von Planern für Planer: Druckluftleckagen erkennen, internal guideline (German only) Miele & Cie KG, Gütersloh, 2013
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VDMA (2005)	Verband Deutscher Maschinen- und Anlagenbau – VDMA (eds); Druckluft effizient, Druckluft Abschlussbericht; Berlin, Karlsruhe, Frankfurt, 2005; retrieved from: http://www.druckluft-effizient.de/downloads/Abschlussbrochuere-druckluft-effizient.pdf

4.2.3. Energy-efficient cooling technology

4.2.3.1. Description

Cooling systems are becoming increasingly important in the EEE sector. The most common application is the removal of process heat that accumulates in the production processes, but also in the production halls. In particular, the continuing trend towards increasingly fine structures, both in the production of integrated circuits and of printed circuit boards, increasingly requires the use of cooling technology.

For example, when considering standard processes such as drilling and milling, the required manufacturing tolerances can only be maintained at relatively cool ambient temperatures. The reason for this is that - due to the expansion coefficients of the processed materials - higher temperatures impair the accuracy of the processes and thus raise rejection rates. This is especially applicable for testing processes, not only in the field of integrated circuits or printed circuit boards, but also electronic assemblies in general (Edelbluth 2014a).

Hence, it is necessary to provide the right amount of cooling energy at an adjusted temperature level, depending on the specific requirements of the different manufacturing processes. Before installing a cooling system, however, it should always be checked whether cooling is really necessary or whether the generated waste heat is acceptable, or can, at least partially, be used elsewhere.

It has to be mentioned that the European Commission published a reference document on the application of Best Available Techniques (BAT) to industrial cooling systems in 2001 (European Commission 2001). This document, however, mainly focuses on cooling energy demand at higher temperature levels (i.e. above 20°C), and thus is applicable for EEE production processes only to a very limited extend. In addition, due to the age of the document, recent developments in the field of cooling technology, such as absorption cooling, are not sufficiently addressed in this document.

Against this background, elements for a strategic approach within the context of best environmental management practice in the field of energy-efficient cooling in the EEE sector are presented here and encompass the following elements:

1. Assessment and optimization of the required room temperatures;
2. Use of cooling cascades;
3. Use of free cooling;
4. Use of absorption cooling technology.

The assessment and optimization of the required temperature level for processes and rooms with cooling energy demand should be the first step within all activities and programs that aim to foster environmental performance in the field of cooling. This recommendation is to be understood against the background that the most efficient cooling is one that is not needed.

In terms of rational use of cooling energy, cooling cascades can provide interesting possibilities. By splitting the existing cooling circuit into two or more temperature levels, a large potential for energy savings can be exploited.

Furthermore, it is necessary to analyse whether the required cooling energy has to be provided by compression chiller units (being currently the technological baseline for cooling energy at low

temperatures) or whether alternative cooling techniques can be applied. In this respect, especially free cooling techniques are worth giving further consideration. In order to utilize the existing potentials for free cooling, mainly the following three options exist and should be considered as implementing measures in this respect:

- Direct cooling (with flow-through colder outside air);
- Free dry cooling (cooling of the water cycle with outside air);
- Free wet cooling (cooling tower).

Another interesting technological alternative to compression chiller can be seen in absorption cooling technology. Instead of electricity, this technology uses heat source (preferably from waste heat) in order to provide the thermal compression of the refrigerant.

It should be noted that the elements mentioned above can be applied separately. However, best results will be achieved through an integrated approach implementing all or most of these measures.

4.2.3.2. Environmental benefits

The supply of cooling energy is associated with particularly large amounts of energy. Together with compressed air, it represents the most sumptuous and thus polluting form of energy in the manufacturing process of EEE. Hence, when reducing the amount of cooling energy and producing the remaining demand more efficiently, substantial environmental benefits can be achieved.

Quantitative data regarding energy savings potentials for above-mentioned measures can be found in section 4.2.3.7.

For further environmental benefits besides conservation of electricity, also the "positive cross-media effect" mentioned in section 4.2.3.4 needs to be taken into account.

4.2.3.3. Appropriate environmental performance indicators

The environmental performance of energy-efficient cooling technology should be measured with an indicator that correlates the electricity consumption of the cooling system and the cooling energy (i.e. heat energy that needs to be dissipated at the target process) provided by the cooling system.

The indicator is thus defined as kWh (electricity) / kWh (cooling energy).

However, it has to be noted that this indicator is only applicable for systems that allow for the quantification of their cooling energy demand.

For systems where this is not possible, an indicator on a qualitative basis needs to be taken into consideration. This qualitative indicator needs to be focussed on the different options of free cooling (see sections 4.2.3.1 and 4.2.3.6). In detail, the following aspects need to be addressed:

- Have all possibilities for direct cooling been examined? In particular, have the maximum possible temperature levels been assessed and (if possible) adjusted in this context?
- Have all possibilities free dry cooling been examined?
- Have all possibilities free wet cooling been examined?
- Was it possible to completely substitute conventional compression chiller units after all measures concerning free cooling have been implemented?

4.2.3.4. Cross-media effects

When opting for free cooling instead of using compression chillers, it has to be taken into account that in case of wet cooling units, a substantial water use is induced. For example, a hybrid cooling tower is characterized by a water use of about 0.5 $m^3/h/MW_{th}$ (European Commission 2001).

Furthermore, fogging on the cooling towers caused by the evaporation of water can be an issue, and should not be considered as a purely optical aspect. Depending on weather conditions, the formation of fog can be amplified locally, and larger equipment can even lead to increased rainfall (Berger & Eisenhut 2012).

On the other hand, free cooling units do not require ecologically problematic refrigerants like R-410A. Though not contributing to ozone depletion as the previously used and phased-out R-22, R-410A (a mixture of difluoromethane and pentafluoroethane) has a high global warming potential, which is 1725 times as much as carbon dioxide. This aspect can thus be regarded as a positive cross-media effect to some extent.

4.2.3.5. Operational data

According to the different approaches mentioned in section 4.2.3.1, the corresponding details for implementation and operational data are given.

Assessment and optimization of the required temperature level

As a rule of thumb, it has to be taken into account that in any air-conditioned room a change of 1°C in temperature leads to a change in energy consumption for cooling of almost 50 kWh per cubic meter of space (Edelbluth 2014b). In other words: If permitted by the requirements of the respective process, each degree Celsius of higher temperature enables direct annual savings of 50 kWh of electricity for cooling purposes.

Hence, temperature levels and correspondent tolerances for the different applied processes and room conditions need to be carefully reviewed and adapted. Within this context, offices and production rooms with standard processes (such as milling) are particularly relevant for this assessment.

Use of cooling cascades

In order to establish a cooling cascade, the return flow of a classic 6/12°C flow/return system for cooling the bath temperature during printed circuit board manufacture can be used as an input for another cooling systems that operates at 12/18°C flow/return requirements (e.g. for space cooling). As a result, less capacity for cooling energy needs to be provided, and thus energy can be saved (Edelbluth 2014c).

This measure will help ensure that the refrigeration evaporation temperature or chilled water temperature will be as high as possible, which increases the energy efficiency of the system even further. For instance, if the refrigeration evaporation temperature or chilled water temperature can be increased by 2°C, a gain of 5% in terms of energy efficiency can be achieved (Farquharson 2013).

Use of free cooling

Through the use of intelligent control equipment, free cooling can be used as a cooling technology as long as the difference between indoor and outdoor air is 5-10°C. This means that up to ambient temperatures of about 15-17°C, a process or space temperature of 22°C can be realised. The savings potential reaches 50-80% of the cooling energy, depending on the local climate and temperature level. In northern Europe, for example, 200-300 days a year can be used for free cooling, but also central and even southern Europe show significant potential for the application of this technique (see following table). In Madrid, for instance, the annual number of hours below 18°C reaches more than 5,600, which equals an annual share of almost two thirds (Edelbluth 2014b).

Table 4-5: Annual number of hours of temperatures up to and including 18°C in selected European cities

	Hamburg	London	Madrid	Paris
Annual number of hours below 18°C	7,760	7,010	5,637	6,708
Annual share	87%	80%	64%	77%

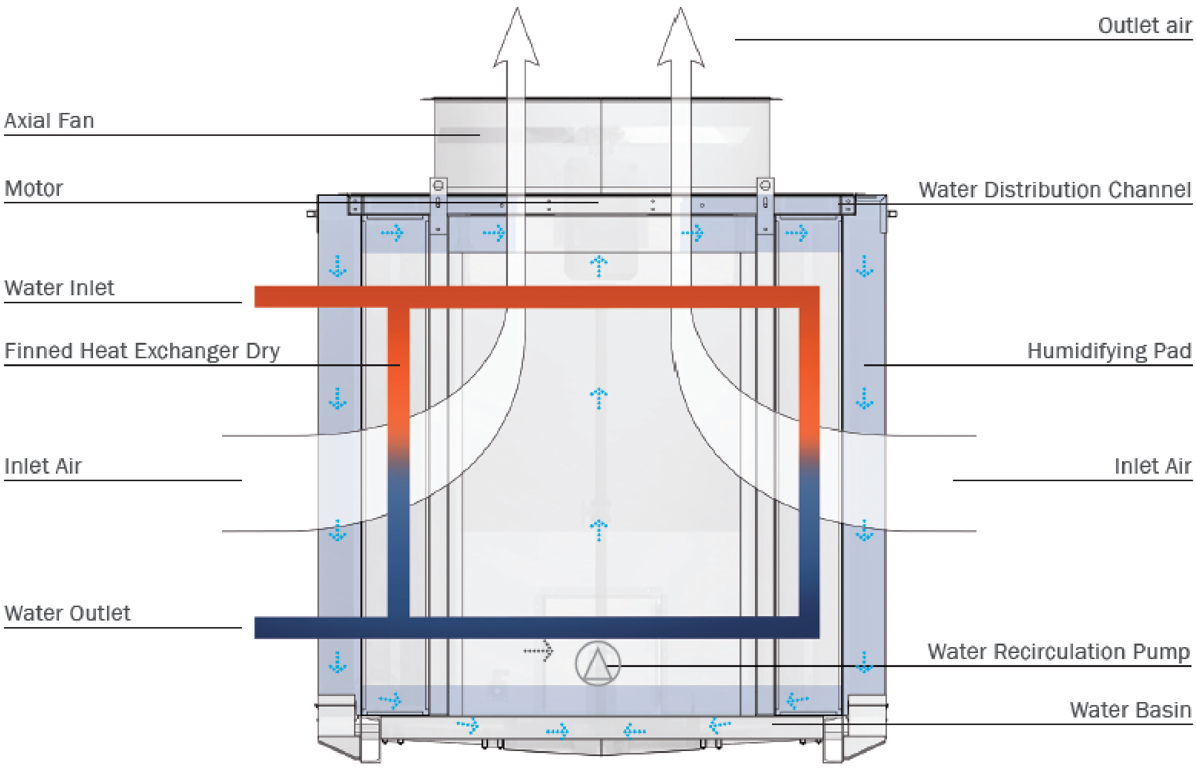
Source: Own table according to data from Stulz (2014)

Direct cooling represents the easiest option of dry cooling in terms of installation efforts; however, it can only be used for space cooling. Here, the rooms are traversed directly with the colder outside air. To achieve this, a pipeline system needs to be installed (if not existing), which allows the flow through the building and the rooms that need to be cooled. For the flow, a sufficiently large ventilation unit has to be provided. Direct cooling is not only feasible in the cooler season, but can also be used during summer time, when cool night air is used to reduce the room temperature and thus compensates the heating of the previous day. This measure works especially well in non-air-conditioned rooms and corridors, but can also be applied in production halls and computer rooms (Edelbluth 2014b).

Free cooling systems need to be adjusted precisely to the requirements of their intended applications. Basically, there are many different systems, whereof dry cooling and wet cooling are the most relevant as well as combinations of the two.

Dry coolers based on a water cycle that is cooled with outside air can only be used when outside temperatures are at least 5°C below the flow temperature of the cooling unit. In this respect, the requirements for free coolers are very similar to direct cooling systems. Unlike direct cooling, dry coolers can also be used for process cooling, since the cooling unit cools down a water circuit, which acts as a cooling medium for finishing the process of heating (see following figure). Compared with wet coolers, however, these systems are characterized by much lower capital and operating costs (see section 4.2.3.7) (Edelbluth 2014b).

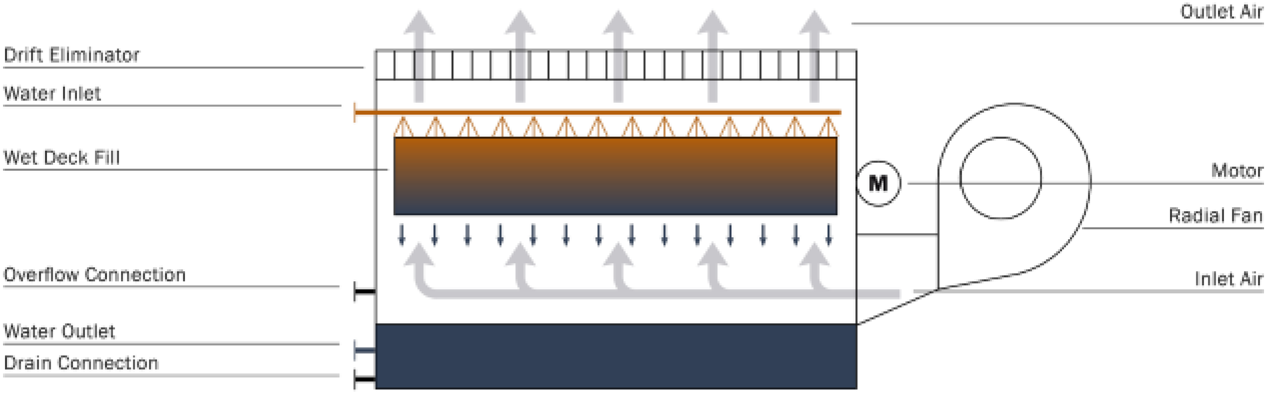
Figure 4-5: Free dry cooling



Source: Gohl (2013)

In contrast to dry coolers, wet cooling systems (i.e. cooling towers) can be used well into the summer period, if the requirements concerning flow temperature can be adjusted by the system control. Wet cooling systems operate upon the principle of evaporative cooling. They are designed as hybrids that pass the working fluid through a coil, upon which clean water is sprayed; a fan finally removes the evaporated water (see following figure). With wet cooling, even very large temperature differences can be handled.

Figure 4-6: Free wet cooling

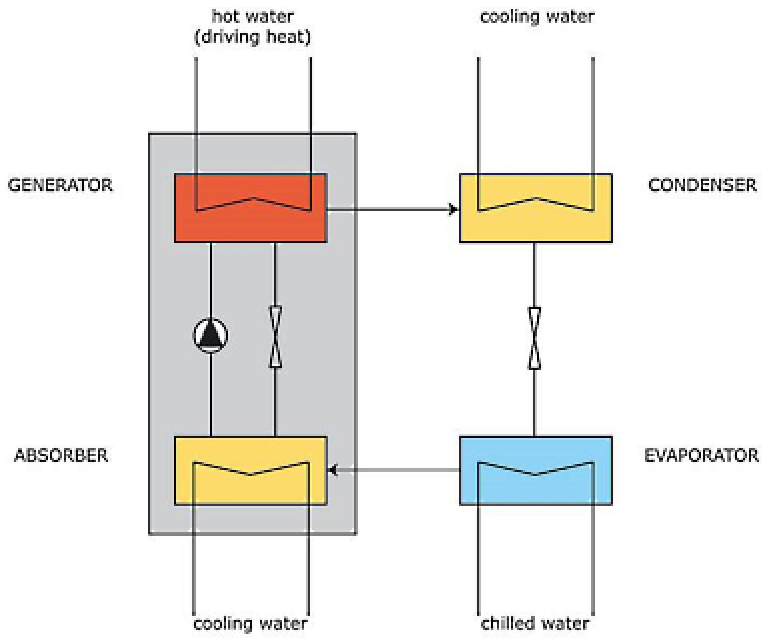


Source: Gohl (2015)

Use of absorption cooling technology

In absorption chillers, a thermal compression of the refrigerant is achieved by using a liquid refrigerant/sorbent solution (typically a water/ lithium bromide solution) and a heat source, which replaces the electric power consumption of a mechanical compressor. The main components of an absorption chiller are the generator, the condenser, the evaporator and the absorber (see figure below). Typical chilling capacities of absorption chillers are several hundred kW. Mainly, they are operating with district heat, waste heat or heat from combined heat and power (CHP) plant (Solair 2009).

Figure 4-7: Scheme of absorption cooling technology



Source: Solair (2009)

4.2.3.6. Applicability

Basically, the approaches for improving the energy efficiency of cooling systems can be applied by all companies with a need for cooling energy.

The assessment and optimization of the required room temperatures are considered to be applicable for all companies, since this measure is a fundamental step prior to the installation of any cooling equipment.

Concerning the applicability of free cooling, the fundamental thermodynamic constraints need to be fulfilled, i.e. the temperature level of the return flow of the cooling system must be above the outside temperature. In this respect, a site with rather continental climate (meaning moderate temperatures during summer and cold temperatures during winter) is favoured (Grauting 2007).

Furthermore, in terms of direct cooling, a flow (of cooling air) through the building is required (Edelbluth 2014b).

When investing in cooling equipment (e.g. free cooling or absorption cooling), a year-round cooling load must be available – at least, it would improve the economic feasibility of the measures. In addition to absorption cooling, a source of waste heat (e.g. a combined heat and power (CHP) plant) needs to be continuously available at the production site or its surroundings.

Finally, when installing equipment for free cooling, enough space must be available on the outside area of the production site.

4.2.3.7. Economics

Already when implementing rather simple measures like the optimization of the required temperature level, substantial cost savings are possible. For example, if the temperature level of an office of 36 m² (at a height of 2.5 m) can be raised by 1°C, approx. 4,400 kWh can be saved per year. Assuming a price for electricity of 0.14 ct/kWh[43], hence annual cost savings of more than 600 € can be achieved. Analogously, at a production area (e.g. for milling of printed circuit boards) with dimensions of 20m x 20m and 4.5m, nearly 88,000 kWh of electricity or 13,000 € can be saved (Edelbluth 2014b).

On the basis of cost information that was collected during the planning / implementation of more complex measures (than just optimizing the room temperature) at Würth Elektronik, the following exemplary information on the most important cost data can be derived for the various approaches on energy-efficient cooling (Edelbluth 2014b):

- In an 800 m² production hall with a heat load of 1 MW, direct cooling was installed. The corresponding operational costs account for 34,000 € p.a. Compared to the technological baseline of compressor cooling that would cause 296,000 € costs p.a., in this case, the savings potential through direct cooling equals 262,000 € p.a. Hence, the corresponding return on investment is only about 1 month.
- Another case study refers to a milling process for printed circuit boards, which is characterized by a cooling energy demand of 816,000 kWh/a. Whereas the conventional 120 kW compressor chilling unit had an electricity consumption of 272,000 kWh/a, the installed dry cooling equipment only consumes 68,000 kWh/a for delivering the required cooling energy. Taking into account the

[43] This price represents an exemplary, typical value for electricity for industrial customers in Germany.

local electricity prices, the achieved decrease of 204,000 kWh/a results in cost savings of 28,560 € p.a. Against the background of investment / connection costs of 45,000 € and annual costs for energy consumption of pumps and fans at about 15,000 kWh/a, a payback time of 1.7 years (or approx. 20 months) can be calculated.

- At a wet processing equipment for printed circuit board manufacture with a bath temperature of 22°C (+/- 2°C) and exothermic reactions and a cooling demand of 246,000 kWh/a, the cooling technique could also be switched to free cooling. Instead of 82,000 kWh/a, that used to be consumed by a compressor chilling unit, the dry cooler consumes only 20,500 kWh/a, enabling annual electricity savings totalling 61,500 kWh or 8,610 €, respectively. Investment / connection costs at 15,000 (pro rata) and energy consumption of pumps and fans at 5,000 kWh/a can be compensated within a payback time of 1.9 years (or approx. 23 months).
- An image-setter with a thermal output of 9 kW per burner and a cooling demand of 108,000 kWh/a formed the basis for another case study regarding the implementation of free cooling. Instead of 36,000 kWh/a, that used to be consumed by a compressor chilling unit, the dry cooler only consumes 9,000 kWh/a. This enables annual electricity savings totalling 27,000 kWh or 3,780 €, respectively. Investment / connection costs at 5,000 € and energy consumption of pumps and fans at 800 kWh/a can be compensated within a payback time of 1.4 years (or approx. 17 months).
- Finally, by installing a CHP plant (based on natural gas) with absorption cooling technology, a compressor chilling unit, but also purchasing electricity from the public grid and natural gas heating can be substituted. The investment costs for this measure account for 290,000 € and enable cost savings totalling 112,000 €. When taking into account annual maintenance cost for the CHP plant at about 24,000 €, net energy cost savings of 88,000 € can be achieved. The payback time is specified at 3.3 years (or approx. 40 months).

Basically, it can be stated that the higher the acceptable temperature level, the smaller the payback time of the corresponding measure.

In the following table, cost data for the different measures mentioned above as well as the respective payback times are summarised:

Table 4-6: Cost data and payback times for selected measures

Measure	Investment costs (€)	Operational costs p.a. (€)	Annual savings (€)	Payback time (months)
Direct cooling (for production hall)	-	34,000	262,000	1.3
Free cooling (for milling process)	45,000	2,090	28,560	20
Free cooling (for wet processing equipment)	15,000	670	8,610	23
Free cooling (for image-setter)	5,000	100	3,780	17
Absorption cooling technology	290,000	24,000	112,000	40

Source: Own table according to data from Edelbluth (2014b)

4.2.3.8. Driving force for implementation

Against the background of the above-mentioned details with regards to economics, cost savings are considered to be the main driver for implementing best environmental management practice in the field of cooling technology.

Besides the identified savings potentials concerning electricity consumption, alternative cooling techniques also offer solutions for other scarce goods such as production area. In particular, free cooling equipment does not require area inside production halls, which might serve as another driving force for implementing this technique (Grauting 2007).

Finally, another important driver can be seen in a legislative framework that increasingly prohibits the removal of water for cooling purposes from surface waters, especially for once-through cooling systems.

4.2.3.9. Reference organisations

- Würth Elektronik GmbH & Co. KG: Various initiatives and measures concerning free cooling and absorption cooling that were planned by Ingenieur-Büro Edelbluth & Dauber (see section 4.2.3.7 for more details)

4.2.3.10. Chapter references

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4.2.4. Energy-efficient soldering

4.2.4.1. Description

Within EEE production, soldering is an important process in which metal items are joined together by melting and flowing solder, i.e. a filler metal, into the joint. Especially for the production of printed circuit boards, soldering is most relevant in order to connect the electronic components to the circuits on the board. Meanwhile, most applications are reflow soldered[44] and/or wave soldered.[45] Hand soldering of some (especially large and heavy) components and for certain EEE applications is also still practiced, but only in very few cases.

Within the context of miniaturisation of EEE and as a result of an ever increasing number of surface mounted devices (SMD), reflow soldering is by far the most relevant soldering technology, both in terms of production volume and ecological optimization potential. For example, reflow soldering equipment is responsible for 70% of energy demand within the SMD production process (Bell et al. 2013). Reflow soldering will thus be the main focus in this section.

Improving the environmental performance of soldering has been (and still is) an important issue with regards to the substitution of lead-based solders stipulated by the EU RoHS Directive. As a result of the phase-out of lead-based solders, the process temperature of the soldering process had to be increased significantly. Whereas lead-based solders were soldered at about 190°C, a minimum temperature of 217°C needs to be reached in order to ensure a lead-free soldering process. For certain applications, temperatures of up to 240°C are needed. Another important aspect within this context is the fact that the so-called manufacturing window (i.e. the temperature span in which soldering can be done) has been reduced by lead-free solders. In this sense, the development of new temperature profiles is a key stage in facilitating the shift to lead-free solders, also impacting the system's energy consumption. From a technological point of view, convection systems are used to ensure that the required temperature level is maintained (Petermann 2014a).

Against this background, the best environmental management practice presented here is predominantly addressing the energy efficiency of the reflow soldering processes. Frontrunner approaches have shown that, in the course of developing the soldering system towards more energy efficiency, they can be equipped with a number of new functions. First of all, an improved power management system has to be mentioned in this respect. For example, innovative soldering facilities can be placed in stand-by or in a dormant state. In these energy saving modes, both temperature of heaters and the rotation of drives are successively reduced. Energy-efficient soldering technology is further characterised by excellent thermal insulation and a cooling aggregate that enables waste heat recovery.

In addition to these measures that refer primarily to the options of new equipment, the energy efficiency of existing plants can also be enhanced. Within this context, in particular approaches with the aim of maximizing the throughput of the soldering line as well as of avoiding the use of nitrogen have to be mentioned.

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[44] Reflow soldering is a process in which a solder paste is used to temporarily attach electronic components to their contact pads, whereas the components are most commonly surface mounted devices (SMD).

[45] Wave soldering is a process by which electronic components are soldered to a printed circuit board, with the solder being provided in waves of molten material in order to attach the components to the board. Wave soldering can be used both for through-hole technology (THT) devices and surface mounted devices (SMD).

Hence, a strategic approach for best environmental management practice in the field of energy efficiency of reflow soldering should consider the following elements:

1. Maximize throughput of existing reflow soldering equipment;
2. Retrofit insulation for older soldering equipment;
3. Installation of new reflow soldering equipment (including the major approaches for enhancing the efficiency such as improved power management system, optimized use of nitrogen and waste heat recovery);
4. Avoid the use of nitrogen for less delicate applications.

Since the energy efficiency of reflow soldering equipment is heavily dependent on the yield of soldered PCB, the maximization of the equipment's throughput is one of the easiest measures in order to reduce the specific electricity demand per m² of PCB. Within this context, the main issue is to optimize the equipment´s conveyor speed while maintaining acceptable limits of the respective process window.

Another very effective approach for existing soldering equipment is the installation of retrofit insulation. This measure can be planned at the company level, and should be carried out together with the respective equipment manufacturer.

When a decision can be made in favour of the installation of new reflow soldering equipment, various best environmental management practices can be realised at once. In particular the following features are relevant within this context:

- improved power management system;
- use of direct-current fan motors;
- use of a cooling unit enabling waste heat recovery;
- optimized use of liquid nitrogen.

Further details, especially concerning the corresponding operation data can be found in section 4.2.4.5.

The main reason for using nitrogen during the soldering process is obviously to reduce defects. Nitrogen inerting can produce better solder joints because it reduces the risk of oxidization. Within this context, the use of nitrogen is especially recommended for delicate assemblies. However, especially in case of less complex applications the use of nitrogen can be avoided, which is considered as a complementary measure within the context of energy-efficient soldering.

4.2.4.2. Environmental benefits

The operation of soldering equipment is associated with a substantial consumption of electricity. The connected load of one reflow soldering line typically ranges between 50 and 100 kW.

Best practice reflow systems are characterized by at least 20% lower electricity consumption, resulting in annual savings (when assuming a 3-shift operation) of approx. 26,000 kWh and reductions of CO_2 emissions of up to 12 tons[46] per year (Bell et al. 2013; Kurtz 2010).

[46] The mentioned reductions of CO_2 emissions are dependent on the specific emission factors for electricity production and refer to German conditions.

In addition to energy savings, also 20% less nitrogen demand can be achieved. This opens up additional cuts in CO_2 emissions since nitrogen has to be produced through cryogenic air separation representing an energy-intensive process.

4.2.4.3. Appropriate environmental performance indicators

It is recommended to assess the environmental performance of energy-efficient reflow soldering equipment with an indicator that takes into account the total energy demand (in terms of electricity) and refers it to the surface of the treated processed printed circuit board (PCB). Hence, the unit for this indicator is defined as: kWh (of electricity) / m² (of PCB).

Since there is a large variety of PCB as well as of electronic components on the assemblies, parameters such as the type of PCB (multilayer, double-sided, etc.) as well as the amount of components and the used solder paste need to be provided as additional information for the indicator described above.

4.2.4.4. Cross-media effects

In general, negative cross-media effects for energy-efficient soldering are not recognizable. One exception could be the installation of energy-efficient fan motors. Here it has to be taken into account that electric motors that enable highest possible efficiency usually require the use of critical metals in their magnets, especially neodymium. As described in section 4.2.1.4, Neodymium is regarded as “critical raw material” in the EU; furthermore, its extraction is associated with heavy burden on the local environment (EU 2014; Schüler et al. 2011).

On the other hand, energy-efficient soldering equipment shows beneficial impacts also with regard to other environmental pressures. For example, in best practice equipment flue gas is treated within internal pyrolysis reactors, which results in 97% particle separation efficiency and separation of 30% total organic carbon (TOC) (Bell et al. 2014).

In addition to this, insulation as well as regulation of fan motors also reduces the noise emissions of the soldering equipment; 5 dB(A) less compared to standard equipment can be achieved. Finally, insulation also causes less heat radiation to the surrounding workplaces, since the equipment has a skin temperature of only about 30°C. (Bell et al. 2014)

4.2.4.5. Operational data

According to the different approaches mentioned in section 4.2.4.1, the corresponding details for implementation and operational data are given below.

Maximize throughput of existing reflow soldering equipment

When maximizing the throughput of existing reflow soldering equipment and thus the equipment’s conveyor speed, the challenge is to deal with the shortened process time by soldering profiles specially adapted to the permissible limits of solder paste and components. For this purpose, special profiling software exists that helps to search a large variety of possible combinations, before recommending the maximum possible conveyor speed without violating thresholds of the process window. As a result, 20% gain in throughput can be achieved (Profilingguru 2009).

Besides the above mentioned measure which is predominantly applicable to existing equipment, throughput can also be increased by means of so-called multitrack systems. These systems enable a new line arrangement within SMD processing, as several lines or placement can feed a

reflow system with several, independently operating transport systems. With this approach, up to four transport tracks can be integrated in the tunnel process of a reflow soldering line, without affecting the thermal properties of the plants. The result is increased productivity by up to 400% compared to conventional systems (Friedrich 2012a).

Retrofit insulation for existing soldering equipment

However, the consideration of heat losses has to be made with respect to the process requirements. A general increase of the thermal resistance achieved by better insulation does not necessarily lead to a lower energy demand. The more insulation is applied, the more relevance can be identified at the level of (usually metal-based) thermal bridges (Friedrich 2014).

Installation of new reflow soldering equipment

Improvements concerning the power management system of new reflow soldering equipment primarily refer to the availability of both stand-by and dormant mode. During stand-by mode, especially the temperature of the heaters and the number of revolutions of the drives and fans is reduced, which results in the conservation of energy. Moreover, also the consumption of nitrogen is reduced. The stand-by mode is applicable for short downtimes, e.g. when the line is set up for a new product or a malfunction is being repaired. The return to the operating mode takes only approx. three minutes. The stand-by mode saves 3 kW of energy compared with the operation mode, predominantly because of reduced fan speed. In the dormant mode, however, some heaters and drives are shut down completely. Hence, this mode is suitable for extended downtimes (Bell et al. 2013; Friedrich 2012b; Friedrich 2014).

Another important measure to increase the energy efficiency on reflow soldering equipment is the use of direct-current fan motors. This is especially relevant against the background of increasing demands concerning throughput, even for complex assemblies, which has resulted in prolongation of the process zone and in an increasing number of fan motors. When using direct-current fan motors (instead of the predominantly used three-phase motors), separate speed regulation of the different motors is possible. In addition to that, direct-current fan motors are characterized by minimised idle power. All in all, energy savings of up to 50% compared to conventional motors can be achieved (Friedrich 2014).

The installation of a cooling unit is necessary in reflow soldering equipment within the context of rising cooling requirements due to extended requirement (i.e. lower temperatures) of down-stream processes, such as automated optical inspection and functional check. Best management practice in this field requires a precise analysis of cooling demand, breakdown of the cooling capacity in different volume flows. Since a part of the waste heat is used for space heating, the energy demand of the active cooling unit can be reduced by more than 50% (Friedrich 2014). Part of a best practice cooling concept could also be a flexible cooling unit, which enables the switch between an internal and external cooling aggregate. This opens up the possibility to use waste heat of the internal cooling unit during heating periods, whereas during times with high outside temperatures, the reflow system can be switched to the external cooling. As a result, the load of the air conditioning unit of the production site can be reduced (Friedrich 2012b).

A major approach for the optimized use of liquid nitrogen consists of an improved consumption monitoring and control system. Nitrogen atmosphere is used when optimal solder wetting and process stability are required. Reduction of nitrogen results in energy savings (during its production), since the production of liquid nitrogen is quite energy-consuming (cf. section 4.2.4.2). By means of several measuring points, optimization for more than one operational point can be

achieved, which enables savings of up to 20% of the nitrogen demand (Friedrich 2012b, Friedrich 2014).

Avoid the use of nitrogen for less delicate applications

The following table gives a summary of conditions / applications that can be optimized when using nitrogen. However, it also shows examples for conditions / applications that do not (strictly) require nitrogen and thus open up possibilities to reduce the environmental impact of the soldering process due to less nitrogen consumption.

Table 4-7: Considerations for using nitrogen vs. oxygen

Conditions optimized by nitrogen	Conditions not requiring nitrogen
Expensive components or assemblies	Low-complexity assemblies
Prototype	Mature assemblies
Low volume	High volume
Non-reworkable components such as chip on board (COB)	Rework easily accomplished
No clean	Aqueous
Wave solder	Reflow
New technologies, such as fine pitch (low-ball soldering)	Standard technologies and packages
Reliability a priority	Cost a priority

Source: Own table according to data from Lawton (1998)

Against this background, it is recommended to check the individual conditions at the company in order to identify whether the use of nitrogen can be avoided for (at least) a certain part of the product throughput.

4.2.4.6. Applicability

Basically, the approaches for improving the energy efficiency of reflow soldering facilities can be applied by all companies that use such equipment. Although for many EEE products mass production of electronic components is outsourced and located outside of Europe (especially in Asia), for innovative and high-end products (as can be illustrated by the example of Miele, see section 4.2.4.9) the soldering processes are still carried out on-site in Europe. Besides Miele, companies like Robert Bosch GmbH, Phönix Contact GmbH and Wilo SE can be mentioned in this context (Petermann 2014c)

Both approaches, i.e. on maximization of throughput as well as on retrofit insulation, are especially applicable for existing equipment.

In contrast to this, approaches like improved power management systems, optimized use of nitrogen and waste heat recovery can only be implemented when installing a new reflow soldering line. Within this context, the innovation cycle needs to be taken into account.

Finally, measures aiming to avoid the use of nitrogen are applicable both for existing and newly installed equipment.

4.2.4.7. Economics

The economics of reflow soldering systems are no longer determined by low purchase prices, but primarily by low total cost of ownership and thus low operating costs. Hence, especially low energy consumption but also high system uptime are important aspects for the economical assessment (Friedrich 2012b).

On the other hand, existing soldering devices are not only replaced just to save energy – there are other aspects that impact the decision and also influence the rate of return of investments. In this respect, performance as well as maintenance requirements are other important aspects (Petermann 2014a).

In terms of the savings potential it could be demonstrated that 20-25% less energy consumption results in annual cost savings of up to 5,000 EUR per soldering line. Moreover, the nitrogen savings of up to 20% (mentioned in section 4.2.4.2) deliver further savings potentials. When assuming a nitrogen consumption for one reflow soldering line of approx. 15 m^3/h, 20% savings can account for more than 2,000 EUR[47] per year (SMT n.y.).

Furthermore, it has to be mentioned that best practice soldering facilities also improve process safety (resulting in less discard) and raise throughput (and thus reduce the floor space soldering needs in the production site). For example, a new reflow soldering equipment can provide approx. 20% increase in yield compared to the previous generation of equipment (Petermann 2014b).

On the other hand, the corresponding investment costs for the installation of a new reflow soldering line need to be taken into account. These account for 120,000 – 180,000 EUR (Petermann 2014b).

With regards to the resulting payback time of new reflow soldering equipment it has to be mentioned that this metric is highly dependent on the individual circumstances of the different companies, especially concerning the savings that can be created because of increased yield. Thus, general information on payback times cannot be provided in this section. In principle, this is also applicable for the other measures described in section 4.2.4.5.

4.2.4.8. Driving force for implementation

As the RoHS directive paved the way for substitution of lead-based solders and the need for new soldering equipment, it has to be stated that this has been an important driving force for the installation of the energy-efficient soldering technology in the EEE sector.

4.2.4.9. Reference organisations

- Miele: The company develops and manufactures all electronic components for their applications. This is especially related to the long life of their consumer products which have different requirements in comparison with conventional components. Concerning the soldering process, all solder techniques are used (aside from hand soldering), the most relevant of which by far is reflow soldering. The following approaches for enhancing the efficiency of the reflow soldering system are applied at Miele's Gütersloh site, where the central administration of the company and the manufacturing of washing machines and tumble dryers as well as the manufacturing of electronic components for all Miele products is located (Petermann 2014a):

47 This cost saving potential has been calculated on the basis of a two shift operation (im 2-Schichtbetrieb (4160 hours p.a.) and nitrogen costs of 15 Cent/m^3.

- A power management system is used and standby and sleep modes are applied to reduce energy consumption when the system is not operating;
- Use of nitrogen is monitored at various points and minimised;
- Thermal insulation is applied – standard equipment for new production lines and retrofit solutions for older production lines (2006);
- External cooling unit with waste heat recovery is implemented.
- All the above mentioned features are realised in best-practice soldering equipment, which has been installed by Miele in recent years (see figure below):

Figure 4-8: Energy-efficient reflow soldering equipment

Source: Miele

Both isolation and nitrogen regulation are regarded to be very important by Miele – those approaches enable a stable process and allow for higher energy efficiency. In order to further reduce the use of nitrogen, Miele considers the soldering of less delicate applications without the use of nitrogen at all (not yet implemented).

4.2.4.10. Chapter references

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4.2.5. Minimising the use of perfluorocompounds

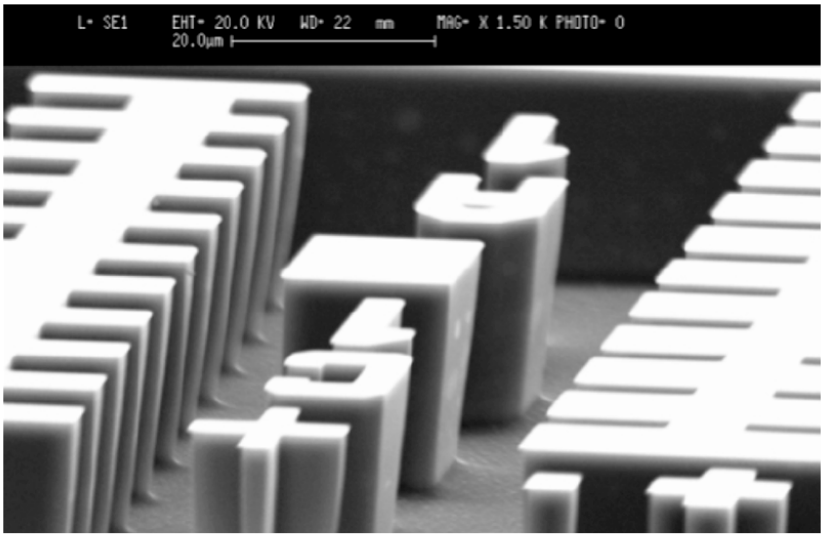
4.2.5.1. Description

During the production of semiconductor devices, various gaseous perfluorocompounds (PFC) are required. The most relevant PFCs that are used in the EEE sector encompass the following substances (Rhiemeier & Harnisch 2009):

- Hexafluoroethane (C_2F_6);
- Octofluoropropane (C_3F_8);
- Tetrafluoromethane (CF_4);
- Octofluorocyclobutane (c-C_4F_8).

In terms of processes, these gases are required in particular for plasma etching and cleaning Chemical Vapour Deposition (CVD) reactors. As regards plasma etching, this is a key process in semiconductor manufacturing in which PFC gases etch the submicron patterns of integrated circuits (see figure below).

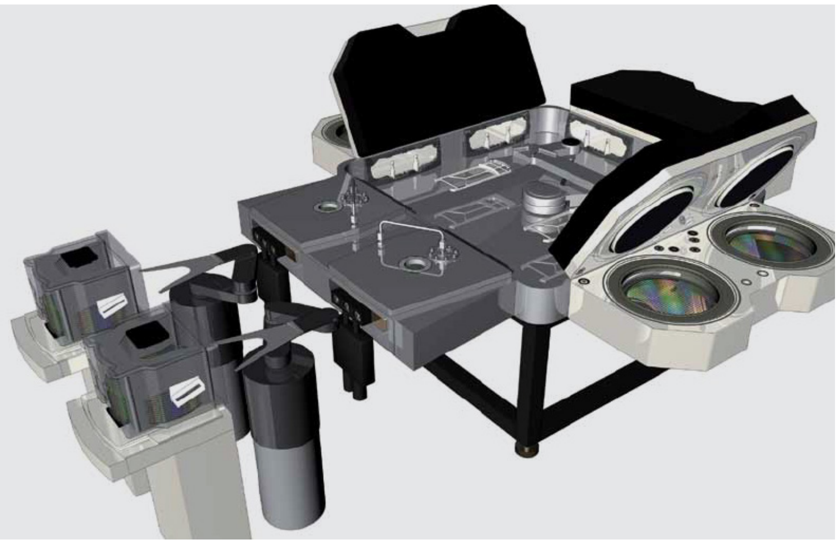
Figure 4-9: Submicron patterns of integrated circuits



Source: www.iht.tu-bs.de, taken out of ZVEI (2011), p. 14

Regarding the cleaning of CVD chambers, PFCs chemically remove the deposits that remain on the chamber surface after silicon and silicon-based dielectric layers have been deposited on the silicon wafers as dielectric or metallic thin films. This cleaning process ensures that the wafers will not be contaminated with these impurities, and furthermore avoids frequent mechanical wet cleanings (Rhiemeier & Harnisch 2009). During the process, PFC gases are only partially dissociated, resulting in atmospheric emissions of unreacted PFC gases, which have very high global warming potentials (see section 4.2.5.2 for more details).

Figure 4-10: CVD chamber



Source: 3D:it – 3D Infotainment Technologies UG, taken out of ZVEI (2011), p. 14

While substitution of the above-mentioned substances is not feasible from a technological point of view, the reduction and abatement of emissions of PFC is an important commitment of the semiconductor industry. Concerning the optimization of processes, a clear focus should be set on CVD chamber cleans because they represent the largest source of PFC emissions (C_2F_6, CF_4) that reportedly constitute 80% of all semiconductor emissions (EPA 2006).

Against this background, a strategic approach for best environmental management practice regarding the minimization of perfluorocompounds in the semiconductor industry should consider the following elements:

- Process optimization;
- Substitution of PFC gases;
- Remote plasma cleaning technology;
- Point-of-use abatement during plasma etching;
- Installation of end-of pipe purification techniques for contaminated exhaust air.

Substantial reductions of PFC emissions can be achieved through process optimization, which is primarily focused on CVD chamber cleaning and consists of monitoring emissions and providing clean end point times. The main goal of process optimization is to increase the conversion factor of the used PFC gases in order to avoid that unused PFC gases are emitted after the chamber cleaning process.

Furthermore, when substituting PFC gases with a high specific global warming potential by substances with a lower potential, a reduction of the environmental impact of those gases can be achieved.

Remote plasma cleaning technology is considered to be a powerful technique that also enables a more efficient use of PFC gases. This process was developed in order to replace in-situ[48] C_2F_6 and CF_4 chamber cleaning and thus addresses the largest source of PFC emissions. Instead, NF_3 is used.

Concerning abatement, both point-of uses as well of end-op-pipe approaches exist. The objective of point-of-use plasma abatement is to abate PFC emissions from the plasma etching process, accounting for 20% of the total PFC emissions in the semiconductor sector. Finally, an effective measure for PFC emissions control is the purification of contaminated exhaust air from various PFC-emitting processes.

4.2.5.2. Environmental benefits

In general, PFC gases are characterized by a high specific impact on global warming. Since they remain extremely long in the atmosphere, they have a much higher global warming potential per molecule than carbon dioxide. This is expressed by the characterization factor; the following table gives an overview of relevant[49] PFC gases with regards to this metric:

Table 4-8: Global warming potential (GWP) of relevant PFC gases

PFC gas	Chemical Formula	GWP characterization factor
Hexafluoroethane	C_2F_6	12,200
Tetrafluoromethane	CF_4	7,390
Trifluoromethane	CHF_3	14,800
Octofluoropropane	C_3F_8	8,830
Octofluorocyclobutane	$c\text{-}C_4F_8$	10,300
Nitrogen Triflouride	NF_3	17,200
Sulphur Hexafluoride SF6	SF_6	22,800

Source: Own table according to IPPC (2007)

As illustrated by this overview, there are substantial differences in terms of GWP between the different PFC gases. This opens up the possibility for environmental benefits, if a substance with a very high GWP (e.g. C_2F_6) can be replaced by a substitute with a lower value (C_3F_8). However, best results in terms of environmental relief can be achieved if the conversion rate of PFCs at their designated process use can be increased, and thus emissions in the environment can be avoided (see section 4.2.5.5 for more details).

4.2.5.3. Appropriate environmental performance indicators

In order to quantify the performance of best practice in the field of PFC emissions abatement, the Global Warming Potential (expressed in CO_2 equivalents – CO_2e) caused by the PFC emissions of a production site should be set in relation to the surface area of the produced wafers. Hence, the indicator has to be defined as kg CO_2e /cm².

48 In-situ refers to a cleaning process that takes place inside the CVD chamber.

49 Relevant in terms of the voluntary agreement mentioned in section 4.2.5.8.

This metric has already been established by the World Semiconductor Council (WSC), is referred to as Normalized Emission Rate (NER) and acts as key performance indicator for monitoring the progress in terms of implementing best practice within the voluntary agreements in the semiconductor sector (see section 4.2.5.8 for more details).

4.2.5.4. Cross-media effects

Cross-media effects associated with the different approaches listed in section 4.2.5.1 can be seen in the use of water that is needed as a process medium in the scrubber process during the purification of contaminated exhaust air (see section 4.2.5.5). Due to water recycling, however, this aspect is considered to be negligible.

The same applies to the additional electricity consumption of the identified abatement techniques, since the CO_2 emissions caused by electricity supply will be clearly overcompensated by the substantial reduction of GWP due to PFC emissions savings.

4.2.5.5. Operational data

According to the different approaches mentioned in section 4.2.5.1, the corresponding details for implementation and operational data are given below.

Process optimization

Within the context of process optimization, process parameters of the CVD chamber cleaning such as chamber pressure, temperature, plasma power cleaning gas flow rates, and gas ratios (in case of PFC gas mixtures) have to be adjusted. These measures could enable a reduction in emissions of up to 73% compared to the status quo (Bühler 2007; Koch 2008). However, the process has to be (partly) re-assessed, which requires significant engineering resources (ESIA 2011).

Substitution of PFC gases

A typical example for the substitution of PFC gases is the replacement of C_2F_6 by C_3F_8 (see differences in GWP characterization factors in section 4.2.5.2). These changes in process design have to be implemented within a complex process with different process tests and subsequent qualification of the modified production process (ZVEI 2011).

Remote plasma cleaning technology

Even though NF_3 also represents a very powerful greenhouse gas (see section 4.2.5.2) the replacement of C_2F_6 and CF_4 by NF_3 in remote plasma cleaning technology is associated with significant environmental relief. Within this process, NF_3 is immediately dissociated by an external plasma source into fluorine radicals. When fed into the CVD chambers, these radicals convert silicon-containing compounds into silicon tetrafluoride (SiF_4). Since a conversion factor for NF_3 of up to 99% can be reached while no recombination of PFCs is taking place, the remote plasma cleaning technology is considered to provide almost PFC-free exhaust gas qualities after treatment (Rhiemeier & Harnisch 2009; ZVEI 2011).

In fact, when compared to the original carbon-based PFC chamber cleans that they replace, retrofit remote cleaning results in 95% PFC emissions reduction (ESIA 2006; EPA 2006).

Point-of-use abatement during plasma etching

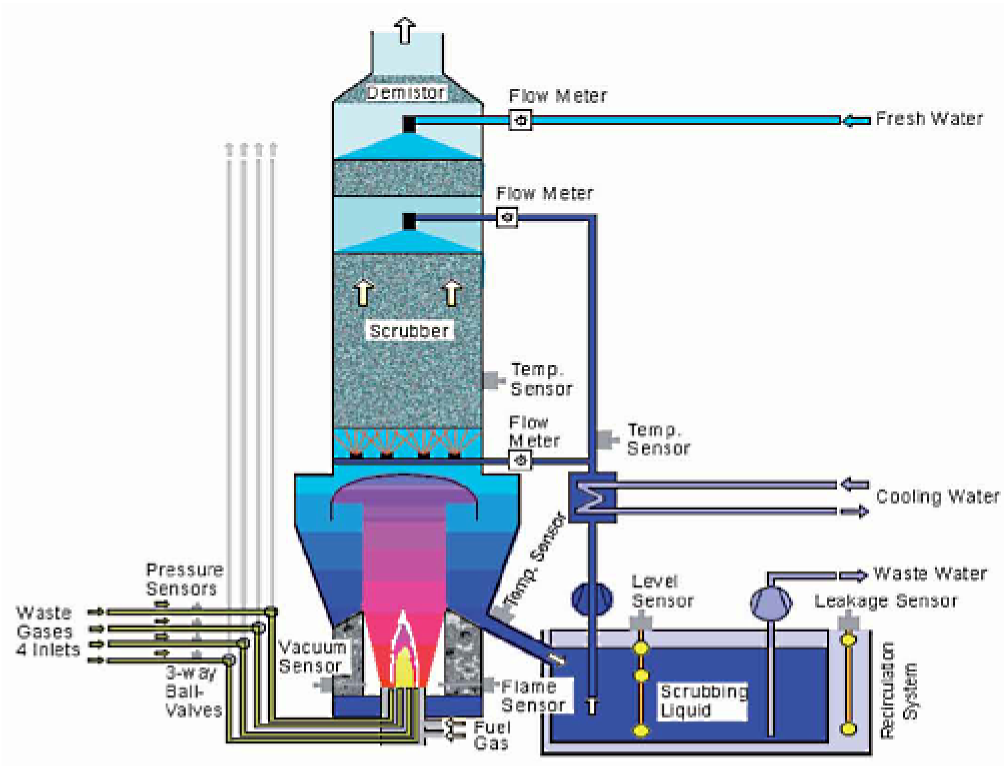
The key element of point-of-use abatement during plasma etching is a small plasma source that effectively dissociates the PFC molecules reacting with fragments of the additive gas (such as H_2, O_2, H_2O, or CH_4). As a result, low-molecular-weight substances like HF with little or no GWP are created. They can, however, be removed by wet scrubbers (Rhiemeier & Harnisch 2009).

Similar to remote plasma cleaning technology, emissions reduction efficiency of point-of-use plasma abatement during plasma etching is estimated at 95% (EPA 2006).

Installation of end-of-pipe purification techniques for contaminated exhaust air

Based on intensive research and development, efficient air purification systems are available on the market for the treatment of PFC-contaminated exhaust air, achieving an efficiency of up to 99%. When installing these exhaust gas cleaning systems (see schematic figure below), PFC emissions remaining after the implementation of the above-mentioned measures can be decomposed. This has a significant impact on reducing the absolute PFC emissions.

Figure 4-11: Schematic figure of an exhaust air purification facility (burner / scrubber system)



Source: DAS Environmental Expert GmbH, taken out of ZVEI (2011), p. 14

4.2.5.6. Applicability

Process optimization is considered to be an effective measure for emissions reduction in older production facilities, but it also helps to ensure minimising gas consumption in new CVD cleaning processes (ESIA 2011).

Due to the complexity of semiconductor processes, a substitution of PFC gases is technically not feasible in every case. This is particularly applicable to plasma etching with its increasingly stringent requirements, calling both for fluorine to etch and the right carbon/fluorine ratio (ESIA 2011; ZVEI 2011).

In principle, remote plasma cleaning technology using NF_3 is assumed to be applicable to all fabrication facilities. The same applies to point-of-use plasma etching abatement (Rhiemeier & Harnisch 2009). The quality of the new processes, however, has to be ensured, which entails the need for an intensive exchange of information with customers, and can be very time-consuming; furthermore, when considering such measures, the innovation cycle needs to be respected due to substantial costs involved (see also below). Against this background, the installation of remote plasma cleaning technology as well as point-of-use plasma etching abatement seems to be feasible only in cases when a new production facility is being built or obsolete processing equipment needs to be renewed on a larger scale.

4.2.5.7. Economics

It has to be noted that currently only process optimization is considered to be a cost-effective measure, since it opens up the opportunity for lower gas consumption and better throughput (ESIA 2011).

All the other measures mentioned in section 4.2.5.5 are associated with substantial costs. For example, it is assumed that the installation of a remote CVD cleaning system involves purchase and installation capital costs of approx. 50,000 € per chamber. In addition to that, net annual costs are estimated to total approx. 12,000 € per chamber (US EPA 2006).

Plasma abatement technology entails capital costs of approx. 30,000 € per etching chamber, which covers the purchase and installation of the system; operational expenses of about 800 € per etch chamber must be added on top of that (US EPA 2006).

The above-mentioned cost data, however, has to be understood as indicative, since there may be a large variation of costs for the different measures. For example, in case of a new fab, the cost impact will be much lower than in case of an already existing one. This is because in older production facilities, the implementation of retrofitting measures may interfere with the running production, and also space limitations can play an important role. In contrast to this, new production sites can be designed and built in accordance with the latest know-how. Thus, it will be much easier to implement best practice here (ESIA 2011).

4.2.5.8. Driving force for implementation

It needs to be stressed that both the political relevance of PFC emission reduction as well as the resulting establishment of various voluntary agreements within this context can be regarded as the most important driving forces for the implementation of best environmental management practice in this field. In terms of stimulating a voluntary agreement on a world-wide basis, the World Semiconductor Council (WSC) has played an important role. This association, which comprises the semiconductor industry associations from the most relevant production countries, lists perfluorocompounds as a top priority among its environmental policies and initiatives. For example, a voluntary agreement had the objective to reduce the absolute global PFC emissions by 10% until 2010 relative to the 1995 baseline (Hermanns 2012; Rhiemeier & Harnisch 2009).

Based on this voluntary agreement, in 2001, the semiconductor manufacturers within the European Union signed the ‘Memorandum of Agreement in between Member Companies of the European

Electronic Component Manufacturers Association (EECA), European Semiconductor Industry Association (ESIA)'. This memorandum can be seen as the relevant driver on the European level, and formed the basis 41% for reduction of PFC emissions in 2010 below the 1995 baseline. Moreover, it induced further voluntary agreements in the member states. For example, in Germany the semiconductor industry was able to reduce absolute emissions by 47%, when comparing the emissions situation of 2010 with 1995. As an important success factor, site-specific reduction plans were developed and the specific circumstances in terms of production sites and applied technologies were taken into account in order to achieve maximum overall efficiency rates (Hermanns 2012; ZVEI 2011).

4.2.5.9. Reference organisations

- Globalfoundries: Launched in March 2009, Globalfoundries is the world's first full-service semiconductor foundry with a global footprint. With operations in Singapore, Germany and the United States, Globalfoundries is represented in three continents. Globalfoundries is owned by Mubadala Technology. Globalfoundries operates Europe's largest production site for 300 mm wafers in Dresden (Germany). Within the climate protection program of the company, best practice for PFC reduction has been applied already since 1996 at the Dresden site. In particular, remote plasma cleaning technology was installed for all CVD tools. Additionally, all etching processes as well as CVD chamber clean processes are equipped with point of use abatements. For more details on PFC emissions reduction see section 4.2.5.5 (Hermanns 2012).
- Micronas: As a manufacturer of sensor-based system solutions for automotive and industrial business, Micronas produces sensors and embedded controllers for smart actuators, such as drivetrains, chassis frames, engine management and convenience functions. Within its wafer production, Micronas has optimized the C_2F_6 cleaning process on a number of CVD chambers; on other CVD chambers the cleaning processes were qualified and changed over. Both measures resulted in a reduction of 50% in C_2F_6 consumption. Even further reduction was achieved through the use of new exhaust PVC gas abatement units. (Micronas 2008).

4.2.5.10. Chapter references

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4.2.6. Substitution and optimized use of VOC-based solvents

4.2.6.1. Description

Solvents on the basis of Volatile Organic Compounds (VOC) are commonly used in EEE manufacturing for processes such as cleaning or degreasing, stripping processes, for thinning coatings, and dissolving raw materials. For example, within the semiconductor industry, the following VOC-based solvents are considered to be of major importance (Infineon 2012; Micronas 2009):

- Amine-based containing hydroxylamine (HDA);
- Cyclopentanone;
- Dimethyl formamide (DMF);
- Isopropanol;
- N-methyl-2-pyrrolidone (NMP);
- Propylene glycol monomethyl ether acetate (PGMEA).

An important process in the EEE sector where VOC-based solvents are used is the removal of residues after etching of the wafer (being the silicon substrate of integrated circuits). In order to form the ultra-fine structures on the wafer during a photolithographic process, photoresist coating is applied to the wafer surface. Subsequent removal of the photoresist mask by oxygen plasma or ozone ashing leaves polymer-like residues and needs to be removed in a further stripping process in order to prevent particle defects, electrical leakage, and subsequent corrosion. During this wet stripping, solvents based on hydroxylamine (HDA) are used; they are harmful both to human health and the environment (see section 4.2.6.2 for more details). In addition to this, also isopropanol, an easily inflammable solvent, is involved in the process (Sohn et al. 2007).

Besides stripping, also cleaning und degreasing processes need to be considered, as they are very important in the semiconductors and printed circuit boards industry as well as in many other sub-sectors of EEE.

Measurements for improving the environmental performance of solvents can comprise the substitution of VOC-based solvents with water-based substances (aqueous solutions), especially dilute-acid chemicals for removing post-etch residues from wafers (see above). More complex measures address the installation of solvent recovery equipment, which produces a secondary solvent that may be used for the same process or other uses with lower process requirements (e.g. degreasing). Other abatement approaches are more focused on the elimination of the hazard potential to humans and the environment, such as incinerators or vapour condensers. Since they do not provide any direct saving potentials for the manufacturer, they will be not further considered within this section.

Against this background, a strategic approach for best environmental management practice regarding the substitution and optimized use of VOC-based solvents should consider the following two elements:

- Substitution of VOC-based solvents by semi-aqueous chemicals;
- On-site solvent recovery.

Amine-based chemicals have been the standard solution for post-etch residue removers for a long time. Therefore, many variations of amine-based chemicals are available from different chemical suppliers, the most common products of which contain hydroxylamine (HDA) as the main active

component. These chemicals also include chelating agents, surfactants, as well as other solvents, and are applied in immersion baths or as wafer-surface sprays. Although HDA-based solvents are reliable and offer a relatively large process window, they require special waste treatment. Hence, they have to be collected after use and need to be transported to the manufacturer for disposal. Furthermore, HDA-based post-etch residue removers are known to produce a pH spike during the initial water-rinsing steps, which leads to etching and pitting of exposed aluminium. This phenomenon can be tackled through an intermediate rinsing step using isopropanol or a buffered solution before final water rinsing. Finally, HDA-based solutions also require relatively high temperatures (60–70°C) and long exposure times (10–20 minutes) in order to ensure effective residue removal.

When installing on-site solvent recovery systems, vapour emissions from VOC-based solvents can be controlled and high-purity solvents will be obtained for different manufacturing processes in the EEE sector, such as (Megtec 2014):

- Lithium-ion battery electrode manufacturing;
- Photoresist stripping from IC and PCB manufacturing;
- Degreasing of metal parts used in general EEE manufacturing.

4.2.6.2. Environmental benefits

Since the vast majority of organic solvents are derived from crude oil, a direct relation between the use of solvents and energy demand / resource depletion as well as associated greenhouse gas emissions is evident (ESRG 2010). When substituting solvents or using them in a more efficient manner substantial environmental savings in terms of these environmental pressures can thus be achieved.

Moreover, concerning health aspects, many VOCs are known to act as irritants or carcinogens; some of them are toxic and highly flammable. When released to the environment, VOCs have a high photo-oxidant formation potential and thus contribute to the formation of summer smog (low level ozone). This causes respiratory diseases and damages crops and plant life.

In terms of environmental optimization, particular attention should be given to substitution of VOCs classified as carcinogenic, mutagenic and reprotoxic (CMR) substances and halogenated VOCs carrying risk phrases R40[50]/R68[51] (Bauer et al. 2009).

Against this background, when substituting e.g. amine-based containing hydroxylamine (HDA), a high-priority substitution potential is addressed, since HDA is labelled (among other aspects) by the following hazard statements (BASF 2012):

- Harmful in contact with skin;
- Causes skin irritation;
- Cases serious eye damage;
- Suspected of causing cancer;
- Very toxic to aquatic life.

50 Limited evidence of a carcinogenic effect

51 Possible risk of irreversible effects

4.2.6.3. Appropriate environmental performance indicators

Concerning the approach of substituting a VOC-based solvent by semi-aqueous chemicals, best environmental performance cannot be measured with quantitative indicators. Hence, a qualitative environmental performance indicator should detect whether such a substitution could be implemented in the respective case (yes / no).

In terms of on-site solvent recovery, best environmental performance can be measured in a quantitative way. As a meaningful metric, the solvent recovery rate should be used, defined as the share of recovered solvent compared to the used amount of solvent. This metric has already been introduced in the public debate concerning the sustainable use of solvents (Creswell 2013).

4.2.6.4. Cross-media effects

When planning and implementing measures concerning the substitution and the optimized use of VOC-based solvents, it is essential to consider the impacts on the environment as a whole on a case-by-case basis. Thus, possible options should be assessed and selected on the basis of a balanced assessment of all relevant cross-media effects, the environmental pressures of energy use, water and waste / soil being of particular importance (Bauer et al. 2009).

In order to adequately address the questions that need to be answered in the context of such an integrated assessment, performing Life Cycle Assessments of life-cycle-thinking oriented studies are highly recommended (see section 5.2.5).

When assessing substitution options, it should also be considered that REACH[52] prohibits the substitution of harmful substances by more harmful substances (see REACH Articles 60(5) and Article 64(4)).

When returning to the example of substituting amine-based formulations containing hydroxylamine (HDA), it can be stated that this measure in total lowers the health risk for the service and maintenance staff, and cuts the environmental impact through the reduced use of solvents. Besides environmental cross-media effects, it has also to be mentioned that process performance can be enhanced, which eventually contributes to cost savings (see section 4.2.6.7).

In terms of solvent recovery, however, it needs to be demonstrated on a case-to case basis in which cases solvent recovery is the best environmental option. This is necessary due to specific and complex energy requirements concerning the production process of a virgin solvent, which needs to be compared with the energy demand of the recovery process and a potential end-of-pipe treatment if the solvent is alternatively combusted. Within this context, also the condition of the incoming exhaust air / solvent waste stream and the chemical type of any solvent contamination needs to be taken into consideration (ESRG 2010).

4.2.6.5. Operational data

According to the different approaches mentioned in section 4.2.6.1, the corresponding details for implementation and operational data are given below.

52 REACH regulation (EC) No 1907/2006.

Substitution of VOC-based solvents by semi-aqueous chemicals

Within the context of environmental concerns already mentioned in section 4.2.6.2 and the shortcomings of HDA-based solutions described above, front-running IC manufacturers have opted for alternative cleaning chemicals. These substitutes are semi-aqueous chemicals containing dilute acid formulations of sulphuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) in the concentration range of 1–15% by weight. Besides sulphuric acid and hydrogen peroxide, also a minor concentration of hydrofluoric acid (HF) is required (see Table 4-9) in the formulation of this solvent, that can be accurately mixed and diluted at the point of use in the production sites based on readily available and relatively inexpensive concentrated solutions (see section 4.2.6.7 for more details) (Sohn et al. 2007).

It is interesting to note that concentrated and dilute-acid mixtures have already been used for decades within IC manufacturing. However, they were only applied where silicon and silicon oxide were processed, and were not used in preference when aluminium and other metals were processed because of to the risk of damage to the metal. In recent years, dilute-acid mixtures have been employed successfully to achieve effective etch-residue removal in aluminium lines (M1 and M2) [53], silicon oxide vias[54], and open bond pads[55] (Sohn et al. 2007).

The following table gives an overview over the chemical concentration ranges, dispense times and solution temperatures that are typical for the application dilute-acid mixtures of H_2SO_4, H_2O_2 and HF.

Table 4-9: Process conditions for dilute-acid mixtures

Application level	H_2SO_4 (wt. %)	H_2SO_4 (wt. %)	HF (ppm)	Dispense time (s)	Solutions temperature (°C)
M1, M2, Vias	5-15	2-20	0-150	60-150	20-35
Bond pads	2-15	2-4	0-150	420-450	20-35

Source: Own table according to data from Sohn et al. (2007)

As the table shows, dilute-acid chemical solutions blended at the point of use can remove etch residues at aluminium lines (M1, M2) as well as the level of silicon oxide vias in approx. two minutes and at a very moderate solution temperature of 20-35°C. This is regarded to be a substantial improvement compared with process conditions of HDA-based solutions (10-20 minutes and 60-70°C, see above).

On-site solvent recovery

In order to remove VOC, solvents and odours from the exhaust air of manufacturing processes during on-site solvent recovery, carbon adsorption technology has proven as an effective method. As collection medium, usually activated carbon is used because it is the most versatile of all adsorbents. The reason for this can be seen in its broad pore size distribution and pore volume,

[53] Layer of an integrated circuit made out of aluminium that defines the conductors (M1 = metal 1 mask; M2 = metal 2 mask).

[54] Part of an integrated circuit made out of silicon oxide that defines the connections between the conducting layers.

[55] Place on an integrated circuit where the bonds (i.e. the connections between chips and circuit boards) are connected.

which makes it suitable for virtually any process generating solvent-laden air. Carbon adsorption technology can achieve removal efficiencies of more than 99.9%. After adsorption with the solvents, the activated carbon is regenerated with steam, followed by a chilled fluid condensation and packed bed fluid scrubbing to remove and recover the solvents from the exhaust air. Depending on the process requirements, these solvents may be reused in the same process, thereby generating substantial savings over other emission control methods that destroy the solvents (Megtec n.y.).

4.2.6.6. Applicability

The processes described in detail in the previous section are primarily applicable for the semiconductor industry, especially concerning the concrete substance substitution information for the mentioned solvents. However, the fundamental principles regarding substitution (of VOC-based solvents by semi-aqueous / water soluble chemicals) are considered to be important and feasible throughout the EEE sector as a whole.

In addition to this, solvent recovery offers an interesting alternative to end-of-pipe abatement technologies for VOC emissions that are generally applicable for the EEE sector. This is particularly relevant in cases where the quantity of solvents is large, the value of the solvents is high, or the solvents contain chlorine, bromine, fluorine or nitrogen (Megtec2).

4.2.6.7. Economics

Concerning the example of substituting amine-based post-etch residue removers, significant cost saving potentials can be realised. While the costs for formulations containing HDA can exceed 1 US-Dollar per wafer, dilute-acid-mixtures of H_2SO_4, H_2O_2 and HF are relatively inexpensive. In the following table, the cost performance of a four-chamber single-wafer tool, a semi-automated batch spray tool, and an automated batch spray tool of different 200-mm wafers are specified, indicating also the total chemical costs. Although these costs may vary between different countries, they can be as low as 2 US-cents per wafer when used in a 200-mm batch spray system (Sohn et al. 2007).

Table 4-10: Performance comparison between 200-mm single-wafer and batch tools used to clean M1 lines with an optimized dilute-acid solution composed of H_2SO_4, H_2O_2, and HF

Performance Parameter	Four-chamber single-wafer tool	Semi-automated batch spray tool	Automated batch spray tool
Batch size (wafers/run)	1	100	100
Throughput (wafers/hour)	130	250	250
Footprint (m^2)	4.6	3.1	6.3
Total chemical usage (ml/wafer)	127	5.1	5.1
Typical chemical cost (US-$/wafer)	0.46	0.02	0.02

Source: Own table according to data from Sohn et al. (2007)

In a case study documented by Micronas, cost savings totalled 1.2 Million Euros for a four-year project that had the objective to implement a substitute for conventional post-etch residue removers (Micronas 2009). For more details see section 4.2.6.9.

Solvent recovery systems help to save costs, both related to purchasing and disposal. This is especially interesting since most solvents are rather expensive to buy, and also to dispose of as they are classified as hazardous waste. If the solvent can be recovered and reused in the process, significant cost savings can be created. The overall economic feasibility and the corresponding payback times, however, depend of the specific situation. In analogy with the ecological feasibility, the cost structure of the production process of the virgin solvent needs to be considered and compared with the specific costs of the recovery process and a potential end-of-pipe treatment if the solvent is alternatively combusted. Generally, it can be assumed that the higher the use value of the produced secondary solvent is, the more advantageous is solvent recovery from an economic point of view.

4.2.6.8. Driving force for implementation

Since important measures described in this best practice approach are associated with cost savings potentials, economic aspects can be considered to be the main driver for implementation. Within this context, existing shortcomings of conventional solvent systems, such as a long process dispense time in the case of amine-based post-etch residue removers (see section 4.2.6.5), can increase this effect.

Another important driver for the substitution and optimized use of VOC-based solvents in the EEE sector and industrial installations using organic solvents in general can be seen in the Council Directive 1999/13/EC1 of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Finally, also the Best Available Techniques Reference document on Surface Treatment using Solvents developed under the IPPC Directive (2008/1/EC) as adopted by the European Commission in 2007 fosters the environmental optimization of VOC-based processes and provides extensive information for solutions at the process level (European Commission 2007).

4.2.6.9. Reference organisations

- Infineon: At its production site in Villach, VOC-based solvents are recycled on-site in an installation, which was developed in-house. Following this approach, 15% to 30% of DMF and PGMEA solvents could be recycled through internal distillation measures in the fiscal years 2009-2012. However, recycling rate has recently decreased, due to increased demands for the separation processes arising from technology-related process-specific impurities. Thus, two-thirds of the amount of recycling, in particular cyclopentanone and NMP, was processed externally with a yield of 50% to 65%. (Infineon 2012).
- Micronas: As a manufacturer of sensor-based system solutions for automotive and industrial business, Micronas produces sensors and embedded controllers for smart actuators, such as drivetrains, chassis frames, engine management and convenience functions. Within its wafer production, Micronas has exchanged a conventional post-etch residue remover by an aqueous solution (Micronas 2009).

4.2.6.10. Chapter references

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Megtec (2014)	MEGTEC Systems, Inc. (eds.); Solvent Recovery Systems; retrieved from: http://www.megtec.com/solvent-recovery-carbon-adsorption
Megtec (n.y.)	MEGTEC Systems, Inc. (eds.); Environmental compliance & energy efficiency improvements; Gas Cleaning & Purification of Solvents; retrieved from: http://www.megtec.com/uploads/Product%20and%20Market%20Brochures/ECE%20Solutions/Environmental%20Compliance%20and%20Energy_Gas%20Cleaning%20and%20Purification%20of%20Solvents_Europe.pdf
Micronas (2009)	Micronas (eds.); Four birds with one stone. In: Micronas Environmental News 2009, p. 3; retrieved from: http://www.micronas.com/sites/default/files/downloads/files/UmweltNews09_E.pdf
Sohn et al. (2007)	Sohn, H.-S.; Butterbaugh, J.W.; Olson, E.D.; et al.; Using cost-effective dilute-acid chemicals to perform postetch interconnect cleans; retrieved from: http://micromagazine.fabtech.org/archive/05/06/sohn.html

4.2.7. Water savings and recovery in cascade rinsing systems

4.2.7.1. Description

Water is essential for life. The management and protection of water resources is “one of the cornerstones of environmental protection”[56] for the European Commission and was therefore the focus of the EU’s water policy over the past thirty years. The most recent policy document is the ‘Blueprint to safeguard Europe's water resources’ (COM/2012/0673). It aims to ensure that good quality water is available across Europe in sufficient quantities for all legitimate uses. Thus, water efficiency is an important target for political reasons.

As for the manufacturing of EEE, there is no comprehensive overview on the amounts of water used. Rather, manufacturing of EEE is considered together with all industry sectors in general (BIO IS 2009; Ecologic-Institute 2007). One of the industrial sectors using the largest amounts of water is metals production and transformation, being relevant for the manufacturing of EEE. Within metal surface treatment, wet processes such as plating use large quantities of water, mainly for cleaning and rinsing and as solvent for metals to be precipitated on the metal surface (Ecologic Institute 2007).

Technological developments for water savings in metal surface treatment generally comprise the separation and advanced treatment of wastewater, the monitoring of bath quality and/or increase of bath lifetime and the reduction of drag out of bath (Ecologic Institute 2007). Best Available Techniques are also summarized in the BREF document on the Surface Treatment of Metals and Plastics (BREF 2006): Basically, a reduction of rinsing water consumption is closely related to the reduction of drag-out that can be achieved by different means such as e.g. the use of compatible chemicals, raising the temperature of the process solution, sucking off or blowing off a considerable part of the drag-out. Among the rinsing techniques described in the BREF document, multiple stage rinsing is assessed as being particularly suitable to achieve a high rinsing rate with a small amount of rinsing water.

This BEMP focuses on the specific wet processes used to manufacture printed circuit boards (PCB). PCB manufacturing is a complex process which can comprise over 40 activity stages and vary greatly depending on the design of the board (BREF 2006). The largest amount of water within the process is used for rinsing purposes between process steps, or as make-up water for recirculating water rinse systems. Water is also used as the medium in process baths, for the washing of filtration and heat-exchange equipment. Furthermore, it may be used in cooling systems, which, however, account for a smaller proportion of the quantity consumed (BREF 2006).

Technologically, the different processes in PCB manufacturing are implemented in individual baths or cascades. Best water savings are achieved by cascade rinsing systems combining a high rinsing rate with a small amount of rinsing water. Cascade rinsing systems are available in horizontal and vertical installations. Horizontal production lines make up 80% of the installations used (Wolfer 2014). The state of the art is the multiple use of rinsing water:

- In vertical installations: two cascades with additional spray rinse; water supply only during treatment; limiting the water supply by spray rinse after treatment.
- In horizontal installations: three cascades; standby function for water flow.

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[56] EU COM DG ENV: http://ec.europa.eu/environment/water/index_en.htm

Frontrunner PCB producing companies implement water saving measures by investment in multiple cascade rinsing systems and in measures for existing plants through retrofitting or optimizing the existing equipment.

4.2.7.2. Environmental benefits

The great amount of water consumed in the multiple process steps in PCB industry has a considerable impact on the environment. The best practices in cascade rinsing systems help protect the environment by conserving drinking water. It has to be noted that water scarcity and drought is an increasingly frequent and widespread phenomenon in the European Union. In some European regions and seasonally-induced, the supply of good quality water in sufficient quantity means a big effort and necessitates the development of specific drought plans.[57]

The reduction of rinsing water also contributes to a reduction of waste water. However, it is rather difficult to quantify this effect on a general basis, since in some production sites additional water input is necessary for e.g. cleaning, water loss occurs by evaporation and additional water re-use might be installed between the lines.

4.2.7.3. Appropriate environmental performance indicators

The amount of water used in PCB production is usually expressed as water consumption in litres per m² PCB produced. However, water consumption differs greatly depending on the type and the functionality of the PCB (e.g. double-sided versus multilayer PCB). Water consumption increases in manufacturing multilayer boards with a higher layer count. According to the BREF 2006 document, water consumption ranges between 170 and 600 l/m². However, it is unclear whether water for washing and cleaning equipment, for example, is comprised in this average value.

For example, Würth Elektronik indicates the amount of water for:

- Double-sided PCB (54 process steps, thereof 36 wet processes): 130 – 160 litres rinsing water per m² PCB
- Multilayer PCB, 10 layers (114 process steps, thereof 72 wet processes): 300 – 350 litres rinsing water per m² PCB

Taking into account the amount of water consumed for new process bath preparations and cleaning water, total water usage, however, is 30% higher (Wolfer 2014).

As for water savings in existing plants by means of internal optimization, a comparison of individual measures is not feasible because measures are not described in detail:

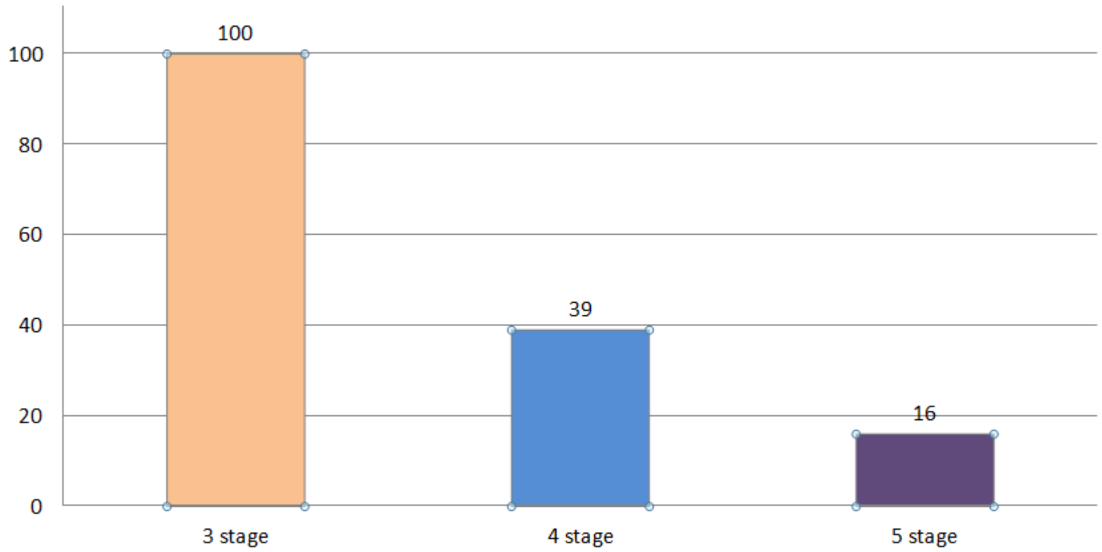
- Würth Elektronik indicates water savings in existing plants through efficiency measures described in section 4.2.7.5 to account for more than 50% of the water quantity consumed (Wolfer 2014).
- Reduction measures concerning the water flow in rinse lines in a PCB producing facility resulted in a 12.5% reduction in water demand (Ecologic-Institute 2007).

[57] e.g. London and south-east England are already seriously water-stressed: https://www.london.gov.uk/priorities/environment/tackling-climate-change/weather-climate/meeting-the-challenge-of-droughts

Against the background of the great differences between the specific rinsing water demand for the different types of PCB and the varying product portfolios processed at the different companies, it is not reasonable to assess best environmental management practice on the basis of rinsing water demand per m² PCB. Instead, a comparison of water consumption of systems comprising different numbers of cascades seems to be much more suitable for the purpose of measuring water efficiency (see Figure 4-12).

This figure shows that a significant reduction of rinsing water demand can be achieved through the implementation of a four-stage cascade rinsing system. Compared to a system with three stages, a reduction of more than 60% can be achieved. When implementing a five-stage cascade rinsing, the reduction exceeds 80%, while the remaining rinsing water demand is less than 1 litre per m² PCB (Wolfer 2014).

Figure 4-12: Comparison of water consumption in cascade rinsing systems comprising 3, 4 and 5 rinsing bathes



Source: Wolfer (2014)

Since a three-stage cascade rinsing system is already defined as state-of-the-art technology by the German legal framework,[58] best environmental management practice should be defined as the **number of cascade rinsing systems with at least four stages** compared to the total number of necessary rinsing systems within PCB production. The result of this comparison should be given as a share (expressed in per cent). This definition already takes into account the currently limited technological and economic feasibility of five-stage cascade rinsing systems (see sections 4.2.7.5 and 4.2.7.7).

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58 Details to Annex 40, Metal Processing and Metal Treatment of the German Waste Water Ordinance: http://www.lfu.bayern.de/wasser/merkblattsammlung/teil4_oberirdische_gewaesser/doc/nr_452_40.pdf (available in German only);

Federal Water Act; Waste Water Ordinance, Annex 40 Metal Processing and Metal Treatment: http://www.gesetze-im-internet.de/abwv/index.html (available in German only), implementing the EU Directive on Urban waste water treatment: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=URISERV:l28008&from=DE&isLegissum=true

4.2.7.4. Cross-media effects

The rinsing water, given varying grades of contamination due to the different process solutions, must be pre-treated prior to discharge into a municipal sewage system, in order to comply with legal requirements. A maximal reduction of waste water in a five-stage cascade system can lead to higher amount of chemicals in deionisation needed for waste water treatment, and in longer time needed for sedimentation and filtration prior to discharge into a municipal sewage system (Wolfer 2014).

4.2.7.5. Operational data

Water auditing of the individual plants as well as of the specific installations is an optimal starting point for identifying the areas where most water can be saved. As for wet processes, water auditing needs to consider both water quantity and water quality aspects (Ecologic-Institute 2007).

For an audit to succeed, each and every employee is required to take a critical look at water consumption patterns for their particular stage of the manufacturing chain, and to continuously monitor the relevant processes (AT&S 2014).

If the parameters such as the drag-out (taking into account the chemical composition and the amount of process solution) and the speed of processing through the lines are optimized as well (Rossmann 2014), the number of cascades is the most important determinant for water saving: As for new installations, multiple cascade rinsing systems with four stages are currently best practice (Wolfer 2014). Rinsing systems comprising four stages need less than half of the water compared to a three-stage system. A five-stage cascade system again cuts the water demand of four-stage cascade system by half (see Figure 4-12). However, as for five-stage cascade rinsing system there are some limiting factors:

- Heating of the rinsing bath water due to increased numbers of pumps, which increases pressure by germ contamination;
- Highly concentrated rinse water leads to a greater use of chemicals and longer time needed for sedimentation in deionisation for waste water treatment.

Thus, five-stage cascade rinsing system can only be recommended in certain cases, and are rather limited to special conditions (e.g. extremely high machine throughput or highly concentrated electrolytes). In cascade rinsing systems with four and more stages, there is a far greater risk of germ contamination by bacteria and fungus, which constitutes a major obstacle to the realisation of water savings. New installations are therefore usually equipped with UV lamps (Wolfer 2014).

Alternatively, a new technology is available that serves as an antimicrobial contact catalyst sterilizing aqueous solutions. Specifically structured and coated silver surface which has been up-graded and conditioned by a patented post-treatment results in a highly efficient antimicrobial surface.[59]

AGXX® can be produced as foil, net or powder, and consists of a coating on different materials like stainless steel, plastic, glass or ceramics. The coating consists of a bio-active silver surface with a micro-porous structure, which is then coated with another precious metal and conditioned by special bio-molecules. This complementary coating as a cover results in a minimal release of silver

59 AGXX®, new bioactive contact catalyst for decontamination of aqueous systems: http://www.agxx.de/en/

ions. Its antimicrobial action mainly takes place on or very close to the AGXX surface by depolarizing biological membranes and subsequent cell lysis.

Würth Elektronik has applied AGXX® Raschig rings in a four-stage cascade rising systems in 2014, and was able to control germ contamination successfully.

Figure 4-13: Baskets with AGXX®-Raschig rings for antimicrobial protection of basins and tanks

Source: Largentec 2014

Water savings in existing installations need a first monitoring in order to optimize the process in the second step. The manufacturer's information on the rinse water flow must be checked carefully, and can be adapted to the specific process conditions.

The following measures are applied by different manufacturers (Rossmann 2014, Wolfer 2014):

- Water intake in rinsing bathes according to process specific quality requirement: The need for water intake depends on the concentration of the active bath, the carry-over and the amount of rinse bath. The quality of rinsing water should be measured in the second last cascades and triggers a defined water inflow regulated by a magnetic valve / electronic volume metre. The last rinse bath has to be monitored periodically in order to detect changes in the carry-over. The monitoring of the conductance value and the controller for the water intake are computer-based applications and need a software tool.
- Re-use (double use) of rinsing bath water for different working steps: The separate collection and re-use of rinsing water can be transferred between processes where the working steps need the same chemical composition (e.g. rinsing before and after post dip).

4.2.7.6. Applicability

The measures described for existing installations can be applied by any companies using cascade rinsing systems.

For new installations, the available space in the facility might be a limiting factor and needs to be taken into account both during planning of the measures and in terms of economic feasibility.

4.2.7.7. Economics

Although a significant reduction of operational costs by water savings are stated by the interviewed companies, it is difficult to indicate prices and revenues, as water pricing and water tariffs vary in the EU. The savings in operational costs derive not only from water savings but also from a reduced amount of waste water. Charges for municipal waste water treatment also vary in the EU; the same is applicable to costs for on-site waste water treatment. The different (waste) water taxes in the EU countries reflect the diversity of local scarcity and pollution conditions as well as legal, administrative and socio-economic set ups (e.g. in terms of water rights, water management structure, market structure for water supply companies, etc.) (Ecologic-Institute 2007).

Against this background, specifications of pay-back periods are provided because they allow confidentiality of business-related information, but give an indication and incentive for other companies to apply comparable measures.

Würth Elektronik indicated the following pay-back periods for the measures described in section 4.2.7.5. The pay-back periods, however, depend on the regional water and waste water tariffs; hence, in different regions or other European countries with higher specific charges for water supply and treatment, economic break-even can be achieved within a shorter period. The pay-back periods given in Table 4-11 are based on a pricing of 4 € per m³ for water and waste water, which does not comprise internal waste water treatment costs; taking internal waste water treatment costs into account, water prices reach 12 to 18 € per m³.

Table 4-11: Water saving measures in cascade rinsing systems and their pay-back periods in Southern Germany

Water Savings achieved through:	Pay-back period in years
Installation of a 4-stage cascade rinsing system in new installations	2–3
Installations of a 5-stage cascade rinsing system in new installations	> 3
Reduction measures in existing installations if implementation (development of software tool, plant modifications) can be done in-house	< 1
Reduction measures in existing installations if implementation (development of software tool, plant modifications) cannot be done in-house	~ 2

Source: Wolfer (2014)

Taking into account the regulatory background and considerations of the EU COM to promote water management also through pricing (COM/2012/0673), it can be expected that water efficiency will become economically more attractive in the future.

4.2.7.8. Driving force for implementation

The interviewed companies stated mainly two streams of driving forces:

- An important driving force is corporate responsibility and the commitment of the companies to protect resources. This goes hand in hand with a validation of EMAS / certification of ISO 14001 environmental management systems that provide incentives to review water use and identify potential water savings. Also the implementation of ISO 50001 Energy management systems was mentioned to trigger the implementation of water saving measures.
- Water savings provide a significant reduction of operational costs.

4.2.7.9. Reference organisations

- AT&S: In the production site in Fehring (Austria), 40% of all cascade systems comprise 4- to 6-stage cascades; besides measures are implemented such as e.g. defined water intake and water re-use between process lines;
- Würth Elektronik: Most of the etching lines installed after 2003 were equipped with a cascade rising system having four or more stages accounting for a share of two thirds of all lines; furthermore; various retrofit measures were implemented (see section 4.2.7.5 for more details).

4.2.7.10. Chapter references

AT&S (2014) AT&S, First choice for advanced applications, Sustainability Report 2013/14; http://www.ats.net/wp-content/uploads/2014/07/ATS_NHB2014_EN_28_WEB.pdf

BIO IS (2009) General overview on water efficiency; study EU COM; http://ec.europa.eu/environment/water/quantity/pdf/Water%20efficiency%20standards_Study2009.pdf

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COM/2012/0673 Blueprint to Safeguard Europe's Water Resources, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0673&from=EN

Ecologic-Institute (2007) Final report EU Water saving potential (Part 1 Report) ENV.D.2/ETU/2007/0001r 19. July 2007: http://ec.europa.eu/environment/water/quantity/pdf/water_saving_1.pdf by Ecologic - Institute for International and European Environmental Policy

Largentec (2014) Largentec Vertriebs GmbH (eds.); Practice Results - AGXX® in the decontamination of Cooling Water; http://www.agxx.de/en/decontamination-cooling-water.htm

Rossmann (2014) Personal communication by Thomas Rossmann, AT&S Fehring – Process Engineering, on 15 December 2014.

Wolfer (2014) Personal communication by Dr. Klaus Wolfer, Würth Elektronik, Resource Management, on 28 October 2014.

4.2.8. On-site recycling of metals in process chemicals

4.2.8.1. Description

In the EEE production, wet processes are the most chemically intensive production processes. Thus, the wet processes have been selected for a closer look on innovative solutions for the recycling of process chemicals, focusing on on-site solutions.

To prevent the loss of metals and other raw materials, several technologies are available in the surface treatment of metals to recover chemicals from industrial waste streams, including contaminated soils (BREF 2006). Thus, the recovery of chemicals from surface treatment of metals and plastics can be seen as an advanced treatment of waste streams. Although technologies are basically available and are being applied by frontrunner companies, the applicability on a large scale is often neither efficient nor cost-effective. This fact is reflected by the research project ECOWAMA funded by the European Union's Seventh Framework Programme.[60]

The recovery of chemicals within installations is widely performed for precious metals, e.g. platinum, gold, silver, palladium, rhodium and ruthenium, the reason being that it is cost-effective. However, electrolytic recovery can also be used for other metals, such as copper or nickel, but, of course, depends on cost-effectiveness as well. The recovery of precious and transition metals is usually achieved from waste water by electrolysis (plating out on high surface area electrodes in metal recovery cells). The process efficiency of the electrolysis can be increased by a sophisticated cathode design (rotating tube cell, graphite fibre cathode), or by fluidised bed cells to overcome cathode surface depletion (BREF 2006).

Advanced recovery systems combine electrolysis with other technologies in order to increase the concentration of the metal ions. For example, ion exchange can be used to concentrate the target metal in the rinse water. Ion exchange techniques remove metal ions from solution by substituting them by weakly bound ions in a resin or organic liquid (BREF 2006). For electrolytic metal recovery, used process solutions (not containing phosphate) from metal electroplating, rinsing (drag-out) concentrates and waste water are suitable. The generated metals are of high purity which permits a direct in-house use. Besides, it can be sold in the scrap metal trade (BREF 2006).

Especially, the printed circuit board (PCB) production involves many special chemicals and valuable materials. In particular for copper, large quantities are contained in the basic etching solution and in the rinsing water. There are methods to concentrate the copper in a solution or in sludge, and to sell it to specialist recyclers. This best management approach describes the possibility of an on-site copper recycling from etching process agents in PCB production. The process is basically also described in the BREF document however the focus there lays on the recycling of alkali etchants which is achieved at the same time. Here the focus is on the recovery of copper as an example for metal recycling in process chemicals.

As for copper, the increasing global demand resulted in an increased ore production. Ore production for copper almost doubled between 1985 and 2005 (see Table 4-12). Against a background of a real threat of physical scarcity, copper requirements are increasingly being met by recycling (Glöser et al. 2013).

[60] http://www.ecowama.eu/index.html

Table 4-12: Ore production of copper in million t/a in 1985, 1995 and 2005.

	1985	1995	2005
Copper ore production in million t/a	8.54	10.1	15.1

Source: Oeko-Institut (2007)

The possibility of an on-site copper recycling from etching process agents in PCB production is presented as an example of metal recovery in process chemicals. The economic conditions are more favourable for an implementation then described in the BREF 2006 based on a basically higher though strongly fluctuating copper price then at the beginning of the millennium.

4.2.8.2. Environmental benefits

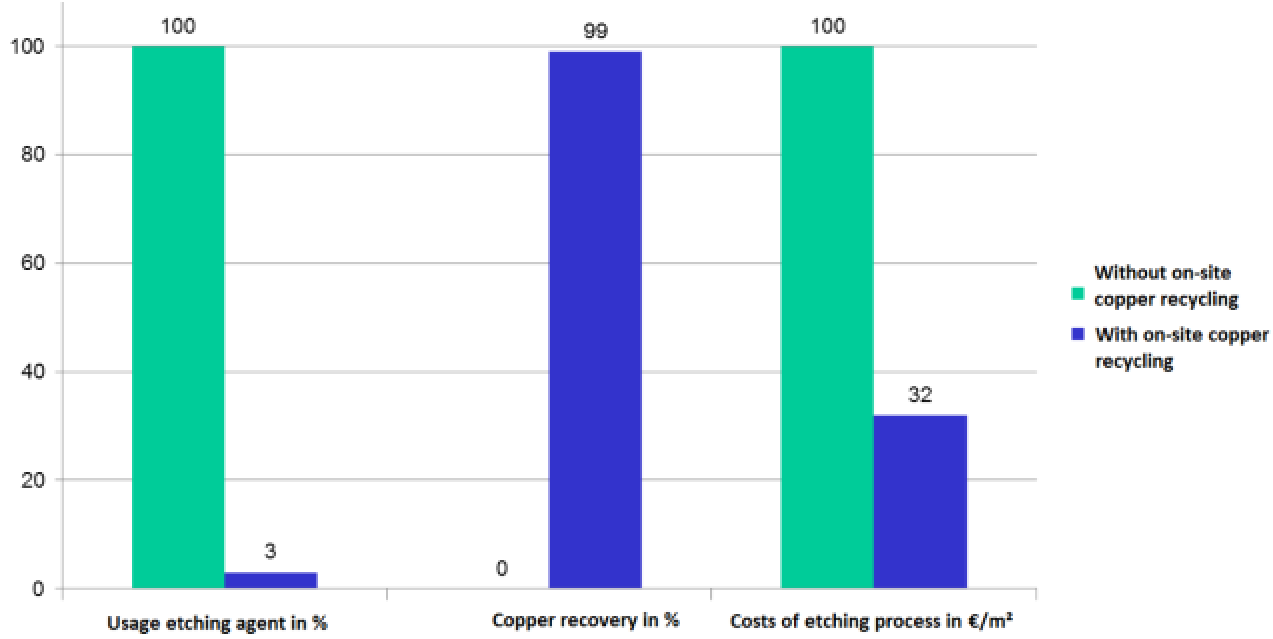
On-site copper recycling from PCB etching processes results in various environmental benefits. So far, the use of etching agents has been limited to the maximum amount of copper in the etching agent. If the value of 150 g/l copper was exceeded, a new etching agent (replenisher) was added. The on-site recycling of copper allows for an extended use of the etching agent. Thereby, the amount of the etching agent is reduced by more than 95% (see Figure 4-14).

As rinsing water also undergoes a copper extraction, it can be recycled, and formation of sludge in the rinse section of the etching line can be eliminated. Thereby, the quantity of water consumption and waste generation is also reduced.

Before on-site copper recycling was available, the etching agent used had to be transported to an external recycler. As the etching agent used was classified as a dangerous substance, it had to be transferred by transport of dangerous goods by road. The reduced amount of dangerous goods and its transport by road is primarily a qualitative aspect (reduced risk for environmental contamination). The overall reduced transport of material can be calculated in reduced CO_2 emissions. The amount of CO_2 equivalents, however, depends on the distance between the facility and the external recycler.

The environmental benefits presented in the BREF 2006 mentioned three points which are the reduction of ammonia and copper in the effluent, the recovery of about high quality copper and the decreased noise to local residential property from delivery and disposal vehicles.

Figure 4-14: Advantages of on-site copper recycling from the PCB etching solution



Source: Wolfer (2014)

4.2.8.3. Appropriate environmental performance indicators

The installation of copper and alkaline etcher recycling has many environmental benefits that are not directly measurable, such as additional water savings, reduced waste by elimination of sludge formation and reduced chemical input (replenisher). Though the amount of recycled and sold copper could be a suitable indicator, the amount of copper depends on the production and throughput. Besides, also original copper foil which was not used in the PCB production is disposed of by selling it together with the recycled copper.

Thus, the installation of a copper recycling system can be a more effective indicator for implementation. It allows an estimation of the various environmental benefits (reduction of etching agent; reduction of transport of hazardous goods, reduced risk of environmental contamination etc.) independent from the current production.

4.2.8.4. Cross-media effects

The electro-winning unit needs energy and increases the energy demand of the company. However, the copper refinement needs an electrochemical process which is the last refining stage anyway. Thus, the higher energy demand for the company is not a negative cross media effect from a copper life cycle perspective.

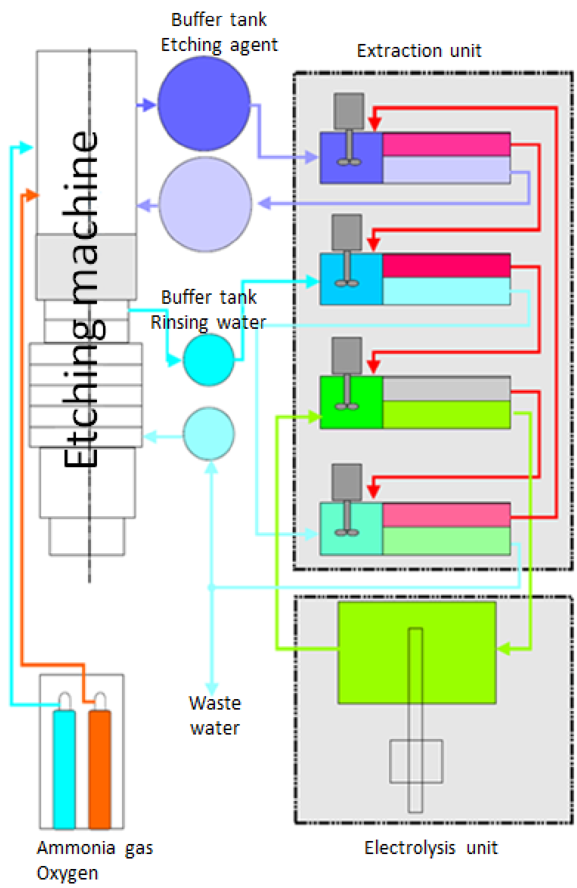
4.2.8.5. Operational data

Copper recycling from the etching solutions in PCB production can be performed in a separate system that does not necessarily need to be installed next to the etching process.[61]

The system comprises several stages where an organic solution is loaded with the copper from used etchant and rinse water, using a solvent extraction process (also called liquid ion exchange). The copper is then transferred to an acid electrolyte. The organic solution is regenerated by a washing cycle with rinse water which reduces the copper content to <0.5 ppm. The acid electrolyte is being led into an electro-winning unit where the copper is plated onto copper starter sheets as cathode surface. When a cathode's weight reaches ~125 kg, it is removed from the system. The acid in the electrolyte is ready to be used again to strip the copper from the organic.[62]

It has to be noted that the installation for the copper and etchant recycling needs space of about 80 m² for buffer tanks for both etchant and rinsing water, the extraction units for the etchant as well as rinse water and for the electro-winning unit.

Figure 4-15: Model of the alkaline etchant and copper recycling installation next to the etching line



Source: Wolfer (2014)

[61] A description of the system 'Alkaline Mecer process' of Sigma can be found at: http://www.sigma-gruppen.com/en/products/mecer-equipment/process-description-alkaline-mecer-15060125

[62] Sigma: Closed Loop Recycling of Alkaline Etchant; brochure can be downloaded at: http://www.sigma-gruppen.com/en/products/mecer-equipment-15027205

4.2.8.6. Applicability

The recycling installation is applicable for any PCB production facility. However, there are two determining factors:

- A PCB production that results in an amount of 60 tons of recycled copper per year is necessary to provide the pay-back period indicated in section 4.2.8.7.
- The space needed for the system that requires about between 50 and 80 m² depending on the arrangement of the installation and the volume of the buffer tanks.

4.2.8.7. Economics

According to the data provided, the pay-back period of the investment usually ranges between 6 and 18 months[63] because of the reduced operational costs for replenisher, rinse water and chemicals for water treatment. Another reason is the revenue from the produced high quality copper.

User of the installation state that the return on investment strongly depends on the amount of sold high quality copper: The pay-back period ranges between 14 months – if an amount of 90 tonnes recycled copper per year is achieved - and 18 months with 60 tonnes of recycled copper per year. The return on investment reaches 48 months if only 7 tonnes of copper metal are recycled per year.

Since 2002, the average market price of copper has risen significantly due to an increased demand.[64] In 2014, however, the copper price fluctuates, around 5,000 Euro per ton and more (see Figure 4-16).[65] Thus the pay-back period indicated in the BREF document (Payback: more than three years cost recovery with a recovery of about 600 kg high quality copper per month (in example plant) has shortened significantly.

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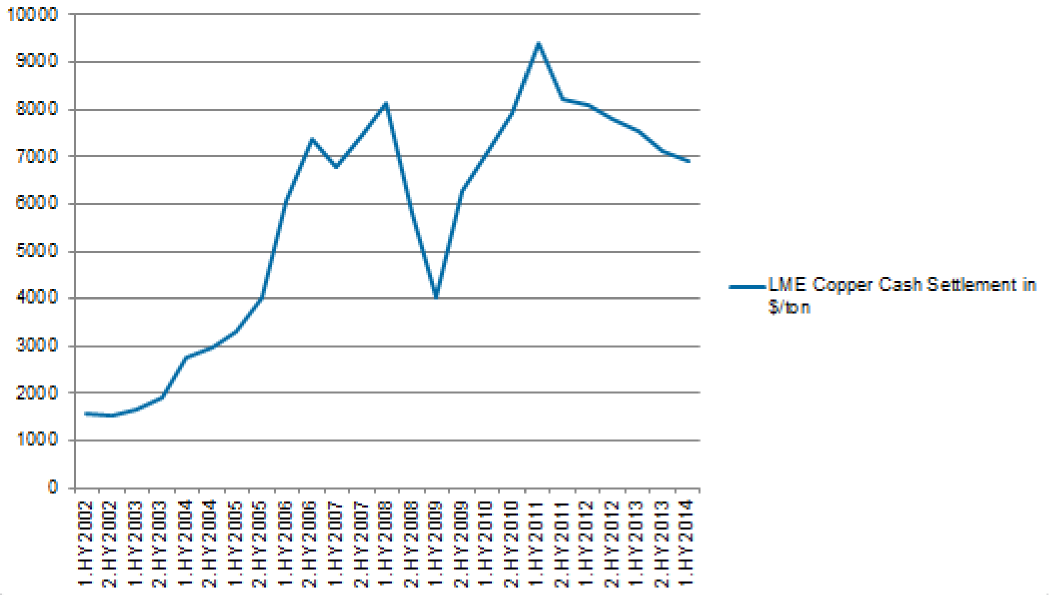
63 Sigma: Closed Loop Recycling of Alkaline Etchant; brochure can be downloaded at http://www.sigma-gruppen.com/en/products/mecer-equipment-15027205

64 European Copper Institute; http://www.copperalliance.eu/about-copper/recycling

65 London Metal Exchange, LME Copper; http://www.lme.com/metals/non-ferrous/copper/

Figure 4-16: Copper cash settlement in US Dollar per tonne



Source: Baron et al. (2014), according to data of Westmetall; http://www.westmetall.com/de/markdaten.php?action=show_table_average&field=LME_Cu_cash

As the recycled copper is of high quality (99.99% purity) it can be sold to different customers, e.g. to the scrap metal trade or to a copper company. Due to the high copper purity, a price of 92% of the copper quotation can be reached (Wolfer 2014). Altogether, the overall costs of the etching process are significantly reduced by almost 70% (see Figure 4-14).

4.2.8.8. Driving force for implementation

The driving force behind the successful implementation of copper recycling on site is the high average market price of copper that has risen significantly since 2002 (see Figure 4-16). This development in the copper segment above all is running in parallel with a general increasing global demand for natural resources and the sharply increasing raw material prices (Oeko-Institut 2007).

However, the implementation of an innovative on-site approach of the companies is embedded in a specific corporate responsibility that aims to promote environmentally favourable solutions.

4.2.8.9. Reference organisations

- AT&S operates a copper recycling system at one production site in Fehring and recycles 100 tones copper per year (Rossmann 2014);
- Würth Elektronik: The company operates a copper recycling system manufactured by Sigma (for more details see section 4.2.8.5)
- Other European PCB producing companies equipped with copper recycling systems from Sigma are according to the Sigma-webpage[66]: Intectiv in Slovenia, Piciesse in Italy, Richter Elektronik

[66] http://www.sigma-gruppen.com/en/references-18790837

in Germany, Luznar in Slovenia, Laskar in Poland, Teltex AB in Sweden, Ei PCB Factory in Serbia and CYNER substrates in the Netherlands. .

4.2.8.10. Chapter references

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Wolfer (2014)	Personal communication by Dr. Klaus Wolfer, Würth Elektronik, Resource Management, on 28 October 2014.

4.2.9. Protecting and enhancing biodiversity

4.2.9.1. Description

“Biological diversity” is defined in the Convention on Biological Diversity as: the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems (UN 1992).

While manufacturing sites impact biodiversity, businesses also benefit from the wellbeing of natural environments through the services that these provide (see section 4.2.9.2).

In the context of manufacture, biodiversity is an aspect that is often dealt with in depth in environmental impact statements and through similar methods used during the planning and construction phase of a facility site. Even though the general treatment and reduction of emissions aims among other things at reducing the risk of impacts on adjacent land and water bodies, regulation usually does not require the execution of direct actions to ensure preservation and enhancement of biodiversity in the vicinity of a specific site at later stages of the value chain.

None the less, the growing understanding that the public is concerned with the environmental undertakings of industry has encouraged companies to become more active in this regard. The sustainability reports of EEE enterprises often mention initiatives for planting trees or supporting the remediation or preservation of wildlife and biodiversity. Such initiatives usually try to involve the community as well as employees in such activities. Furthermore, they provide some financial funding. However, only a handful of enterprises have also started developing and implementing mechanisms for enhancing these resources at or adjacent to manufacturing sites.

Such initiatives may include concrete measures for business activities and social action programs that take biodiversity into account, both as a general aim in the country or region of activity and as an issue of specific concern where the natural environment adjacent to enterprise facilities is concerned. Enterprises can learn from international biodiversity-related efforts as a source of inspiration for developing measures in both cases, but initiatives on the local level of a site should also examine connections between facility activities and possible impacts on adjacent ecosystems. Appropriate measures to be taken at each stage of the value chain should be developed in order to prevent and reduce possible negative influences on biodiversity. Additionally, involvement of employees, their families and adjacent communities serves the purpose of changing the awareness of individuals towards biodiversity and methods for its protection and enhancement.

General measures may include activities such as planting trees or reintroducing native species into sites where the natural environment has been destroyed in the past. Participants can also be involved in surveys of flora and fauna, aimed at documenting and monitoring the state of biodiversity at a specific site. In parallel, surveying the changes to the natural environment that were, or are associated with a manufacturing facility, may constitute a good basis for planning future actions in support of biodiversity within manufacturing facilities or around them. Where possible, open land within a facility can be allowed to “revert to nature”, or biotopes can be developed to create new habitats, such as wet lands, where employees can spend their lunch break, for example.

4.2.9.2. Environmental benefits

Activities performed in natural areas (some of which are adjacent to manufacturing sites) such as sapling cultivation, grass cutting, sapling planting, can help create better conditions for an abundance of plants and wildlife to thrive. The creation of biotopes, recreating a rich ecosystem, can also facilitate the strengthening of the surrounding ecosystems.

Sites where activities for enhancing biodiversity are performed can also be established to serve as areas where employees and visitors can learn about the environment and develop a higher awareness of the importance of biodiversity. Even if this is not a direct environmental benefit, it can support the development of further conservation initiatives in the future.

Although it is difficult to quantify the benefit from such activities, initiatives for raising awareness of employees and nearby communities to biodiversity, as well as for performing activities to remediate and enhance natural areas may benefit the environment. This can take the form of supporting natural processes such as forest rejuvenation through cultivation and planting of saplings, as well as by remediation of areas which have been impacted by industry, through reintroduction of species which are in decline. Possible environmental benefits include the enhanced diversity of local species (both flora and fauna) as well as the establishment of better conditions for their development in terms of cleaner water and soil. It is also important to understand that a healthier environment facilitates the provision of various ecosystem services.

Ecosystem Services are the processes by which the environment produces resources often taken for granted such as clean water, timber, habitat for fisheries, and pollination of native and agricultural plants (ESA 2014). Whether in an urban or a rural area, ecosystems provide various goods and services, including for example:

- Land uses with high levels of tree cover, can help regulate water flows in a watershed and **reduce the risk of catastrophic flooding or landslides**. Supporting the wellbeing of such areas is understood to be a preventive measure, which is often less expensive than remedial measures needed where damages have occurred (World Bank 2014).
- **Purification of water** by wetlands and root systems of vegetation (ESA 2014).
- Regulation of weather extremes and their impacts and contribution to climate stability (ESA 2014). This is furthermore known to have a beneficial effect on the requisite acclimatisation in adjacent buildings in densely built areas (McPherson 1999).
- Dispersion of seeds and pollination of crops and natural vegetation (ESA 2014).
- Detoxification and decomposition of wastes (ESA 2014).

A study prepared by McPherson (1999) offers some insight as to the possible benefits that ecosystems may provide. The study indicates that healthy city trees can mitigate impacts of [anthropogenic] development on air quality, climate, energy for heating and cooling buildings, and storm water discharge. Healthy street trees increase real estate values, provide neighbourhoods with a sense of place, and foster psychological well-being (Dwyer et al. 1992).

Activities for supporting the wellbeing of ecosystems and the enrichment of biodiversity must be carried out with caution, with the guidance of experts where possible, in order to avoid the sensitive balance of ecosystems being destroyed. Where performed correctly, such practices can have a positive impact on the environment as well as on the awareness of society to the importance of their wellbeing.

The types of benefits to the environment as well as their range depend on the actions carried out. In the case of SMF, a manufacturing facility of SHARP located in France, various actions have led to the reintroduction of native species to open spaces within the facility, which were previously treated with conventional gardening. In this sense, such spaces add to the natural habitat available to animals, birds, insects and various types of vegetation, and appear to have also raised the number of species (diversity) in these areas (SMF 2014).

4.2.9.3. Appropriate environmental performance indicators

Possible tools for measuring the progress of efforts for enhancing biodiversity by enterprises have been developed by some of the companies where such practices have been implemented (see section 4.2.9.9).

To facilitate the implementation of this technique by other industries, it is proposed to consider the following items as a minimum requirement for the development of a check list aimed at monitoring the progress of biodiversity actions. It should be noted that the proposed items only apply to areas considered relevant for the purpose of surveying and monitoring biodiversity adjacent to manufacturing sites, which are in the scope of this document, however such aspects should also be developed for other activities such as logistics and sales.

- **Regulation** – Apart from ensuring compliance with legislative requirements related to biodiversity, reviewing regulation can also assist in identifying governmental incentives and planning initiatives that can be incorporated into the development of biodiversity projects of a local facility.
- **Manufacturing activities**
  - Implement third party monitoring of biodiversity on and adjacent to sites;
  - Provide training for employees involved in biodiversity initiatives, to support decisions and activities; include also public awareness campaigns for residents close to the manufacturing plants/sites;
  - Implementation of greening efforts on factory premises:
    - Analyse and set numerical targets for the impact of manufacturing activities on biodiversity;
    - Develop green spaces on manufacturing sites with native species, where relevant creating natural corridors for adjacent natural green spaces;
    - Integrate phyto-remediation and bio-remediation technologies in treatment of waste water and other wastes, where feasible. Where possible, this should be done through development of wet-lands, land farming and further applications, with the use of native species;
    - Allow parts of facility ground to “revert to nature”, possibly through reintroducing native species or through creating habitat conditions that may attract such species;
  - Implementation of greening efforts adjacent to factory premises, including species survey and effort to preserve and enhance biodiversity of ecosystems.
- **Procurement** for manufacture, aimed at extending practices to the supply chain.
  - Stage 1 (company strategy): Incorporation of the evaluation of the biodiversity protection efforts of suppliers within Green Procurement Guidelines. In this sense, new suppliers would be required to document activities and impacts of their activities and/or products relevant to biodiversity;

  - Stage 2 (company strategy): Percentage of purchases made from suppliers considered to have lower impacts on biodiversity;
  - Stage 3 (facility strategy): Consider procurement of products with positive biodiversity aspects such as procurement of paints, cleaning materials and chemicals that are biodegradable or less harmful to the natural environment than alternatives;
- Additional areas for consideration involve **Research and Development (R&D)** activities. Enterprises which would like to further develop their approach towards biodiversity, should consider implementing principles in R&D activities in order to give priority, in the design of products and of manufacturing processes, to changes with a positive impact on biodiversity. This may be targeted at in-situ aspects, regarding the implementation of design changes of processes and use of materials, to facilitate reductions of emissions from manufacture in order to lower possible burdens on the environment surrounding the facilities. Furthermore, ex-situ aspects should also be kept in mind, having preference for materials or out-sourced components with lower impacts on biodiversity.
- **Social contribution** – this may include supporting initiatives such as forest stewardship as well as developing educational activities to raise awareness of the employees and the public. In this respect, combining educational activities into biodiversity projects performed at a facility is important both as a way of providing individuals involved (employees/other) with sufficient background for various tasks, as well as for raising awareness to biodiversity aspects associated with the performed activities.

The simultaneous implementation of such management tools at all manufacturing facilities allows an enterprise to centrally monitor the progress of efforts made at all its bases by means of a single system to enable the ranking of performance in comparison with earlier years as well as in comparison between facilities. As a first stage, an enterprise should ensure that all facilities have prepared a survey of all activities to identify areas where actions could create improvements in biodiversity. This could be **monitored through a checklist** used to confirm that the aspects such as those mentioned above have been reviewed, while also serving as a means for providing details as to identify areas for improvement and proposed actions. In a second stage, each facility should be required to **plan actions** to be carried out with the purpose of creating benefits for biodiversity. Such planning may also integrate minimum targets for improvement outlined by the enterprise. The implementation of these actions is then to be monitored over the course of time and to be compared between facilities in order to be able to assess the success of actions of each individual facility as well as the total performance of the enterprise.

For example, SHARP uses a 29-item checklist. This tool monitors the progress being made at each step of the value chain: procurement, development, manufacture, sales, and logistics — the fundamentals of Sharp's business activities — as well as in social action programs. The list of monitoring items is revised each year, and in fiscal 2011, an item relating to greening efforts on factory premises was added to the list of items in the area of manufacturing, and relating to the weight of social action. In the monitoring system applied by SHARP, bases are ranked into three levels, from A to C. Grade A is allocated to those sites whose rate of progress is at least 20% greater than the fiscal 2009 average for all sites, based on the Sharp Biodiversity Initiative. Sharp has set a target to ensure achievement of Grade A, by all sites worldwide, by 2015 (Sharp 2012).

From the way that Ricoh have set targets for implementing their biodiversity policy and how they report about progress towards such targets in their 2014 sustainability report (Ricoh 2014a), it is understood that they also monitor activities implemented at their sites similarly. It is reported that in FY 2014, Ricoh (2014a) implemented biodiversity activities in 23 countries. This includes biodiversity protection activities for the protection of rural landscapes, river/forest/coastal clean-up

activities and activities for the removal of identified invasive species. In the communication of progress on the implementation of their biodiversity policy, made through their 17th Action Plan (applied 2011-2014), RICOH specifically addresses implementation of programs to care for biodiversity within the premises of Ricoh plants. Progress in 2014 is detailed as: Determined actual conditions regarding biodiversity status at business sites and continued to reduce impact. Achieved stated objective at 16 locations, where only IPM (Integrated Pesticide Management[67]) compliant pesticides were used in the grounds maintenance or no chemical pesticides were used at all.

The report further details (pg. 35) targets for Ricoh's 18th Environmental Action Plan (2014-2017). RICOH aims at conducting biodiversity conservation and restoration activities by the entire Ricoh Group. This objective is to be implemented among others in the following areas of activity:

- Use wood-based products carefully in consideration of biodiversity;
- Consider biodiversity at all Ricoh Group operational sites;
- Conduct biodiversity conservation activities with local societies, using company forests;
- Develop preservation activities for forest ecosystems;
- Conduct biodiversity conservation activities in cooperation with stakeholders;

4.2.9.4. Cross-media effects

Although the objective pursued is the creation of environmental benefits, activities for supporting biodiversity may lead to negative impacts, if they are applied without a sufficient basis of knowledge. For instance, introduction of new species into a habitat where natural enemies do not exist can lead to uncontrollable development of the new species, resulting in negative impacts on the wellbeing of other species. This may be referred to as the introduction of invasive species, though the range of impacts is often only apparent ex-post.

It is worth mentioning in this regard that SMF works with local organisations on the development of biodiversity-motivated action, and that this may have had a positive impact in light of the expertise and previous experience that personnel of such organisations bring with them. SMF emphasize that biodiversity is a complex topic and that actions should be planned under the supervision of experts who have knowledge as to regional species and ecosystems, and thus can prevent the introduction of invasive species as well as harm to local ecosystems which may result from actions that have not been properly planned (SMF 2014).

4.2.9.5. Operational data

As explained in section 4.2.9.1, besides supporting biodiversity-oriented actions in natural areas that are not related to an enterprise's site, such actions can also be targeted at the enterprise's own facilities. For instance, possible initiatives to conserve and enhance biodiversity can be applied both within and adjacent to manufacturing facilities to address the status of nearby ecosystems directly. This may include the execution of environmental conservation activities – such as planting and nurturing trees and releasing juvenile fish into water areas – that lead to biodiversity protection. The targeting of various environmental social issues at company facilities can help develop environmental awareness among employees, while at the same time contributing to the global environment.

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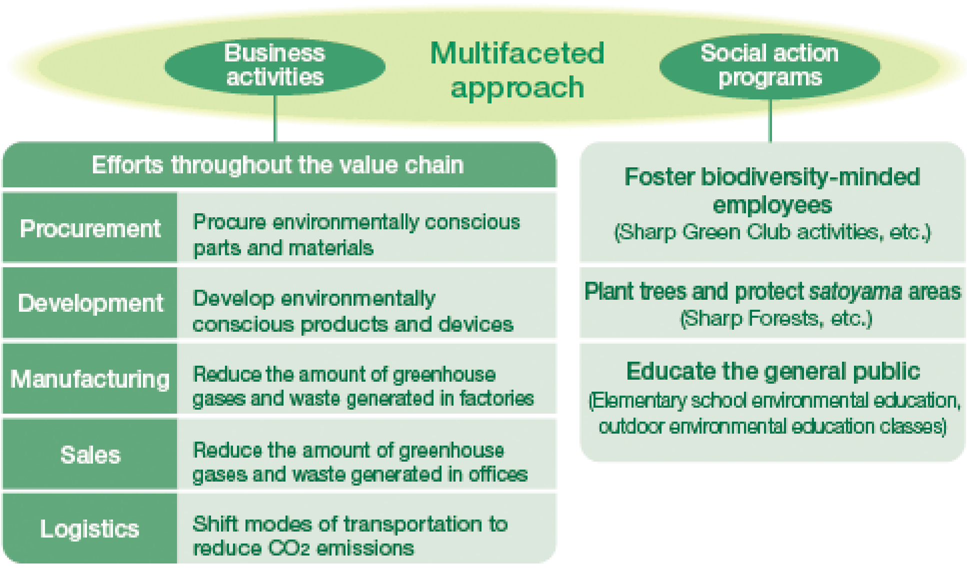
[67] Pesticides with a minimal negative impact on the ecosystem, according to the IPM (Integrated Pest Management) concept.

For example, the Sharp Biodiversity Initiative was formulated in November 2009, detailing concrete measures for business activities and social action programs that take biodiversity into account. Under the Sharp Group Policy on the Sustainable Support of Biodiversity, the Sharp Group carries out a multi-facetted approach (See Figure 4-17) in which it protects biodiversity through business activities and social action programs at all facilities worldwide (SHARP 2014a).

Figure 4-17: Sharp's multi-facetted approach for protecting biodiversity



Source: SHARP (2014a)

The first objective outlined for managing and developing business activities is to understand the link between these and biodiversity (how do business activities affect biodiversity and benefit from it). The second objective promotes the reduction of negative impacts of business activities, so as to protect biodiversity and use it in a sustainable manner (SHARP 2014a).

Activities carried out by enterprises can include:

- Screening of business activities to identify links to biodiversity, followed by formulation of pre-cautionary practices to eliminate or reduce possible impacts on biodiversity.
- Initiate activities to enhance biodiversity and natural habitats at company sites.
- Initiate activities to enhance biodiversity and natural habitats elsewhere.
- Revision of Green Procurement Guidelines to incorporate the evaluation of the biodiversity protection efforts of suppliers.

Activities can also include offering seminars for employees with experts to provide knowledge and training for the above mentioned activities. On this basis, employees can carry out surveys of the flora and fauna found on plant grounds or at external sites.

In areas and communities near its production sites and offices throughout Japan, Sharp reports that it promotes clean-up campaigns,[68] greening activities, and other biodiversity protection activities as community-based activities. The planting and nurturing of trees, biodiversity protection campaigns, and other environmental conservation activities are also conducted continuously at facilities outside Japan. With the aim of not just contributing to the natural environment but also to the awareness of its importance, activities are often carried out by employees as well as by their families and the local community (Sharp 2014b).

For example, SHARP reports that in the Kameyama Plant (Kameyama City, Mie Prefecture) in Japan, employees have received training and have assisted in performing surveys that enabled the identification of roughly 70 species of plants, insects, and animals, and the preparation of an illustrated guide by SHARP. Employees have also taken part in sapling cultivation, grass cutting, sapling planting, the development of biotopes and other activities in order to create a greener environment where an abundance of plants and wildlife can thrive. Such sites can also be developed to serve as locations where local communities can learn more about the environment. They can also serve the local community for recreation, also to the benefit of employees when sites are adjacent to manufacturing facilities (Sharp 2012).

SHARP explains that biotopes have been created on the Kameyama Plant premises since 2010, recreating rich ecosystems. These biotopes are home to local flora and fauna: small fish that live in a nearby stream have been released in a man-made pond, and employees have planted acorn seedlings. For FY 2012, employees planted Japanese irises, the official flower of Kameyama City (Sharp 2013).

Sharp detail that in order to promote the implementation of the biodiversity policy, it began issuing the “Good Examples towards Biodiversity Conservation and Sustainable Use” in FY 2010. Published in a number of languages, this resource introduces successful biodiversity initiatives undertaken at various facilities. Increasing understanding and sharing information about each facility’s activities serves to lift the level of the whole Sharp Group (Sharp 2012).

As part of its efforts to promote biodiversity, at the UK manufacturing site in North Wales, Sharp Manufacturing has allowed parts of the site to revert to nature. This has increased the level of local flora and fauna that can now be found on the factory premises. Additional activities in conjunction with the North Wales Wildlife Trust (NWWT) include planning a fruit orchard which will be planted on the Phase 3 premises of the site. This orchard will consist of apple and other fruit trees which are local to the area. Sharp has participated in a number of projects with the NWWT over the years, including the Dormice project, donating materials and funds to build nesting boxes. The latest project that Sharp will be supporting is the Green Horizons Project to construct a sensory garden. Sharp has supplied timber, compost bins and hedgehog hotels so far and will continue to assist NWWT’s efforts with the sensory garden (Sharp 2014c).

SMF has implemented a number of projects to promote biodiversity in the areas adjacent and within their facility, as well as in relation to business activities, such as (SMF 2014):

- Planting of native vegetation in areas designated by regional plans as natural corridors (green belts) and as natural green areas (Relais in French);

[68] In October 2012, employees and their family members participated in a clean-up campaign in Aichi Prefecture’s Fujimae Tidal Flat, one of Japan’s largest stopovers for migratory birds. Home to large numbers of the shellfish and small fish that form the diet of migratory birds, the tidal flat is a vital rest area and feeding ground for the birds. To preserve this precious resource, Sharp employees participate in periodic clean-up campaigns there.

- Creation of a natural pond in the facility's green area;
- Introduction of an "insect hotel" and a beehive to the facility to attract pollinators;
- Distribution of melliferous seeds to visitors, employees etc. Planting of seeds aimed at attracting pollinators and enhancing biodiversity throughout the region and not just at SMF;
- Switch to use of biologically degradable paints and cleaning materials where alternatives provide comparable performance (in some cases despite additional costs) and where this is technically possible;
- Procurement of products with lower biodiversity impact, for SMF this mainly regards procurement of paper products for packaging certified by FSC (Forest Stewardship Council);

In FY 2013, a total of approximately 18,800 Sharp employees, business partner employees, and their family members participated in approximately 800 events (Sharp 2014a).

Another example is the "Ricoh Group Biodiversity Policy" established in March 2009. Based on this policy, Ricoh make an effort to reduce the adverse impact of business activities on biodiversity, as well as to promote forest ecosystem conservation with employees' volunteer activities.[69]

The policy mentions actions of relevance for Ricoh's business activities and provides examples of measures that can be implemented to reduce impacts on biodiversity of such activities. This includes among others:

- "*Understanding and reducing impact – Assess, grasp, analyse, and set numerical targets for the impact on biodiversity of all our business activities, including raw materials procurement, and work continuously to reduce this impact.*
- *Implementation – Give priority to measures with a high degree of impact and effectiveness from a biodiversity and business perspective.*
- *Developing new technologies – Aim to realise a sustainable society, develop technologies that make use of biological resources, learn from the mechanisms of ecosystems and the nature of living things, and employ the knowledge gained to develop technologies and sustainable production processes.*
- *Expanding the scope of our activities by collaborating with customers, suppliers, other companies, NGOs, international organizations, and so on, share information, knowledge and experience concerning biodiversity, and expand the scope of our protection activities*."
  (Ricoh 2010)

In FY 2014, Ricoh (2014a) implemented biodiversity activities in 23 countries, with a total of 365 events being organised and a total of 9,589 people participating.

For example Ricoh Industrie France S.A.S. (RIF) launched and is promoting the Vie & Couleurs (Life & Colors) project in fiscal 2009, with the aim of achieving environmentally, socially and economically sustainable development. Among others, this project is said to aim at creating a comfortable environment for plants, birds, and other animals in the vicinity. In cooperation with a local environmental organization called the Regional Association for Initiation into the Environment

[69] For further details see http://www.ricoh.com/environment/biodiversity/outline.html

and Nature in Alsace, employee volunteers plant trees and clear land on the factory premises. The project has the following three objectives: (Ricoh 2014b)

- Increasing the biodiversity in the 120,000 square-meter area of RIF's premises and thereby contributing to the development of a "green network" in Alsace;
- Protecting indigenous species in Alsace and conserving the wild flora and fauna of the surrounding areas; and
- Promoting awareness of environmental conservation to RIF employees, partner companies, and the broader public;

Under this initiative, RIF volunteers have created a biotope pond, a pasture, and a flower field of some 1,400 m^2 with various kinds of flowers in all four seasons; installed birdhouses; and developed the inventory list of flora and bird species inhabiting the factory premises. Hedgerows and fruit trees were also planted. RIF has also been focusing on communicating its biodiversity conservation efforts to the public. For instance, the company provided related employee education programs, and produced a video introducing its green activities, which it shown at external seminars and lecture events. (Ricoh 2014b)

Ricoh UK Products Ltd. ("RPL") also began their biodiversity conservation activities in fiscal 2009. In this program, the manufacturing subsidiary in Europe carries out conservation projects on the company's premises, at the local Wrekin Forest, and other neighbouring areas, working closely with experts from local NGO's. Activities involve building nest boxes for birds and mammals, and live mammal trapping surveys are conducted (only by RPL volunteers who have obtained a regulatory permit after receiving appropriate training, provided in collaboration with Shropshire Wildlife Trust and the Shropshire Mammal Society). The data from these projects is collected and used for the region's Biodiversity Action Plan. In June, such volunteers surveyed hedges on the RPL premises and found evidence that they serve as habitats for many kinds of small mammals as well as moths, birds, lichens, fungi, and other species that contribute to maintaining the ecosystems in the local community. As part of Ricoh's Social Contribution policy priorities (global environmental conservation; community development; raising the next generation) the volunteers also involve the local community and other business organizations to raise awareness of sustainability issues. (Ricoh 2014b)

Philips (2014) has also been developing a policy concerning biodiversity management. Past activities have included:

- Business & Ecosystems Training (BET) on the topics of Natural Capital, Ecosystem Services and Biodiversity and the link to business. Active preservation of biodiversity in and around industrial sites, involving local communities and environmental organizations.
- Site-specific activities in the EU have included conservation efforts in the Miribel (France), Ketrzyn Farel and Pila (Poland) and restructuring of the Drachten (Netherlands) Consumer Lifestyle and Best Healthcare plants for optimal restoration of biodiversity and employee well-being.
- Biodiversity surveys and water risk investigations of industrial sites have been used as a basis for building a knowledge base of endangered and resident species, nature reserves and wildlife corridors, biodiversity initiatives and partnerships at Philips industrial sites. Philips intends to use this information for preparing biodiversity guidelines for sites.

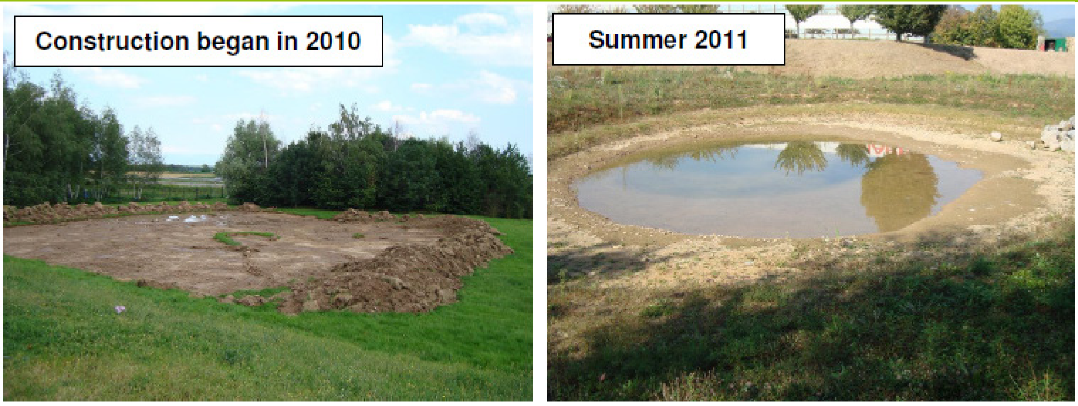
It is also important that facilities monitor the impacts of actions implemented to promote biodiversity, as a means of measuring the success of various projects in terms of positive impacts on the environment.

For example, SMF (2014) have surveyed the types of species (flora and fauna) on their premises to learn about the richness of species. As part of the strategy, surveys of plants growing in the area of the facility are to be carried out every three years. Similarly, SMF is considering conducting surveys of animals living or passing through these areas on a periodical basis, as part of their biodiversity activities. Such practices can allow the monitoring of possible changes on the site and its surroundings, as well as in relation to specific actions implemented as part of a biodiversity strategy.

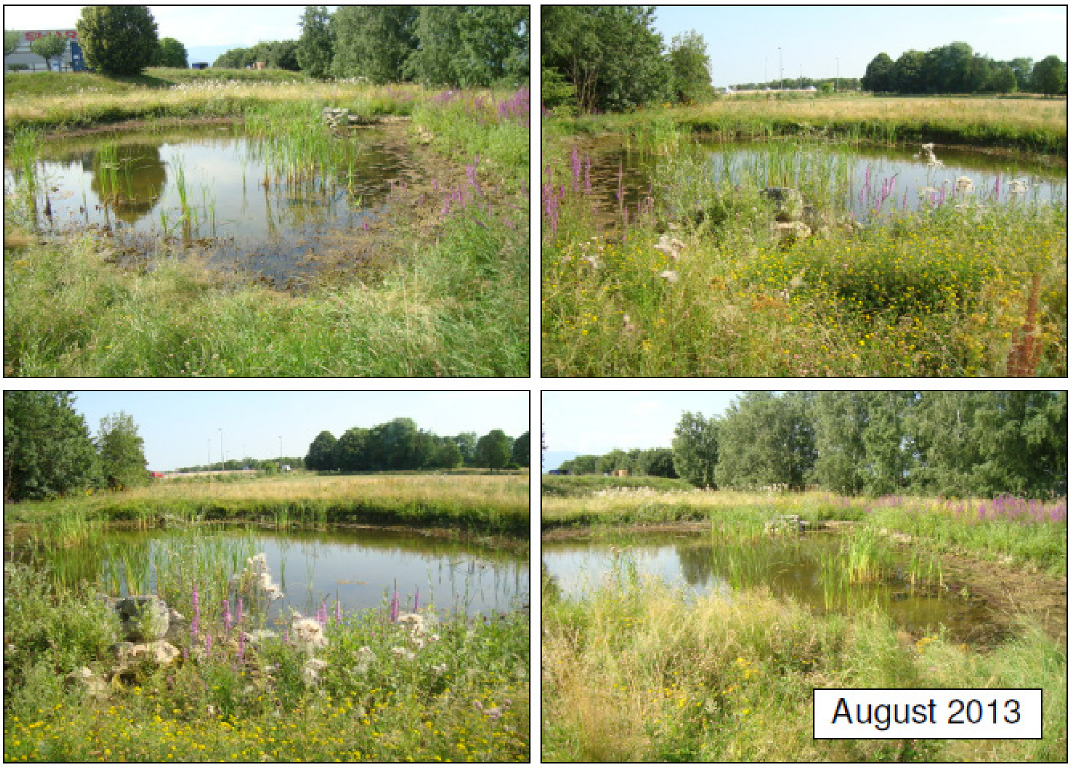
In some cases, such on-site monitoring may be as simple as photographic documentation for the purpose of comparing stages of progress, such as in the documentation prepared on the development of a biotope-pond on the SMF facility grounds, which is presented in Figure 3-12. (SMF 2014)

Figure 4-18: Natural development of the pond at SMF, France

The pond was dug out in 2010 and allowed to develop naturally. The natural rainfall and high ground water level at the site maintain a sufficient water level. The pond has provided additional habitat to birds and insects attracted to the water source, which in turn have transported seeds and enabled the development of vegetation naturally (SMF 2014).



Since spring 2013, this natural area "came to life", and it now includes fauna and flora in abundance. The following pictures were taken in August 2013, and document the change.



Source: Fuchs (2013a) unless stated otherwise

Concerning implementation of biodiversity actions, the potential of working with local environmental associations in the development and implementation of various actions should be considered. Developing a biodiversity strategy requires knowledge of regional ecosystems and of how to promote their development. According to SMF (2014), cooperation with associations which contributed relevant know-how facilitated a faster implementation of specific projects while also saving costs. At the first stages of development of the biodiversity action plan, SMF consulted Ariena (see www.ariena.org), an umbrella organisation in the Alsace area concerned with nature and environmental education. Ariena assisted SMF in liaising with other organisations operating in

specific areas in which SMF wanted to develop a specific project, such as organisations that could recommend what species to plant or how they should be nurtured. SMF explains that without such help, progress would have been much slower and costs would be higher.

4.2.9.6. Applicability

From a review of sustainability reports performed at the onset of the preparation of this document, it is observed that most EEE enterprises have only started to become proactive in the implementation of practices for enriching and conserving biodiversity adjacent to manufacturing facilities. Communication with stakeholders has also clarified that, though such practices are starting to become well-established at some of the Japanese manufacturing facilities, they are in their first stages in most European facilities. It is thus concluded that there is a large potential for the European EEE industry to adopt and implement the management approaches and techniques described in section 4.2.9.5.

From communication with SMF, it is understood that smaller projects can be implemented at manufacturing facilities with relatively low financing (see section 4.2.9.7 below), through co-operation with associations and with volunteer work of employees. This means that applicability is in reach for most facilities, and it is more of a question of how to bring management on board.

However, a few aspects are apparent that may contribute to the applicability of the best management approaches and techniques on biodiversity and to implementation activities related to them. SMF (2014) mentions that an important point for a company is to make a commitment – it is difficult to persuade facility management to support actions, once these may entail costs and/or time of employees. However, once this is supported on the company level, it is easier to achieve implementation on the facility level.

Although the management approaches and techniques described above are oriented at enhancing biodiversity at and around EEE manufacturing facilities, it should not be mistaken for a practice relevant only to facilities surrounded by natural areas. Though enhancing natural habitats adjacent to facilities may have a larger public resonance, development of green spaces is equally important in the urban fabric. As can be understood from section 4.2.9.2, trees and green spaces within cities provide multiple ecosystem services, not to mention aesthetic value and possible impacts on adjacent real estate. Both in urban and rural areas, enhancing natural ecosystems contributes to the state of biodiversity and should be endorsed.

4.2.9.7. Economics

Referencing actual costs and benefits related to actions aimed at protecting and enhancing biodiversity is difficult. The range of activities that can be undertaken, as well as the conditions of implementation at a specific location mean that referring to a range of expected costs can be misleading, whereas most benefits are intangible and thus difficult to speak of in monetary terms.

Where costs are concerned, facilities can make first estimations of actual costs on the basis of resources needed for implementing a specific action:

- costs of labour (gardening, surveying);
- costs of consulting with experts (establishing know-how or planning needed construction works);
- costs of purchasing plants or equipment; etc.

SMF (2014) provided some information as to costs of specific actions. In general it is important to note that planned costs, estimated at the development stage of an action often differed from actual

costs, as often some of the work was done by volunteering employees, assisted by machinery operated at the site in parallel to the time of implementation (and thus used without additional costs), etc. Some examples include the following:

- Planting of trees in green corridor areas surrounding the site (done as voluntary action in support of regional conservation plans) – costs were related to purchase of trees and of equipment as well as labour, as the work volume was too substantial to be performed by volunteering employees alone. 10,000 € were spent in total for 400 meters of corridor, comprising 80% of the originally planned costs;
- Establishment of a biotope-pond at the SMF site was originally estimated to cost 10,000 €, but ended up with no actual costs. Equipment used to dig the pond was already on site and did not require expenses. Reinforcing the pond banks was not needed in light of local soil conditions. Trimming vegetation is not required often;
- Species inventories were originally estimated to cost 5,000 € by a local consultant.
- SMF also mention that donations (financing and/or equipment) often made to local environmental associations providing assistance (cooperation) in respect of activities carried out at a later stage, are a further method of reducing costs in this respect. This has to do with donations being tax deductible in France, whereas the associations may provide a service for the value of up to 25% of the donation. In this sense, in some cases actual costs were reduced in light of services provided by associations such as in the case of a donation of 35,000 € to a local association (Mecenat), which later performed flora and fauna surveys at the site.

On the other hand, benefits are much more difficult to quantify, though they can be addressed at least qualitatively. Concerning quantitative analyses, McPherson et al. (1999) estimate benefits that can be associated with the "urban forest" of the city Modesto in California, USA, in order to clarify whether benefits resulting from ecosystem services that trees provide, justify the municipal budget (~2 million $) that goes into maintaining these trees. The estimated benefits are 75% higher than the costs of maintaining the urban forest.

When referring to a specific action, the benefit to the environment can be expressed in terms of the improvement of the level of biodiversity, i.e., the number and diversity of species related to new habitats created or to the preservation and enhancement of existing ones. For example, a survey prepared at a pond developed at the SMF site in 2010 has shown that a diversity of species has developed in an area, which was gardened conventionally until just a few years ago (Fuchs 2014). The survey was carried out in May 2014 and showed the presence of tens of different species, most of which are typical to wetlands and thus understood to have been introduced through the development of the pond (SHARP 2014a).

The development of such green areas within or adjacent to a facility can also serve employees as a place to take a break in a more natural environment, adding to their well-being.

SMF (2014) also mention raising awareness to biodiversity aspects as an important benefit, as this is an environmental area which has not yet been sufficiently recognised in terms of preservation efforts and supporting enhancing efforts. In this respect, raising awareness through involvement of employees and of the community in certain projects and through publishing information about such projects and their background in the local media can result in such benefits. Communication of such activities to the public is also expected to have a positive influence on the image of a facility and indirectly also on that of the company.

Furthermore, in some cases, manufacturing sites may have actual benefits, where an enhanced natural environment can provide certain services. For example, in built areas with higher densities, vegetation has been shown to regulate extreme temperatures by 2-3°C, often allowing savings in

costs for air conditioning respectively. Wetlands may also be developed using native species to assist in treatment of slightly contaminated run-off water from facility grounds, or as biological remediation as a stage of treatment of process waste water. In such cases, besides the natural environment created or enhanced through realisation, facilities may have a chance of cutting costs for treatment of waste water and effluents.

4.2.9.8. Driving force for implementation

A major driving force for protecting and enhancing biodiversity can be seen in legislation or local master plans that already exist in some countries and regions and prescribe activities for maintaining or preserving the natural environment. For instance, the biosphere reserve concept[70] is based on a differentiation between the core area (in which natural resources must be strictly preserved) and outer areas (transition or cooperation zones) in which urban activity is possible through adopting more sustainable planning and development practices. If a manufacturing site is adjacent or located in such an area, the facility may be required to tend to its open spaces in a certain way. Similarly, facilities located within a river basin may have to comply with more stringent criteria in terms of discharging treated effluents to local water bodies. In such case, facilities may be motivated to develop biodiversity supporting practice as part of fulfilling urban planning (or zoning) obligations. In parallel, incentives providing certain benefits to organisations who promote biodiversity activities may, in such areas, also be in place. While action on this basis may require companies to be aware of such aspects (i.e. as a precondition for taking advantage of such incentives), such initiatives can be a first driver for a facility to develop a biodiversity strategy.

Within this context, it is interesting to note that SHARPs first target to develop activities related to biodiversity enhancement were catalysed by the Aichi Targets[71] established in Japan in 2010. This subsequently motivated some Japanese companies to become more active in reducing impacts on biodiversity (SMF 2014a).

The possibility of improving the company image (or preventing potential damage to it) can be an additional motivator for manufacturers for implementation of this BEMP. It is, however, worth mentioning that single actions may also raise some suspicion that company image is the main reason for action. It is thus important to cultivate the development of biodiversity strategies as a continuous commitment, as is common in other areas of environmental activity.

As donations to environmental NGOs are, in some countries, tax deductible, this can also serve as a driving force for indirect support of biodiversity as well as for developing cooperation initiatives that can also contribute to biodiversity at the facility level.

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[70] For detail please see http://www.nrdc.org/land/wilderness/fbios.asp

[71] **Aichi Biodiversity Targets** – In 2010, in Nagoya, Japan, 193 countries meeting for the U.N. Convention on Biological Diversity (CBD) agreed on a Strategic Plan for Biodiversity 2011-2020. The goal of this plan is to promote effective implementation of the Convention through a strategic approach, comprising a shared vision, a mission, and strategic goals and targets ("the Aichi Biodiversity Targets") that will inspire broad-based action by all Parties and stakeholders. The Strategic Plan provides a flexible framework for the establishment of national and regional targets and for enhancing coherence in the implementation of the provisions of the Convention on Biodiversity. Among others, the aims at supporting the implementation of the Global Strategy for Plant Conservation as well as the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of the Benefits Arising from their Utilization. For further details see http://www.cbd.int/sp/default.shtml

4.2.9.9. Reference organisations

- Ricoh[72]
- Philips[73]
- Sharp
- Lexmark[74] (it is not clear if Lexmark manufacturing sites in the EU in which biodiversity practices are implemented).

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[72] For further details see http://www.ricoh.com/environment/biodiversity/outline.html

[73] For further details see http://www.philips.com/about/sustainability/ourenvironmentalapproach/biodiversity/index.page

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UN (1992)	United Nations; The Convention on Biological Diversity, 1992, available at: http://www.cbd.int/doc/legal/cbd-en.pdf

Site visit:

A site visit to SMF, a manufacturing facility of SHARP located in France, was held on 28.10.2014. Information originating from the site visit or in the correspondence thereafter is referenced based on the source of information as follows:

Fuchs (2013a)	Fuchs, E.; SMF Biodiversity reporting to SHARP, dated 09.09.2013
Fuchs (2014)	Fuchs, E.; Summary of Pond Project and findings of Flora and Fauna survey at SMF pond, dated 05.11.2014
SMF (2014)	SMF; Site visit at SHARP SMF manufacturing facility; 28.10.2014

4.2.10. Use of renewable energy

4.2.10.1. Description

Climate change mitigation measures for energy can be subdivided into two broad categories, one involving the reduction of energy requirements and the other involving the use of renewable energy sources. Since the reduction of energy consumption within EEE manufacturing processes has been extensively elaborated in many of the previous best environmental management approaches (see especially sections 4.2.1 – 4.2.4), this BEMP is focussed on the integration of renewable energy sources in the EEE manufacturing process.

A strategic approach for best environmental management practice regarding the use of renewable energy in the EEE sector should consider the following elements:

- Purchase of green electricity with additional environmental benefit;
- Own production of electricity from RES-E;
- Own production of heat from RES-E.

Measures for increasing electricity generated by using renewable energy sources (RES-E), such as electricity from photovoltaic systems, wind power or hydropower, include both requirements imposed by the regulator (e.g. feed-in tariffs) and voluntary measures undertaken by businesses or consumers (e.g. supply of green electricity usually at a higher premium price).

However, where the electricity is supplied from existing RES-E plants, all that happens is that the "green" electricity is virtually "re-routed" for accounting purposes – away from normal electricity customers (who are usually unaware of this "loss") towards the "green" electricity customers. In environmental terms this re-budgeting has no effect, since the amount of green electricity is not increased. It only makes sense to consider separately purchased green electricity as a "truly environmentally friendly option" if this green electricity creates an additional environmental benefit.

To begin with, this includes checking whether the separately purchased green electricity is new (i.e. whether it comes from newly built plants and not, for example, from existing hydropower plants) and how "new" green power plants are defined. Secondly, it must be verified that the "new" green electricity has been produced through an additional and separately paid-for measure and not as the result of a government requirement or feed-in tariff.

Against this background, the selection of green power supply options should address the possibility to include criteria for active extension of green electricity production in the respective country (additionality) and criteria on ecological aspects, beside effects on climate change above and beyond legal requirements (eligibility). Such criteria may serve as important element to ensure sustainable generation of the electricity supplied.

As an alternative to the purchase of green electricity, the option of installation of own RES-E power devices (e.g. photovoltaic cells installed on the manufacturing buildings, use or re-activation of existing water power potentials) can be an interesting alternative for companies to improve the environmental performance of the specific electricity mix.

In addition to the use of green electricity, the installation of heat technologies could provide a significant potential for emission abatement, which may be enhanced in particular by the exploration of regional opportunities (e.g. solar energy in southern European countries, wind

energy at the coastline and other favourable locations, geothermal power according to local availability). In addition to this, the use of biomass and biogas are further strategic options that need to be considered (Carbontrust 2014).

In terms of solar thermal energy, for example, several application fields beyond the low temperature applications exist at medium or medium-high temperature levels (80°C-250°C). Heat production of process energy, solar cooling and air conditioning, solar drying, distillation and desalination are considered to be important examples (Schweiger et al. n.y.).

Besides solar thermal energy, also the substitution of conventional fuels by biomass (e.g. wood) within CHP plants can be considered as an interesting option for the use of renewable energy, especially for those EEE manufacturers who opted for the installation of such a plant in the past. The benefit of this measure can be seen in the combination of a CHP plant's specific high energy efficiency with the relatively low environmental impact of the production of biomass-based feedstock compared to conventional fuels.

4.2.10.2. Environmental benefits

Although electricity generated by using renewable energy sources is physically identical for consumers, ecological impact differs significantly. In principle, conventional fossil and nuclear power generation, with their climate impact and nuclear risks respectively, can be replaced.

In contrast to this, the reference case for power supply is considered to be "grey" electricity. This means, the electricity fuel mix is of no particular relevance for purchasing decisions and therefore usually accords to the particular national electricity fuel mix.

Since the electricity fuel mix is considerably different for the European Member States, the environmental benefits of RES-E are particularly high in countries with a low share of renewables in the national electricity mix. This can be demonstrated with the following table. For example, when using RES-E from photovoltaic plants in Poland, the savings of greenhouse gas emissions exceed 1.1 t CO_2-eq/MWh, whereas in Austria only 0.26-0.29 t CO_2-eq/MWh can be saved.

Table 4-13: Greenhouse Gas Emissions of Different Sources to Generate Green Electricity Compared to the National Emission factors

Emission factors for local renewable electricity production

Electricity source	t CO_2-eq/MWh
Photovoltaic	0.020-0.050
Wind power	0.007
Hydropower	0.024

National mission factors for consumed electricity

Country	t CO_2-eq/MWh
Austria	0.310
Belgium	0.402
Germany	0.706
Denmark	0.760
Spain	0.639
Finland	0.418

Emission factors for local renewable electricity production

France	0.146
United Kingdom	0.658
Greece	1.167
Ireland	0.870
Italy	0.708
Netherlands	0.716
Portugal	0.750
Sweden	0.079
Bulgaria	0.906
Cyprus	1.019
Czech Republic	0.802
Estonia	1.593
Hungary	0.678
Lithuania	0.174
Latvia	0.563
Poland	1.185
Romania	1.084
Slovenia	0.602
Slovakia	0.353
EU-27	**0.578**

Source: Own table according to data from Convenant of mayors (n.y.)

When considering renewable heat, it has to be taken into account that current energy demand in the EU for medium and medium-high temperatures is estimated to reach 300 TWh (Schweiger et al. n.y.)

Within this context, renewable heat technologies could abate 120 Mt of CO_2 by 2030, which is considered to be a very important contribution in order to achieve the goals concerning the abatement of climate change that have been set at the international, EU and Member State level (IEA 2012).

4.2.10.3. Appropriate environmental performance indicators for monitoring the implementation of the BEMP and/or its environmental benefits

When taking into account the large differences of RES-E in the national electricity mix of the different EU Member States, the environmental performance of the implementation of this BEMP should be measured with the following two indicators:

- Share of electricity from renewable sources (RES-E) in electricity mix of the company;
- Greenhouse gas emissions (in CO_2-equivalents) of the company-specific electricity mix.

In analogy to electricity, the use of heat from RES-E should be monitored by the following metrics:

- Share of heat from renewable sources (RES-E) in heat energy mix of the company;
- Greenhouse gas emissions (in CO_2-equivalents) of the company-specific heat energy mix.

4.2.10.4. Cross-media effects

In terms of cross-media-effects, it has to be taken into account, that for example photovoltaic cell fabrication facilities may adversely affect environment by emitting pollutants during routine operation or accidental events. Due to the fact that a large variety of materials is used during manufacturing of photovoltaic devices, there is a risk of exposure of the environment (as well as of employees) with substances, some of which are toxic carcinogenic, pyrophoric or flammable (Fthenakis & Moskowitz 2000). The following table gives an overview of hazardous materials used in photovoltaic-cell manufacturing.

Table 4-14: Hazardous Materials Used in Photovoltaic-cell Manufacturing

Material	Source	Comments
Arsine	GaAs CVD	Highly toxic
Cadmium compounds	CdTe and CdS deposition	Suspected carcinogenic
Carbon tetrachloride	Etchant	Toxic, potent greenhouse gas
Chloro-silanes	a-Si and x-Si deposition	Decomposes to toxic fumes
Diborane	a-Si deposition	Highly toxic
Hydrogen	a-Si deposition	Fire hazard
Hydrogen fluoride	Etchant	Noxious, corrosive
Hydrogen selenide	CIS sputtering	Highly toxic, flammable
Hydrogen sulfide	CIS sputtering	Highly toxic, flammable
Phosphine	a-Si deposition	Highly toxic, flammable
Silane	a-Si deposition	High fire and explosion hazard

Source: Own table according to data from Fthenakis & Moskowitz (2000)

However, routine conditions in manufacturing facilities should not pose any threats to health and the environment. Quality control in these facilities demands especially clean conditions and air concentrations of contaminants in occupational space are thus expected to be much lower than threshold exposure limits.

4.2.10.5. Operational data

According to the different approaches mentioned in section 4.2.10.1, the corresponding details for implementation and operational data are given below.

Purchase of green electricity with additional environmental benefit;

According to the basic principle of additionality (see 4.2.10.1), the following options for green electricity have been distinguished by Rüdenauer et al. (2007) within the European context:

- **Non green version:** 'Grey' electricity means that the electricity fuel mix is of no particular relevance for purchasing decisions and therefore can be considered to accord approximately to the particular national electricity fuel mix.
- **Green version 1:** 100% RES-E according to the European Directive 2001/77/EC without any accessory requirements.
- **Green version 2:** 100% RES-E and HE-CHP[75], whereas HE-CHP may account to not more than 50%, including accessory requirements. These accessory requirements result in a defined environmental leverage effect, which is not (necessarily) guaranteed by green version 1. The accessory requirements refer to either eligibility[76] or additionality[77]. Requirements on these criteria might refer directly to the supplying power plants or to a fund[78] fed by the green product.
- **Green version 3:** 100% RES-E, including accessory requirements. Again, the accessory requirements refer to either eligibility[76] or additionality[77], whereas requirements on these criteria might refer directly to the supplying power plants or to a fund[78] fed by the green product.

Conventional fossil and nuclear power is automatically excluded.

Own production of heat from RES-E

The most important source for heat from RES-E is solar heating. This technique is based on collector panels, which are heated from direct solar radiation. A heat transfer fluid (in most cases consisting of water) is circulated through a duct, whereas the heat from solar radiation is transferred. The annual amount of heat energy that can be captured ranges from 300-800 kWh/m^2, but varies with design and location. (IEA 2007)

According to (Lauterbach n.y.) the following processes are suitable for solar heat, some of which are also considered to be relevant for the EEE sector (underlined):

- Pre-heating of raw materials
- Cleaning and washing
- Pasteurization, sterilization
- Surface treatment
- Drying
- Boiler feed water
- Supply of hot water or steam

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[75] As reference values for calculation of efficiency highly efficient combined heat and power generation (HE-CHP) plants according to the CHP Directive (Article 4).

[76] Eligibility comprises requirements in order to reduce the environmental impact of specific renewable energy sources (such as hydropower or biomass) or technologies and usually refers to nature conservation.

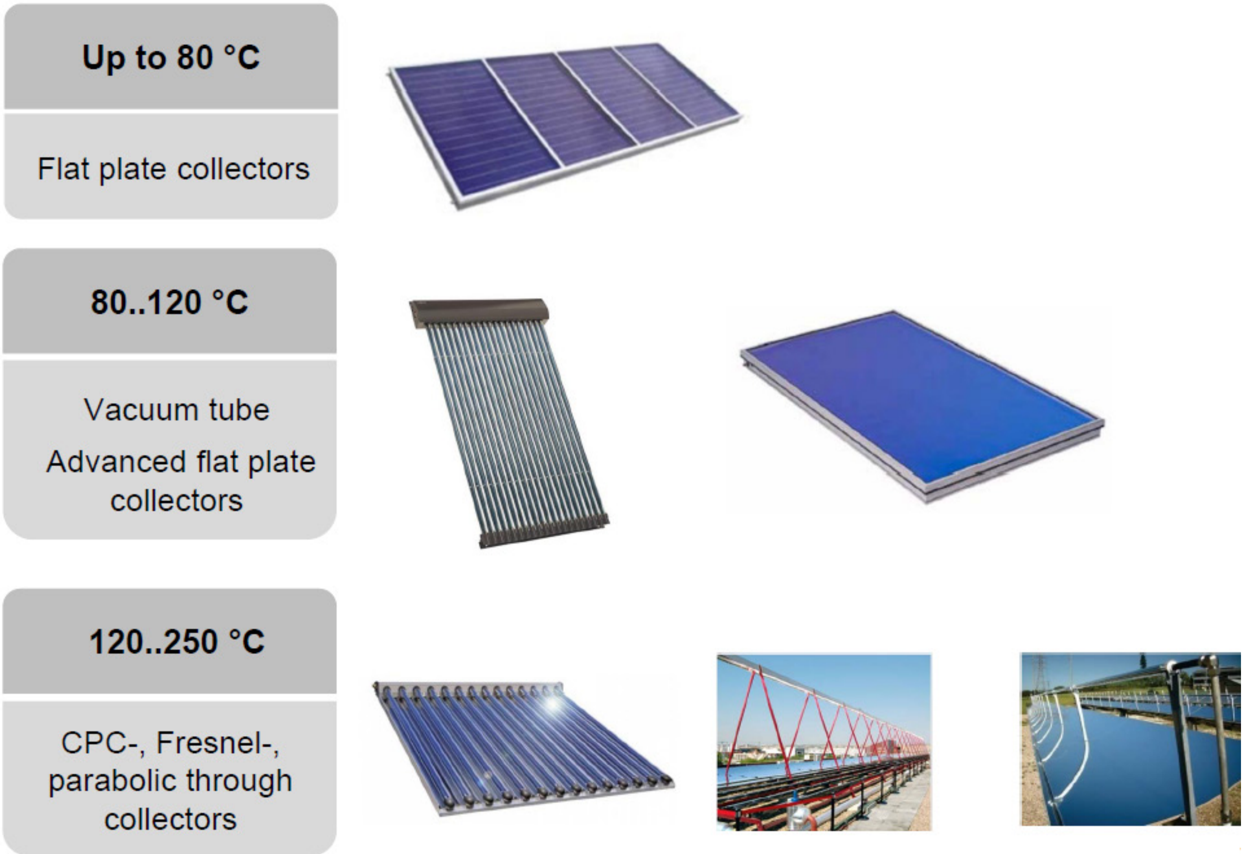
[77] Additionality means that the consumption of the green product has to stimulate directly an expansion of RES-E and HE-CHP generation. Thus, requirements have been specified that at least 50% of the electricity must be produced in plants not being older than 12 years, whereas at least 25% must be produced in plants not being older than 6 years.

[78] Funds ensure that a certain amount of the electricity price is invested in the erection of new renewable power plants. As first estimation, one can assume that the environmental leverage effect of 1 ct/kWh is in the same order of magnitude as the defined additionality criterion (see above). This could be proved within the Oeko-Institut's EcoTopTen project (cf. 'Hintergrundpapier Strom' at http://www.ecotopten.de/download_forschungsberichte.php)

Due to the introduction of highly selective coatings, flat plate collectors can reach temperatures of more than 200°C. With these collectors good efficiencies can be obtained up to temperatures of 100°C, especially in in Southern European climates. (Schweiger et al. n.y.)

As illustrated by the following figure, collectors for process heat applications at different temperature levels are available on the market.

Figure 4-19: Collectors for process heat applications at different temperature levels



Source: Lauterbach n.y.

Concerning the integration of RES-E as an energy carrier for the operation of CHP plants (that are already widely used by EEE manufacturers), both a single source feedstock basis as well as variable and mixed feedstock is feasible. According to Biomass Power (n.y.), the following biomass-based feedstock is considered to be acceptable fuel for a CHP plant:

- Wood chips;
- Waste wood from a single source;
- Waste wood from multiple sources (larger units only)
- Chicken litter;
- Agricultural residues and waste;
- Specially grown biomass crops;
- Compost oversize;
- Garden waste;

- Paper & cardboard;
- Refuse derived fuel (larger units only);

When taking into account this feedstock portfolio, it has to be concluded that EEE manufacturers have only very few of the above mentioned energy carriers available in larger quantities. Thus, they have to be bought from suppliers, which makes the integration of biomass in EEE manufacturing less attractive than in other businesses (like e.g. in the food and beverages sector).

4.2.10.6. Applicability

Concerning applicability of purchasing green electricity it needs to be mentioned that green electricity products are not explicitly offered in each EU Member State. Reason for this phenomenon is that all offers of RES-E products are strongly depending on the national electricity market (Rüdenauer et al. 2007):

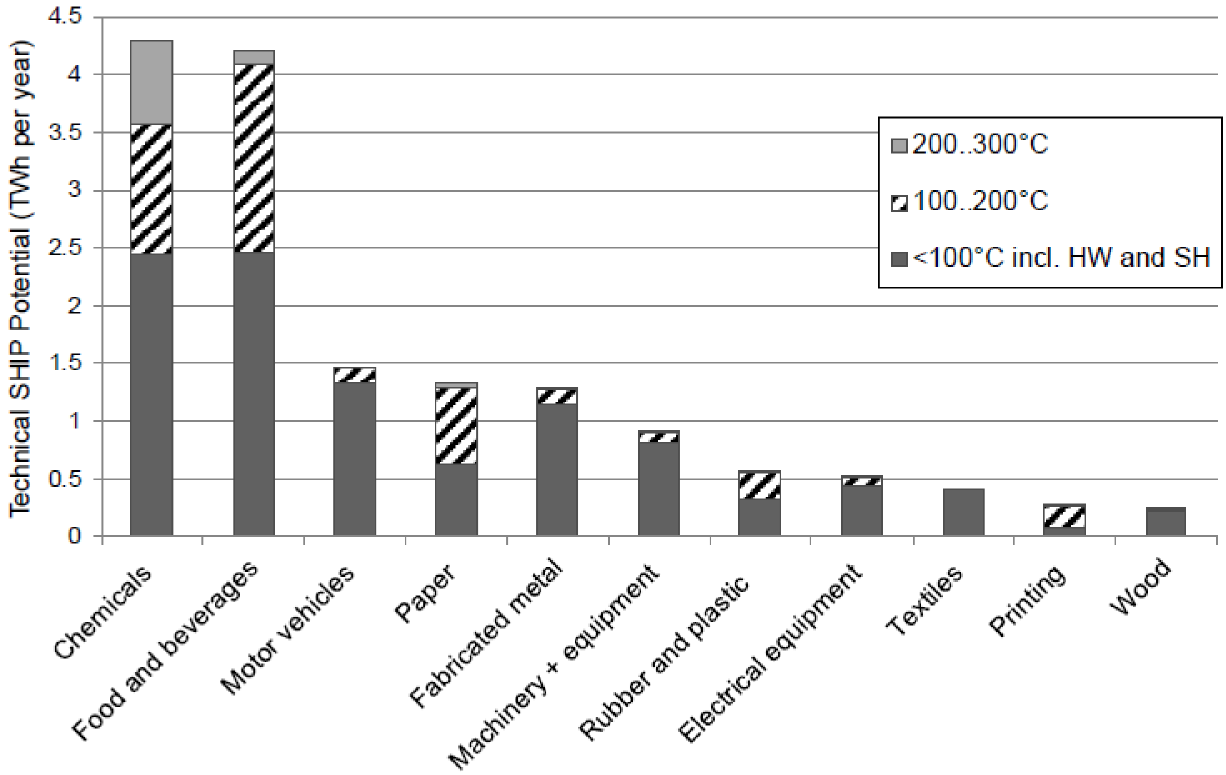
- Sweden, for example, already has a high share of hydropower. Thus, fossil CHP, being part of green version 2, is not perceived as a green option at all. Similar, additionality criteria aiming at further extension of RES-E production capacities are not requested by consumers. The focus of green electricity in Sweden lies on eligibility aspects in order to decrease negative environmental impacts related to hydropower and use of biomass. Data on prices for green version 3 therefore comprises offers according to the well-established Bra Miljöval standard for ‘electricity supplies’ (SNF 2001).
- In Germany, however, the focus is on decreasing CO_2 emissions, which is also reflected by German electricity labels like “Grüner Strom Label” and “ok-power” (EnergieVision & Grüner Strom Label 2000). Hence, green electricity products are characterised by strong additionality aspects. HE-CHP is perceived as green, as CHP plants have a significant potential to reduce CO_2 emissions compared to the coal-dominated national electricity mix.
- The same would be applicable for other countries with a relatively low share of RES-E in the national electricity mix, e.g. like Slovenia and the Czech Republic. However, due to incomplete liberalisation of electricity markets and low interest of consumers in green electricity, the markets for green options are still under development in these Member States. Therefore, only very few green offers are available. Especially in this case the installation of own RES-E power devices is recommended for companies to improve the environmental performance of their production.

In terms of renewable heat, a number of challenges limit the applicability of renewable heat deployment. Besides economic aspects (see section 4.2.10.7 for more details), especially technical issues and other barriers need to be considered. Technical barriers refer to the incompatibility of technologies with sub-sector’s temperature demands, difficulties in integrating renewable sources into the existing conventional systems, and potential incompatibilities between heat demand and seasonality of renewable heat offer. Other barriers include aspects like regional climate conditions, resource availability, planning guidelines, risk percipience, and lack of long term confidence. (Carbontrust 2014)

In contrast to other sectors (like e.g. food and beverages), where integration of solar heat in processes is considered to be easier due to lower complexity of the production processes, the potentials in the EEE sector are relatively low (Lauterbach 2014). Besides its relatively high complexity of production processes, a further specific barrier for expanding the actual use of renewable heat in EEE manufacturing can be seen in CHT plants that have been recently installed at a number of EEE production sites (see also section 4.2.10.7). Within this context especially the limited availability of suitable feedstock than can be taken directly from the EEE manufacturing

processes has to be mentioned (see section 4.2.10.5). As a result and illustrated by the following figure, the technical potential accounts for only 0.5 TWh p.a., whereas in the chemicals as well as the food and beverages sector an annual potential of more than 4 TWh can be achieved.

Figure 4-20: Technical potential for the use of solar process heat of the eleven selected sectors divided in temperature ranges



Source: Lauterbach 2014

4.2.10.7. Economics

The purchase of RES-E is often associated with significantly higher costs. However, Rüdenauer et al. (2007) could show, that is not applicable in general. Instead, it could be shown, that country-specific constraints need to be considered also in terms of economic aspects. The following table shows the results of the comparison of the prices for green and non-green versions of electricity (for the definitions of the green versions of electricity see also section 4.2.10.5):

Table 4-15: Additional Charges for the Three Green versions (GV) Relative to 'Grey' Electricity

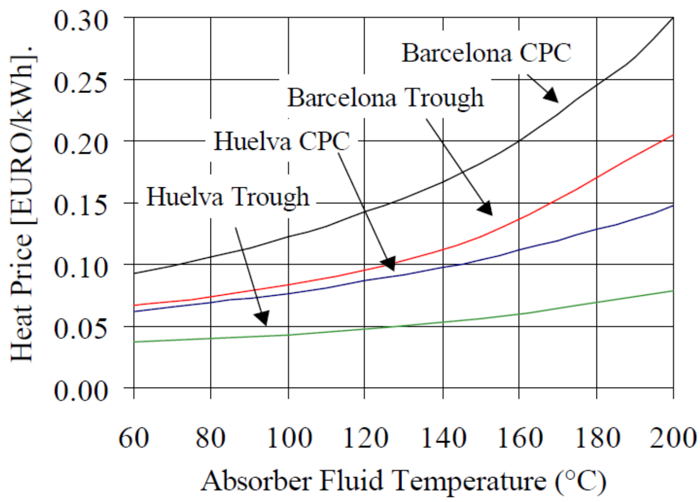
Member State	Baseline price [€/MWh]	Additional charge [€/MWh]			Comment
	'grey' electricity	GV 1	GV 2	GV 3	
Sweden	70.70	0.1-0.8	–	0.4-1.0	GV 3: comprehensive requirements on eligibility
	100%	0.1-1.1%	–	0.6-1.4%	
Germany	118.60	0-4	0	1-21	GV 3: requirements on additio-nality (fund or new plants)
	100%	0-3.4%	0%	0.8-17.7%	
Slovenia	76.10	0	–		GV 3: requirements on additionality (fund)
	100%	0%	–	5.6%	
Czech Republic	88.20	–	–	3.6	GV 3: requirements on additionality (fund)

Source: Rüdenauer et al. (2007)

According to this assessment, the additional charges for the three green product versions, relative to the baseline price for grey electricity, account for 0-18% of the baseline price, depending on the Member State and the green version. The green versions 1 and 2 are characterised by very low additional charges, which tend towards zero. In Germany, for example, a supplier of green electricity successfully provides offers for procurement tenders of conventional electricity. Besides offers with a very low surcharge, the highest additional charges (up to 21 €/MWh in Germany) were found for green version 3, which is the version with the highest environmental leverage effect. For those products which include a fund for the support of green electricity, it is essential to have a surcharge compared to grey electricity. As first estimation, one can assume that the additional value for the environment is proportional to the surcharge feeding the fund.

Concerning the use of RES-E, for applications at 100ºC heat costs are in the range of 0.04-0.12 EUR/kWh (Schweiger et al. n.y.). The following figure indicates the heat prices from CPC (Compound Parabolic Collector) devices a function of mean collector fluid temperature for different locations in Spain.

Figure 4-21: Heat prices as a function of mean collector fluid temperature



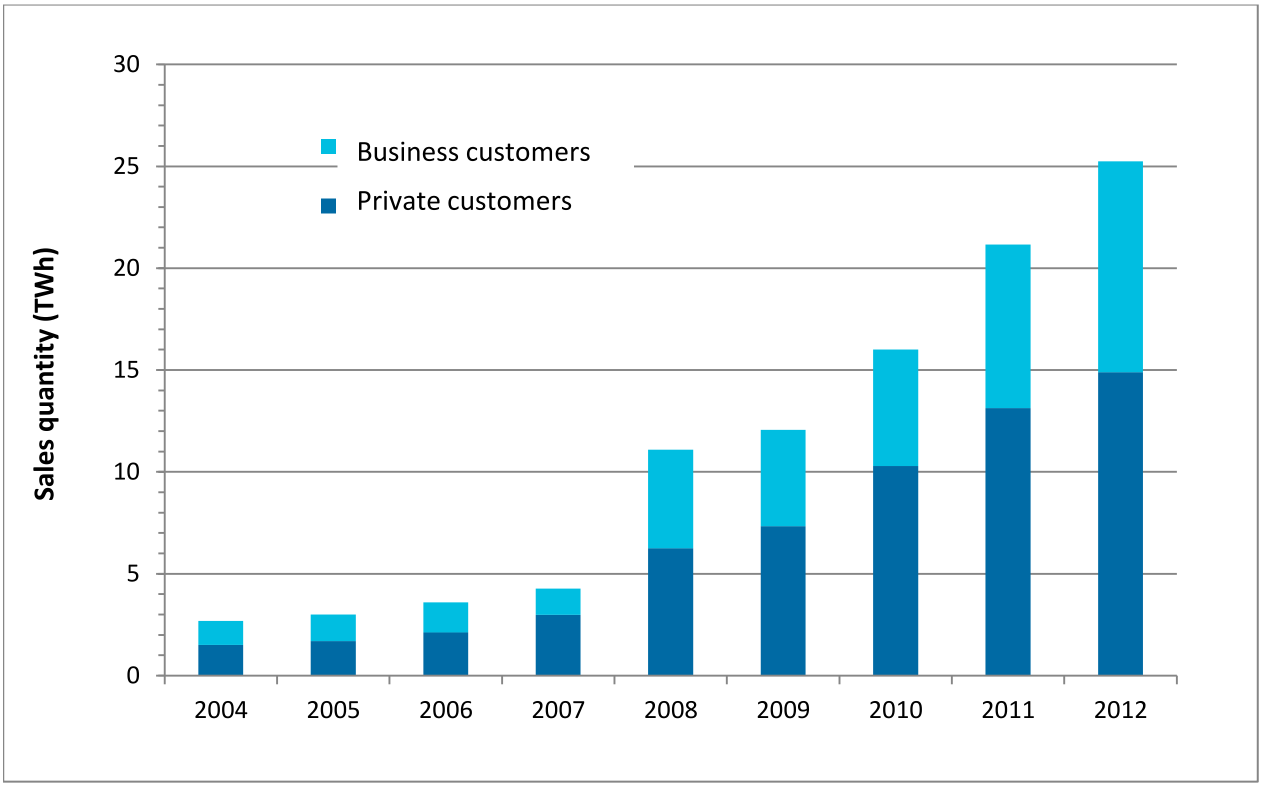
Source: Schweiger et al. n.y.

In contrast to this, costs for thermal energy in industry from conventional sources are typically as low as 0.01 EUR/kWh. Economic barriers for heat from RES-E are thus mostly related to cost comparisons between renewable and conventional heat options. In particular, the most frequent reason for a rejection of a solar system recent investment of a combined heat and power (CHP) plan, which often produces an excess of heat. (Schweiger et al. n.y.).

4.2.10.8. Driving force for implementation

Major driving force for the use of electricity from renewable resources is the general tendency in industry to reduce greenhouse gas emissions or even become carbon-neutral. This is especially applicable for companies who have already largely realised existing potentials to increase the energy-efficiency of their processes. Other important drivers for RES-E are national feed-in tariffs as stipulated by national legislation. For example in Germany the Erneuerbare-Energien-Gesetz (EEG 2008) has to be mentioned within this context. This initiative has contributed to Germany becoming the largest market for green power in Europe. As shown in Figure 4-22, a total of approx. 25 TWh of green electricity has been sold in Germany in 2011. About two thirds of these sales are in demand by private customers, whereas business customers have ordered only 10 TWh. However, it has to be mentioned, that the current sales of RES-E accounts only for approx. 4% of total electricity demand in Germany. Relevant labels for green electricity with a demonstrable environmental benefit (see section 4.2.10.2) are “Grüner Strom Label” and “ok-power” (Energie-Vision & Grüner Strom Label 2000).

Figure 4-22: Sales Quantity of Green Electricity in Germany



Source: Oeko-Institut / own calculations

In Scandinavia, especially the label "Bra Miljöval" by the Swedish Nature Conservation Federation has to be mentioned with certification volume of about 8 TWh per year. The correspondent label criteria mainly include conservation requirements in terms of environmentally friendly power generation. It is interesting to note, that the construction of new hydropower plants shall be explicitly avoided. This will, inter alia, implemented by a maximum age for hydroelectric power plants. According to these criteria, further impacts on the landscape and aquatic ecosystems should be avoided in view of the already widespread hydropower in the Nordic countries. The comparison with the explicitly supported construction of new generation facilities within the German green energy market demonstrate the diversity of ideas and concepts regarding RES-E production and how much they depend on the respective national conditions.

Both in Belgium and in the Netherlands, the development of the green power market has been encouraged through tax incentives for RES-E production. Even though this is no longer the case today, the share of RES-E products is still high.

UK as a pioneer of a liberalized, but also regulated electricity market shows how much the development of RES-E production can be influenced by governmental bodies. For example, the national regulator Ofgem initiated the Green Energy Supply Certification Scheme (GESCS) in 2009. Ofgem defined for this voluntary certification program additional criteria according to which a certain amount of annual savings of CO_2 emissions must be proven. The certified companies can decide whether they promote a fund for the development of RES-E production, or perform efficiency measures, or whether they opt for CO_2 offsetting by means of gold standard certificates. Furthermore, also governmental institutions and NGOs promote the use of RES-E in the UK. For example in UK, the Energy Saving Trust recommends buying green electricity (Energy Saving Trust 2014).

In addition to the labelling initiatives on the national level, an international standard for green electricity products has been initiated in 2013. The "EKOenergy" network, a coalition of 31 organizations from over 25 countries, aims to establish a pan-European benchmark for RES-E. The focus of this initiative is on criteria of ecological requirements for RES-E production facilities as well as on funding in order to finance international projects in the field of renewable energy. Despite of its already wide network, EKOenergy is still characterized by a low volume of sales and a strong focus on the Finnish market and is thus still in its infancy.

In order to overcome the barriers concerning the use of renewable heat mentioned in section 4.2.10.6, a combination of favourable policies including especially economic support is regarded to be a driver that is needed. However, only few countries have regulatory frameworks to incentivise renewable heat technologies, and even less countries provide specific incentives to foster their penetration in the industry (Carbontrust 2014).

4.2.10.9. Reference organisations

- Apple: Corporate offices, retail stores as well as data centres of Apple are powered with energy from renewable sources. As of 2013, 73% of the energy for all facilities have been converted from conventional to renewable sources (86% for the corporate campuses and 100% for data centres). An addition to that, in 2014 more than 140 retail stores in the U.S. are powered with renewable energy (Apple 2014)
- STMicroelectronics: The energy strategy of STMicroelectronics covers both the generation and purchase of green energy. The different sites of the company are encouraged to adopt renewable energy sources and greener energy technologies wherever possible, such as solar panels, which have been installed in Catania (Sicily), Geneva (Switzerland) and Grenoble

(France) sites (STMicroelectronics 2014). In 2004, STMicroelectronics has received the Award for the Best Industrial Renewable Energy Partnership from the European Commission (STMicroelectronics 2004)

- Tesla Motors: Tesla recently announced that its so called "Gigafactory", which will produce batteries for Tesla's electric cars, will produce all of the required energy (estimated to account for 2,400 MWh per day) based on RES-E, using a combination of solar, wind, and geothermal. Due to its location with favourable conditions for electricity from photovoltaics (average of five peak sun hours per day), 850,000 m² of the site's roof area are expected to be covered with solar panels, that gives a solar energy production of 850 MWh per day. In addition to this, about 85 turbines (at 3 MW each) will generate approx. 1,800 MWh per day of wind energy. Finally, a 10 MW geothermal power plant will contribute with 240 MWh to the renewable energy supply (Lombardo 2014).

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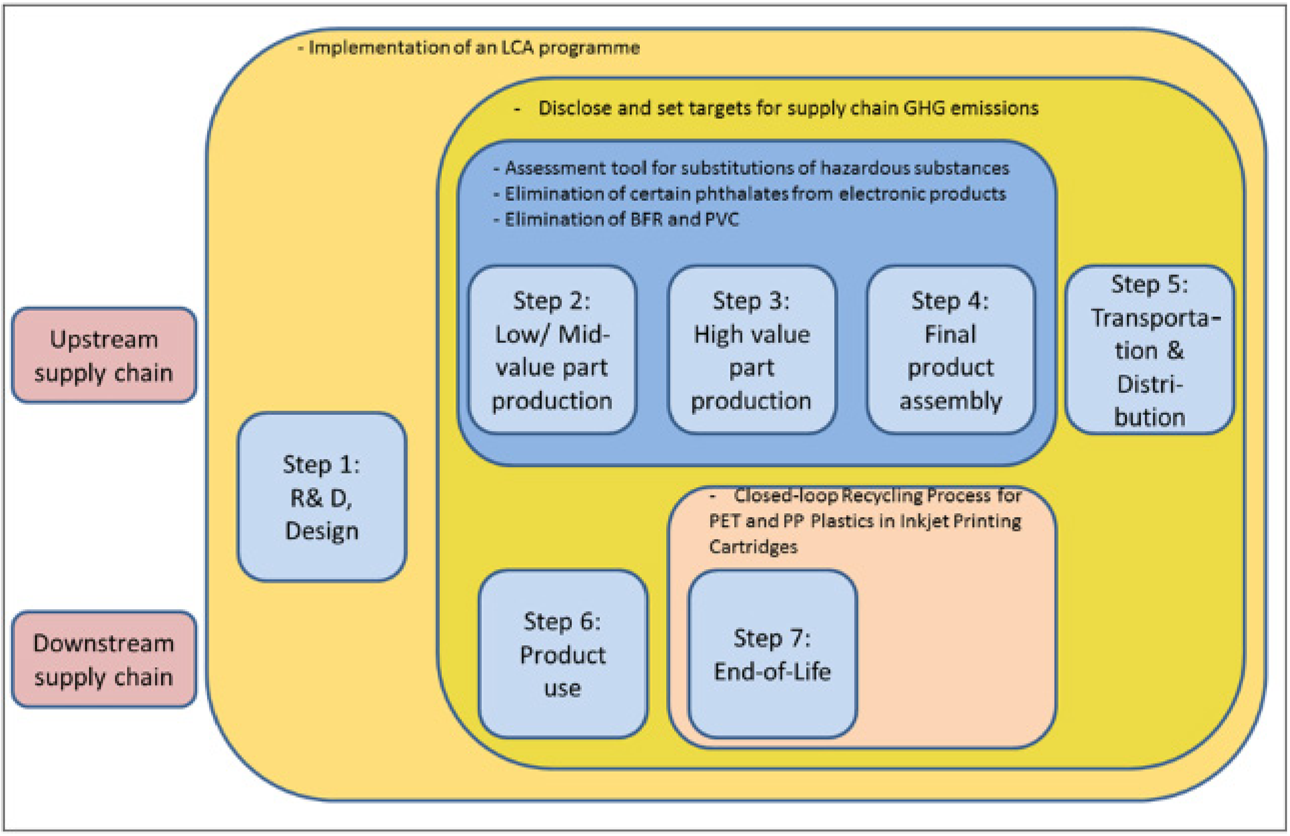
5. Supply chain management in the EEE sector

5.1. Scope

The scope of this chapter encompasses activities at various stages of the supply chain of EEE. As supply chains of EEE are very complex networks with many different participants performing many different functions (Wood & Teltow 2013), it is deemed necessary to restrict the focus of the BEMPs to selected parts of the supply chain. However, BEMPs selected for this study cover various parts of the EEE supply chain. The figure below gives a simplified illustration of the focus of supply chain BEMPs:

Figure 5-1: Focus of supply chain BEMPs



Source: Own illustration

As mentioned in the BEMP "Disclose and set targets for supply chain GHG emissions", Scope 3 emissions, i.e. upstream and downstream supply chain emissions, typically make up a major share of overall corporate GHG emissions (more than 90% of total GHG emissions) in the EEE sector. Even today, only few front-runner companies are reporting comprehensively on Scope 3 emissions, partly due to limited number of standards for Scope 3 emission reporting. However, the main reason for limited reporting lies in the complexity of widely ramified supplier network and a lack of experience in collecting data and reporting on Scope 3 emissions. Thus, disclosing and setting targets for reducing supply chain GHG emissions is deemed as a necessary first step towards minimising the overall impact of EEE.

The major portion of Scope 3 emissions arise as a result of product use and purchased goods & services, which includes component manufacturing. In the latter case, manufacturing of electronic components, such as motherboard, memory, CPUs etc. is related to high energy and/or material consumption as well as use of several harmful substances. For example, the energy and material consumption of a notebook's mainboard results in a GWP of approx. 70 kg CO_2e, representing almost 50% of the overall emissions of the production phase. In terms of hazardous substances, EEE products contain various hazardous substances, such as lead, mercury, cadmium, zinc, yttrium, chromium, beryllium, nickel, brominated flame retardants, antimony trioxide, halogenated flame retardants, tin, polyvinyl chloride, PVC. In printed circuit boards, cadmium occurs in certain components together with other hazardous metals such as lead, chromium, beryllium, zinc, mercury, and nickel. Brominated flame retardants and antimony trioxide are also often used in PCBs. Wiring is often coated in PVC, which often contains numerous additives, such as heavy metal compounds or softeners such as phthalates (DG ENTR Lot 9).[79] There is sufficient empirical evidence to suggest that BFRs, PVC and Phthalates lead to severe health and environmental impacts not only during manufacturing, but also during use and end-of-life treatment (Greenpeace 2010[80]; Prakash & Manhart 2010[81]). Thus, the BEMPs on the elimination of BFR, PVC and Phthalates are considered to be addressing one of the most relevant topics as far as worker's health protection in manufacturing and recycling facilities as well as protection of the environment around such facilities is concerned. At this point, it is important to mention that restriction and regulation of hazardous substances, such as certain phthalates and halogenated flame retardants are not always applied to imported articles from countries outside the EU. Hence, there effective phase-out on voluntary basis is even more necessary (refer to 5.2.2 and 5.2.3).

Overall environmental impacts in the supply chain can also be reduced by reducing the use of virgin resources. The BEMP on the use of recycled plastic polymers in the manufacture of new ink cartridges shows the way to decrease the demand for virgin materials – in this case crude oil.

Finally, true overall impacts of EEE products can be estimated only on the basis of life-cycle based impact assessments. For this reason, it is inevitable to conduct LCA, especially at important milestones of product development, such as during design of a new product, selecting materials, suppliers etc. As also shown in the BEMP on the implementation of an LCA program, LCA serve as an important tool to assess life-cycle based environmental impacts and identifying appropriate strategies to reduce them.

Against this background, the following table gives an overview of the developed best environmental management practices for EEE supply chain management and the addressed environmental pressures.

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79 Preparatory study for implementing measures of the Ecodesign Directive 2009/125/EC – DG ENTR Lot 9, Enterprise Servers and Data Equipment, Task 5: Environment & Economics, October 2014, Draft Report (BIO Intelligence Service / Fraunhofer IZM). Website: http://www.ecodesign-servers.eu/documents; Accessed: 15.11.2014

80 Why BFRs and PVC should be phased out of electronic devices, Website: http://www.greenpeace.org/international/en/campaigns/toxics/electronics/the-e-waste-problem/what-s-in-electronic-devices/bfr-pvc-toxic/, Accessed: 15.11.2014

81 Socio-economic assessment and feasibility study on sustainable e-waste management in Ghana, commissioned by the Inspectorate of the Ministry of Housing, Spatial Planning and the Environment of the Netherlands (VROM-Inspectorate) and the Dutch Association for the Disposal of Metal and Electrical Products (NVMP), Öko-Institut e.V., 2010

Table 5-1: Overview of the Developed BEMPs for EEE Supply Chain Management and the Addressed Environmental Pressures

No.	Title of BEMPs	Environmental pressures addressed						
		Resource efficiency	Water	Waste	Emis-sions to air	Energy & climate change	Bio-diversity	Hazar-dous sub-stances
	SUPPLY-CHAIN MANAGEMENT							
11	Assessment tools for substitu-tion of hazardous substances							X
12	Elimination of certain phthalates							X
13	Elimination of BFR and PVC							X
14	Disclose and set targets for supply chain GHG emissions					X		
15	Conducting LCA		X	X	X	X		
16	Increasing the content of recycled plastics in EEE	X				X		

Source: Own table

5.2. Description of best environmental management practice

Electronics supply chains are very complex networks with many different (worldwide) participants performing many different functions. The vast majority of assembly operations for finished electronic goods (FEG) are located in China, along with production of generally lower-value added parts (Wood & Tetlow 2013). Korea also plays an important role, producing high-value parts such as television and computer displays, and components including dynamic random access memory (DRAM) chips, and memory circuits. Further important roles in the electronic supply chain are played by Malaysia (contract manufacturing of parts), Thailand (production of parts, especially data storage components), Vietnam and Indonesia (assembly of FEG) and the Philippines (production of Intermediate Electronic Goods – IEG, notably HDDs and semiconductors) (Wood & Tetlow 2013). Thus, the supply chain of electronics involves several tiers of suppliers who each place articles on the market for assembly into more complicated articles by the next producer in the supply chain, often located in a different country. According to Hewlett-Packard (HP), its supply chain comprises of some 700 production suppliers in the 1st tier and tens of thousands of non-production suppliers, spanning more than 45 countries and territories in six continents (Wendschlag 2014a). The complexity of the supply chain and its geographical core area in Asia is also illustrated in Wood & Tetlow (2013) by showing the geographical sites involved in the part production and assembly of smartphones:

Table 5-2: Parts production and assembly locations for smartphones

Production step	Main locations
LCD panels	Japan, Korea, Chinese Taipei, China, Singapore
Printed circuit boards	Japan, USA, China, Chinese Taipei, Korea, Thailand, Singapore, Malaysia, Viet Nam, India, Mexico, EU
IC chips	Thailand, Malaysia, Philippines, Indonesia, Singapore, Viet Nam, Chinese Taipei, China, Korea, USA, Japan, EU
Capacitors	China, Chinese Taipei, Korea, Japan, Thailand, Malaysia, Philippines, Indonesia, Singapore
Inductors	China, Chinese Taipei, Korea, Japan, Thailand, Malaysia, Philippines, Viet Nam
Frame, accessories, and electromechanical parts (microphones, batteries)	Brazil, China, Chinese Taipei, India, Korea, Japan, Malaysia
Intermediate components (camera modules)	Brazil, China, Chinese Taipei, India, Korea, Japan, Malaysia
Final product assembly	Brazil, China, Chinese Taipei, India, Korea, Japan, Malaysia

Source: JEITA (2009), as shown in Wood & Tetlow (2013)

According to Graulich et al. (2013), the producers' influence on the design, performance and chemistry of (components of) computers and televisions depends on the article in question. For standard commodity articles like wires, screws and printed circuit boards, the producers often have little or no influence on design or chemical composition. Due to the complexity of the electronics supply chain, an Original Equipment Manufacturer (OEM) may therefore face a range of challenges in seeking to verify compliance with company-specific substance restrictions that go beyond legal requirements. However, there are several approaches to monitor and assess the compliance if suppliers with company-specific restrictions and differences between the OEMs in this regard are not very significant. Generally, OEMs have written contractual agreements with their suppliers regulating the compliance with company-specific restrictions of substances. However, the consequences of non-compliance by suppliers vary between companies, ranging from termination of supplier contracts, issuing written warning to no-action. Various tools are applied within such contractual agreements to verify compliance, such as Full Material Declaration, Supplier Declaration of Conformity, in many cases complemented by (internal or third-party) laboratory testing, audits and certification. According to Graulich et al. (2013), most OEMs have developed material questionnaires (also known as green procurement surveys) that require suppliers to disclose information about their products. These questionnaires usually take the form of a list of banned or restricted materials and substances for which the supplier must certify that they are not present in the product or subpart. In addition, OEM's often include a separate list of materials and substances that need to be reported when present.

Graulich et al. (2013) list several ways how various companies/OEMs have been managing their supplier base in terms of requirements pertaining to the exclusion of hazardous substances in the supply chain:

1. Hewlett-Packard's Green list of substances: According to Hewlett-Packard, the company has developed a Green list of substances, partially as a result of the assessment of Green-

Screen® (refer to 5.2.1.1), which is recommended to the suppliers. The Green list is, however, confidential and hence not publicly available. Use of GreenScreen® assessment results is included in the agreement with the suppliers, meaning that suppliers are asked to use materials with GreenScreen® Benchmark 2 or better (Wendschlag 2014b).

Apple's Supplier Declaration of conformity: While restricting the use of bromine- and chlorine-based compounds in all homogeneous materials of its products, Apple's suppliers were required to establish strict compliance management programs, which included using certified laboratory testing to demonstrate that they were complying with the new requirements. Throughout the transition to bromine- and chlorine-free materials, Apple monitored its suppliers' compliance via internal audits. A transparent compliance program which allows for quick and inexpensive material testing (here: analysis of Br and Cl on elemental level) enabled Apple to identify problems early on and take corrective action. According to the experience of Apple, an extensive auditing program in a supply chain is critical to increasing compliance and ensuring full implementation of new material specifications, particularly during the early stages of the transition (Nimpuno et al. 2009).

Dell's Supplier Declaration of conformity: Dell requires suppliers to sign a Supplier Declaration of Conformity (SDoC) to ensure that all product materials comply with Dell's environmental policy (Dell 2013). To sign the SDoC, the supplier must ensure that the product meets the Dell Materials Restricted for Use specification and record any applicable exemptions. At Dell's request, the supplier must also be able to provide technical documentation in the form of internal design controls, a supplier declaration or analytical test data. Dell's goal is to collect supplier declarations for each part of a product's bill of materials. This will ensure that each product meets the legislated materials requirements. A second tier in Dell's compliance verification strategy is the supplier RoHS audit program. This program can be divided into two parts: a traditional audit and an in-depth supplier survey. A traditional audit, in which Dell parts are selected at random and submitted for third-party analytical testing, is conducted on a quarterly basis. Samples are tested for the presence of restricted materials, including those prohibited by the RoHS Directive. The audit is used to further validate SDoCs and to ensure that Dell's entire supply chain complies with the directive. Dell also actively screens samples in-house by using X-Ray Fluorescence (XRF) equipment.

Seagate's bromine- and chlorine-free hard disk drives: Seagate is a manufacturer of bromine- and chlorine-free hard disk drives. Seagate compliance incorporates supplier full disclosure, with third party data review and audit. Software automation is used to gather and manage data (Martin n.y.). Seagate implemented an automated Compliance Assurance System for tracking the use of all materials in hard-drive components. The system was based on an industry-standard reporting form developed by IPC (originally the Institute for Printed Circuits). Seagate used it to launch a full material reporting and disclosure requirement across its supply chain. The system requires component suppliers to report on all substances present, regardless of whether or not the substance is restricted. To do so, the vendors provide the CAS numbers for each compound they use. Seagate also specified that suppliers provide independent laboratory analyses to prove conformance to RoHS and low-halogen restrictions, as well as an official statement confirming that the materials conform to Seagate's list of several hundred banned substances (Nimpuno et al. 2009).

Philips uses BOMcheck: BOMcheck[82] provides easy-to-use declaration tools to generate and maintain their substance declarations in the database. The declaration tool covers a list of restricted and declarable substances which are relevant to hardware articles and electrical and

[82] https://www.bomcheck.net/en/

electronic equipment (EEE). The list is aligned with the IEC 62474 screening of REACH Candidate List Substances. The IEC 62474 database of restricted and declarable substances will replace the Joint Industry Guide (JIG) later in 2013 (BOMcheck 2013). BOMcheck offers either a Full Materials Declaration (FMD) or a Regulatory Compliance Declaration (RCD). A FMD provides the % weight of each individual material in the part and the % weight of each substance which is intentionally added to each material. For example, a FMD for a PVC coated copper wire will contain two materials – the PVC coating and the copper wire. The PVC coating will include all intentionally added substances (e.g. stabilisers, plasticizers, flame retardants etc).

A Regulatory Compliance Declaration (RCD) includes only those substances which are restricted or declarable for hardware products by regulations in North America, Europe and Asia Pacific. BOMcheck provides detailed practical guidance on where these substances can be found in materials or parts of hardware products, and any exemptions that apply. Knowledge on where to look for restricted and declarable substances saves sample testing costs. However, the RCD needs to be updated every 6 months when more substances are added to the REACH Candidate List and other regulatory requirements. Therefore, OEMs encourage their suppliers to make a Full Materials Declaration (FMD) because BOMcheck automatically uses the FMD to re-calculate an RCD for the suppliers' parts when the list of regulated and declarable substances changes. For example, Philips has asked its suppliers to declare compliance with REACH, RoHS and other requirements by making BOMcheck declarations, with a preference for Full Materials Declaration (FMD).

The contractual agreements of OEMs with their suppliers are confidential and hence not accessible. But the tools to verify compliance, as mentioned above, are applied universally with various degrees of detail and stringency. In the following description of BEMPs for the supply chain management, reference to those tools will be used to define measurable environmental performance indicators.

5.2.1. Assessment tools for cost-effective and environmentally sound substitution of hazardous substances

5.2.1.1. Description

The complexity of the electronics supply chain represents the main factor hindering the transfer of knowledge on hazardous substances within the supply chain, as also concluded by Jepsen et al. (2009). Information on hazardous substances in materials is often only available if collected for RoHS and REACH compliance, as evidenced by the content of declarations available from manufacturers such as HP,[83] and/or compliance with company-specific substance restrictions.

Currently, there are few assessment tools for identifying chemicals of high concern and safer alternatives. Such assessment tools could serve as a basis for the OEMs to regulate their suppliers towards the use of substances with lower environmental and health impacts. In general, an assessment tool is applied after the identification of the hazard has taken place, substitution criteria have been set and possible alternatives have been identified. The internet portal SUBSPORT provides a list of available assessment and substitution tools on the website www.subsport.eu:

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83 Hewlett-Packard (HP), REACH Article 33 declarations, http://www.hp.com/hpinfo/globalcitizenship/environment/productdata/reachall-products.html#.UgfmFRyGg2V

Table 5-3: List of assessment and substitution tools for hazardous substances

Assessment/Substitution Tool	Elaborated by	Source
Column Model for Chemical Substitutes Assessment	Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA, Institute for Occupational Safety and Health of the German Social Accident Insurance)	http://www.dguv.de/ifa/Praxishilfen/GHS-Spaltenmodell-zur-Substitutionspr%C3%BCfung/index-2.jsp
COSHH Essentials (control of substances hazardous to health)	UK Health and Safety Executive	http://www.hse.gov.uk/coshh/essentials/index.htm
Technical Rules for Hazardous Substances (TRGS) 600 "Substitution"	German Committee on Hazardous Substances (AGS), 2008	http://www.baua.de/cln_135/en/Topics-from-A-to-Z/Hazardous-Substances/TRGS/TRGS-600.html
GreenScreen® for Safer Chemicals	Clean Production Action (CPA)[84]	http://www.greenscreenchemicals.org/
Determination and work with code numbered products (MAL Code)	National Working Environment Authority, Denmark	http://webcache.googleusercontent.com/search?q=cache:YHbrHw3LkHkJ:arbejdstilsynet.dk/~/media/48245F6E041C4FBBA99EFC6E1FA322A2.ashx+&cd=2&hl=de&ct=clnk&gl=de
Pollution Prevention Options Analysis System (P2OASys)	Toxic Use Reduction Institute of Massachusetts (TURI)	http://www.turi.org/home/hot_topics/cleaner_production/p2oasys_tool_to_compare_materials
Priority-Setting Guide (PRIO)	Swedish Chemicals Inspectorate (KEMI)	http://www2.kemi.se/templates/PRIOEngframes____4144.aspx
Quick Scan	Dutch Ministry of Housing, Spatial Planning and Environment	http://www.rijksoverheid.nl/documenten-en-publicaties/brochures
Stockholm Convention Alternatives Guidance	Persistent Organic Pollutants Review Committee of the Stockholm Convention on Persistent Organic Pollutants, 2009	http://chm.pops.int/Convention/POPsReviewCommittee/hrPOPRCMeetings/POPRC5/POPRC5Documents/tabid/592/language/en-US/Default.aspx
Stoffenmanager	Safe and Healthy Work Department of the Ministry of Social Affairs and Employment of Netherlands	https://stoffenmanager.nl/

Source: www.subsport.eu; accessed: 08.09.2014

In addition, a decision tool for substance manufacturers, formulators and end users of chemicals has been developed by the German Federal Environment agency (available in English and in German):

[84] Clean Production Action is a tax-exempt, nonprofit corporation under section 501(c)(3) of the Internal Revenue Code (http://www.greenscreenchemicals.org/about; accessed: 12.12.2014)

(1) Guide on sustainable Chemicals. Source: http://www.umweltbundesamt.de/publikationen/guide-on-sustainable-chemicals (English), http://www.umweltbundesamt.de/publikationen/leitfaden-nachhaltige-chemie (German)

Apart from that, two more tools need to be mentioned, which, however, are not dealt with in this report:

(2) Toxic Potential Indicator, developed by Fraunhofer IZM, Source: http://www.izm.fraunhofer.de/en/abteilungen/environmental_reliabilityengineering/key_research_areas/environmental_assessmentandeco-design/toxic-potential-indicator--tpi-.html

(3) Quick Chemical Assessment Tool (QCAT), developed by Washington State Department of Ecology, Source: http://www.ecy.wa.gov/programs/hwtr/chemalternatives/QCAT.html

All tools mentioned in Table 5-3 have advantages as well as disadvantages. The internet portal SUBSPORT has evaluated the above mentioned tools in terms of their reliability, user-friendliness and limitations. In the following Table 5-4, the evaluation results have been summarized. Detailed description of the tools is available at: http://www.subsport.eu/substitution-tools.

Table 5-4: Evaluation of the assessment and substitution tools for hazardous substances

Assessment/ Substitution Tool	Reliability	User-friendliness	Limitations
Column Model for Chemical Substitutes Assessment	Main source of information – Chemical Safety Data Sheets, which are known to have important shortcomings	Easy to handle by non-professional users and does not require special expertise if Chemical Safety Data Sheets are available	Since the method is based on risk phrases (R-phrases), it covers 7000 chemicals classified with such phrases, included in Regulation (EC) 1272/2008 on classification, labelling and packaging (CLP). However, once the CLP inventory is published at the ECHA website, the classification of all substances placed on the EU market will be available independent of their registration status. Estimates can also be drawn using the description of hazards associated with R-phrases, if there is an additional source of information on the assessed risks. For these estimations, a higher level of expertise would be recommended.
COSHH Essentials	Same as above	Same as above	Same as above. It does not take into account eco-toxicological properties, but only deals with risks to health.
Stoffenmanager	Same as above	Same as above	Same as above
Technical Rules for Hazardous Substances (TRGS) 600 "Substitution"	Same as above	Same as above	Since the method is based on R phrases, it covers 7000 chemicals classified with such phrases, included in Regulation (EC) 1272/2008 CLP. However, once the CLP inventory is published at the ECHA website, the classification of all substances placed on the EU market will be available independent of their registration status.
GreenScreen® for Safer Chemicals	Very reliable method due to the wide variety of parameters assessed and its highly reliable sources of information	It requires expertise and dedication to obtain the necessary information	The method requires specific training since it becomes necessary to consult databases and scientific literature

Assessment/ Substitution Tool	Reliability	User-friendliness	Limitations
Determination and work with code numbered products (MAL Code)	The reliability depends on the reliability of the Threshold Limit Values.	Once the code number is calculated it is very easy for downstream users and consumers to compare hazards of different products. The designation of code numbers requires expertise. The substances in sub-annex 1 are not supplied with CAS-numbers for identification of the substances	To determine the code number, you need information about the percentage by weight of the individual substances in the product. The code number can only be calculated for substances with a TLV (Threshold Limit Value). The Danish official code numbers relate to the Danish TLV's from 1993. It is possible though to use the code number system with other TLV's or tentative TLV's for comparison of products.
Pollution Prevention Options Analysis System (P2OASys)	Very reliable method due to the variety of indicators and the use of solid sources of information	Not easy to use. It requires expertise and dedication to obtain all the information about the different indicators	Access to the required information is difficult. There is not one single database or source providing the necessary data.
Priority-Setting Guide (PRIO)	The criteria and source of information used to define the hazardous properties of the substances are mainly the EU classification system. However, only a minority of existing substances has undergone EU classification work, therefore, substances that may have toxic properties as stated by scientific literature may not be considered.	If substances are included in the PRIO database it is easy to use and not time-consuming. Neither expertise nor training is needed.	Since the method is based on R-phrases, it only covers 7000 chemicals classified with such phrases, included in Regulation (EC) 1272/2008 CLP. However, estimates can be drawn using the description of hazards associated with R-phrases, if there is an additional source of information on the assessed risks. For these estimations, a higher level of expertise would be recommended. If the substance is not included in the PRIO database, access to information on PBT/vPvB and endocrine disrupting process is difficult and requires expertise. Physicochemical properties are not considered.

Assessment/ Substitution Tool	Reliability	User-friendliness	Limitations
Quick Scan	The method is reliable considering the variety of parameters it examines. However, the main source of information comes from R-phrases included in the European Regulation for labelling and classification of chemicals, therefore it does not consider updated scientific literature.	This tool requires certain expertise and training to obtain the necessary information.	Access to information on PBT properties is difficult. No criteria for identification of endocrine disrupting substances are included. Since the method is based on R-phrases, it covers 7000 chemicals classified with such phrases, included in Regulation (EC) 1272/2008 CLP. However, once the CLP inventory is published at the ECHA website, the classification of all substances placed on the EU market will be available independent of their registration status. Estimates can also be drawn using the description of hazards associated with R-phrases, if there is an additional source of information on the assessed risks. For these estimations, a higher level of expertise would be recommended.
Stockholm Convention Alternatives Guidance	Very reliable method due to the wide variety of parameters assessed and its highly reliable sources of information	The guidance requires expertise and dedication to obtain the necessary information.	The guidance requires specific training since it becomes necessary to consult databases and scientific literature.

Source: www.subsport.eu; accessed: 08.09.2014

Regarding reliability and user-friendliness, the above mentioned Guide on Sustainable Chemicals can be considered as similar to the Column Model for Chemical Substitutes Assessment and the Technical Rules for Hazardous Substances (TRGS) 600 “Substitution”.

While the tools described above differ in terms of the degree of expertise required for their use, it is considered necessary that the assessment results achieved after using a tool are highly reliable. High reliability is an important criterion because substitution of substances might be associated with very high costs as well as (unknown) risks.

From the above-mentioned list of tools, only three tools were found to be very reliable:
(1) GreenScreen® for Safer Chemicals, (2) Pollution Prevention Options Analysis System (P2OASys), and (3) Stockholm Convention Alternatives Guidance. Therefore, this BEMP is being explained mainly taking the examples of Green Screen® for Safer Chemicals and Pollution Prevention Options Analysis System (P2OASys). In case of the Stockholm Convention Alternatives Guidance, the published paper is available only in the form of guidance on the step-wise approach for hazardous substance assessment and substitution.

Note: For many small and medium sized enterprises, Green Screen® for Safer Chemicals and Pollution Prevention Options Analysis System (P2OASys) require specific knowledge which will not be available inhouse. For such companies, less complex tools as the Column Model for Chemical Substitutes Assessment, the Technical Rules for Hazardous Substances (TRGS) 600 “Substitution” or the Guide on Sustainable Chemicals are the best choice available. These tools use data from safety data sheets as main data source. This leads to a lower reliability, if the quality of the safety data sheets is limited.

The most important information taken from the safety data sheets is the classification of the substances. The reliability of the tools mentioned above can be substantially improved, if the quality of the classification of the substances has been checked. This can be easily done by a comparison of the classification data from the safety data sheet with the classification of the substance as documented in a publicly available official database on hazardous substances (e.g. the GESTIS database. Source:
http://www.dguv.de/ifa/Gefahrstoffdatenbanken/GESTIS-Stoffdatenbank/index-2.jsp).

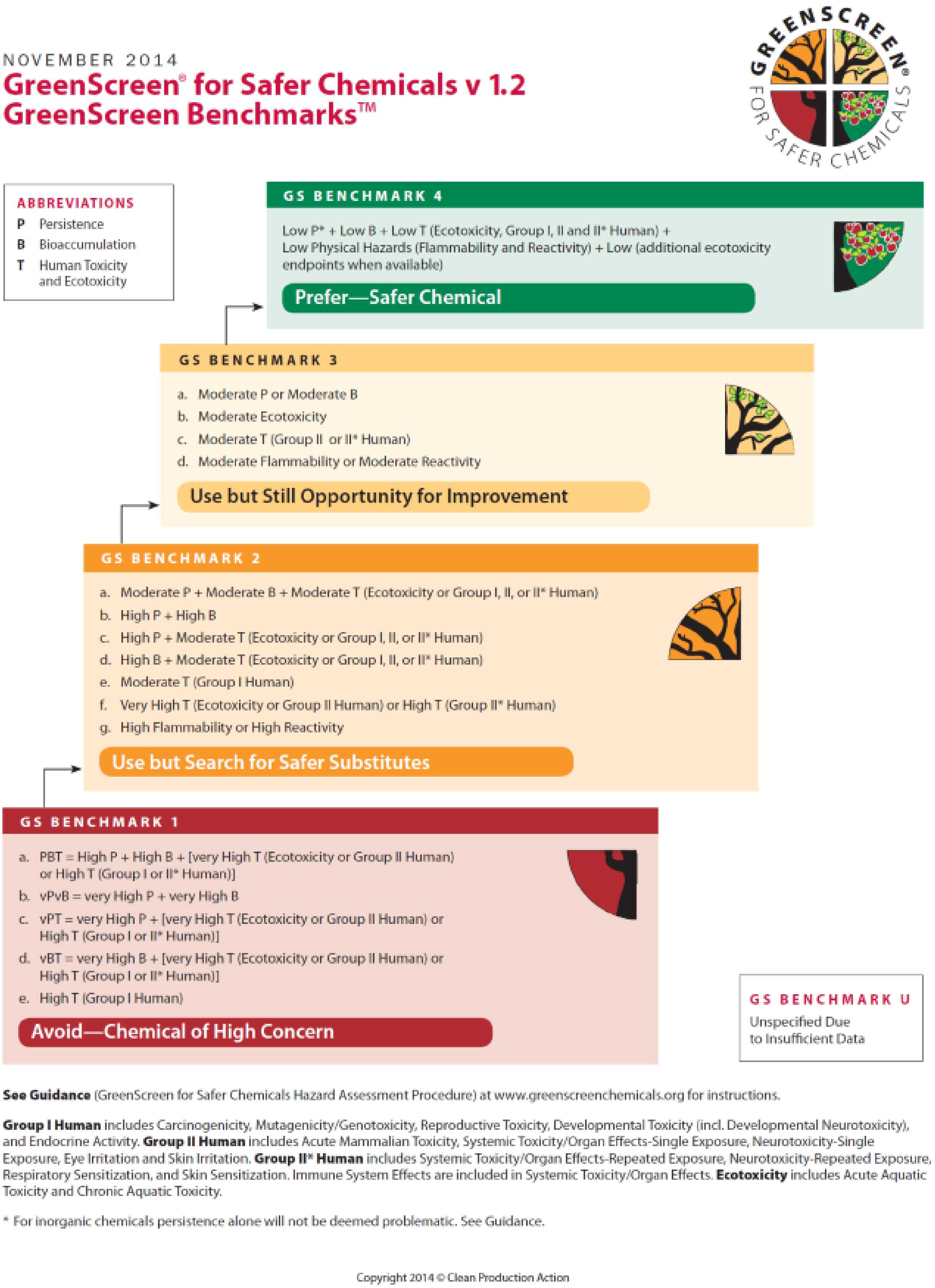
In summary, three steps are recommended for the sound substitution of hazardous chemicals.

- First step is clarification, whether the substance under discussion is a substance of very high concern, as listed on the REACH candidate list (source: http://echa.europa.eu/candidate-list-table). For these substances, substitution has high priority.
- In the second step, the classification of the substance under discussion is taken from the safety data sheet and confirmed by comparison with the data from a database of hazardous substances. In case of differences, the classification from the database should be used.
- With this classification, one of the above mentioned tools can be used (3rd step). First indications on the need for substitution or on a first comparison between substances based on the REACH Candidate List and based on the classification is available in a short time (some hours). In addition, for well-known problematic groups of substances such as phthalates and halogenated flame retardants, companies should use the available information on best alternatives (see e.g. sections 5.2.2 and 5.2.3 of this report).

In the following, the tools GreenScreen® for Safer Chemicals and Pollution Prevention Options Analysis System (P2OASys) are explained in more details.

GreenScreen® evaluates a chemical - along with its known and predicted breakdown products - based upon 18 hazard endpoints (refer to Table 5-5). It defines four benchmarks whereby each benchmark consists of a set of hazard criteria which encompass a combination of hazards and threshold values (Figure 5-2). Thus, substances can be allocated to one of these four benchmarks depending on their intrinsic properties. GreenScreen® leads to benchmark ratings where 1 is ‘do not use’ and 4 is ‘preferred’. For benchmark 1 ratings, these substances can be expected to be classified as Substances of Very High Concern (SVHC) with a very high probability to be regulated in the future.

Figure 5-2: Benchmark of GreenScreen® for Safer Chemicals



Source: Clean Production Action (2014a)

The allocation of different chemical substances having a similar function (e.g. different flame retardants) to the four GreenScreen® benchmarks allows a comparison between the substances and the selection of those substances with the lowest negative impact on environment and human health (see Figure 5-3).

Figure 5-3: Example GreenScreen® Assessment of Similar Function Chemicals

Green Screen Assessments of Similar Function Chemical

Common Name	CAS #	Full Name	Benchmark
Preferred			
Design	none	Design material out, dematerialize	4
Substance 0	#####-##-#	Chemical name	4
Use but still opportunity for improvement			
Substance 1	#####-##-#	Chemical name	3
Substance 2	#####-##-#	Chemical name	3
Use but search for alternatives			
Substance 3	#####-##-#	Chemical name	2
Substance 4	#####-##-#	Chemical name	2
Substance 5	#####-##-#	Chemical name	2
Substance 6	#####-##-#	Chemical name	2
DO NOT USE			
Substance 7	#####-##-#	Chemical name	1
Substance 8	#####-##-#	Chemical name	1
Substance 9	#####-##-#	Chemical name	1
Substance 10	#####-##-#	Chemical name	1
Substance 11	#####-##-#	Chemical name	1
Substance 12	#####-##-#	Chemical name	1

Source: Hewlett-Packard (2013)

In P2OASys, exposure potential is estimated as low, medium or high. The process or chemical under evaluation receives a score for each type of hazard that indicates a very low to very high risk. It uses the “max-min” principle, meaning that the highest value within any hazard category dominates that category of analysis (e.g. chronic toxicity, acute toxicity, etc.). Users must begin by filling in the data for the technology in use in a spreadsheet. Users must also fill in a certainty factor between 0 and 100 that indicates the user’s level of trust in the provided values. If the technology in use is a mixture of substances, information for each component must be added. P2OASys converts data for each hazard category into a numeric scale (0 to 10), the lowest score representing a lower hazard and the highest score representing a higher hazard. Users must fill in similar sheets for each alternative that they want to compare with the technology in use. The Comparative Scores Worksheet collects all of the Scores and Certainties from the different technology alternative worksheets. Afterwards, the Hazards worksheet collects the Scores and Certainties from all of the categories of the current and alternative technologies and allows the user to compare them against each other (Source: www.subsport.eu).

Figure 5-4: Screenshot of the Hazard Score worksheet

<– Compare Alternatives	Help!!!								
Hazard Score Table									
Category	Current Process Score	Current Process Certainty	Alternative 1 Score	Alternative 1 Certainty	Alternative 2 Score	Alternative 2 Certainty	Alternative 3 Score	Alternative 3 Certainty	Value Weight
Acute human effects									10
Chronic human effects									10
Physical hazards									10
Aquatic hazard									10
Persistence/bioaccumulat									10
Atmospheric hazard									10
Disposal hazard									10
Chemical hazard									10
Energy/resource use									10
Product hazard									10
Exposure potential									10
Final									110
Weighted Final									
Current Technology									
Alternative 1									
Alternative 2									
Alternative 3									

Source: Toxics Use Reduction Institute – TURI, as available at www.turi.org/P2OASys; accessed: 08.09.2014

The Stockholm Convention Alternatives Guidance provides a general description of the issues to be considered in identifying and evaluating alternatives to listed persistent organic pollutants and candidate chemicals included in the Stockholm Convention on Persistent Organic Pollutants. It is intended for use by the Persistent Organic Pollutants Review Committee and by Parties when considering the listing of new persistent organic pollutants. It may also be useful for manufacturers or users of listed persistent organic pollutants and candidate chemicals in terms of identifying and deploying alternatives (Source: www.subsport.eu).

5.2.1.2. Environmental benefits

GreenScreen® helps users to evaluate chemicals and their potential degradation products against a range of toxicity and environmental fate, based upon the assessments of 18 hazard endpoints (see Table 5-5). Each hazard is divided into three levels of concern: high, moderate, and low. Two hazards, persistence and bioaccumulation, have an additional level of concern, namely “very high”, which reflects the growing international consensus in defining very persistent and very bio-accumulative (vPvB) chemicals. Each level of concern (for each hazard) is defined by threshold values that are quantitative, qualitative, or based on expert references.

Table 5-5: Hazard Endpoints in GreenScreen®

GreenScreen for Safer Chemicals: Hazard Endpoints				
Environmental Fate	**Environmental Health***	**Human Health Group 1**	**Human Health Group II**	**Physical Hazards**
Persistence (P)	Acute Aquatic Toxicity (AA)	Carcinogenicity (C)	Acute Mammalian Toxicity (AT)	Reactivity (Rx)
Bioaccumulation (B)	Chronic Aquatic Toxicity (CA)	Mutagenicity & Genotoxicity (M)	Systemic Toxicity & Organ Effects (incl. Immunotoxicity) (ST)	Flammability (F)
		Reproductive Toxicity (R)	Neurotoxicity (N)	
		Developmental Toxicity (incl. Developmental Neurotoxicity) (D)	Sensitization (SnS)	
		Endocrine Activity (E)	Respiratory Sensitization (SnR)	
			Skin Irritation (IrS)	
			Eye Irritation (IrE)	

*Other ecotoxicity studies when available.

Source: Clean Production Action (2014b)

Hazard categories evaluated by P2OASys include:

- Acute and chronic human effects
- Physical and chemical hazards
- Atmospheric hazards (ozone layer depletion, greenhouse effect)
- Aquatic toxicity
- Waste generation
- Energy/resource use
- Product hazard
- Exposure potential

5.2.1.3. Appropriate environmental performance indicators

Appropriate indicators for monitoring the implementation of the BEMP and/ or its environmental benefits would be:

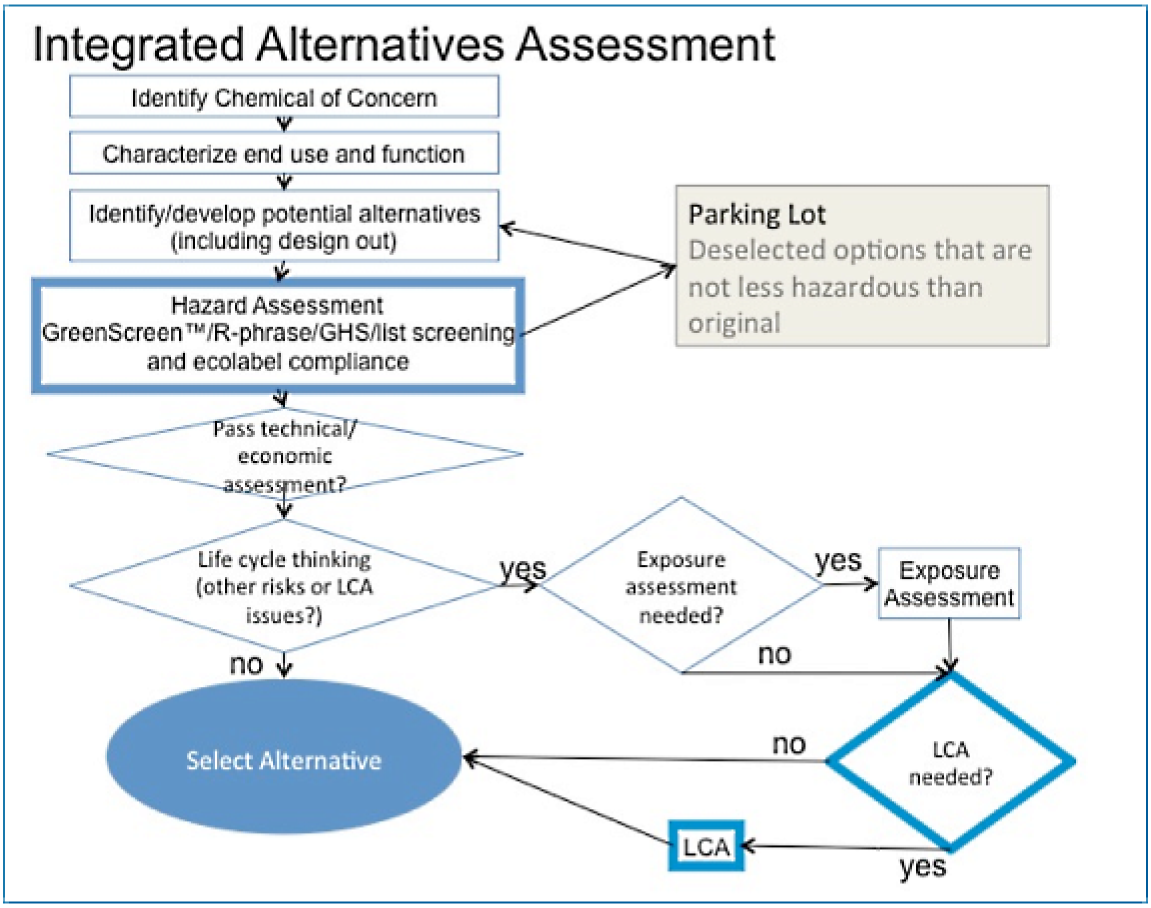
- Major OEM suppliers (in terms of % of supply chain expenditure) provide a Full Material Declaration; and/ or

- Major OEM suppliers (in terms of % of supply chain expenditure) issue a Supplier Declaration of Conformity for company-specific list of restrictions, complemented by a certification (preferably third-party) based on laboratory testing
- OEM publishes the information on its web-site and annual sustainability reports disclosing the % of suppliers (in terms of % of supply chain expenditure) complying with the above-mentioned requirements.

5.2.1.4. Cross-media effects

The assessment tools such as GreenScreen® or P2OASys do not address the full range of life cycle and exposure impacts. Therefore, it is recommended to complement the assessments with other tools such as life-cycle assessment and risk assessment. Hewlett-Packard, for instance, declares using an integrated alternatives assessment protocol (IAAP) to address life-cycle and exposure issues before final material selection. Figure 5-5 shows the graphical illustration of the steps performed while implementing an integrated alternatives assessment approach:

Figure 5-5: Integrated Alternative Assessment Approach



Source: SUBSPORT (2012)

The IAAP combines the strengths of each assessment tool and allows each tool to be used as intended, and at the appropriate time, in the product design process. Alternatives assessment projects range from simple “white lists” to application of the full IAAP process. Example applications including flame retardants, plasticizers, PVC-free power cords, cleaners and fluxes are described (Wendschlag et al. 2012).

Recently, TCO Development (www.tcodevelopment.com) published the so-called “White List” of acceptable non-halogenated flame retardants for the TCO Certified sustainability certification for all eligible IT product categories (Table 5-6). Acceptable flame retardants in the TCO Development are based on the GreenScreen® hazard assessment[85].

Table 5-6: White List of non-halogenated substances as published by the TCO Development[86]

TCO Certified Accepted Substances List

Last updated: 2014-04-16

Substance name	CAS	Benchmark	Assessment date (expires 3 years)	Sunset date	Assessment available
Aluminum diethylphosphinate	225789-38-8	2	Feb 9, 2014	-	IC2
Aluminum Hydroxide	21645-51-2	2	Feb 9, 2014	-	IC2
Melamine Polyphosphate	15541-60-3	2	Feb 9, 2014	-	IC2
Poly[phosphonate-co-carbonate]	77226-90-5	2	Feb 9, 2014	-	IC2
Resorcinol Bis-Diphenylphosphate	125997-21-9	2	Feb 9, 2014	-	IC2
Red Phosphorus	7723-14-0	2	Feb 9, 2014	-	IC2
Substituted Amine Phosphate mixture	66034-17-1	2	Feb 9, 2014	-	IC2
Triphenyl Phosphate	115-86-6	2	Feb 9, 2014	-	IC2
Ammonium Polyphosphate	68333-79-9	3	Feb 9, 2014	-	IC2
Magnesium Hydroxide	1309-42-8	3	Feb 9, 2014	-	IC2
Polyphosphonate	68664-06-2	3	Feb 9, 2014	-	IC2

All substances on this list have been reviewed and the benchmark set by CPA approved profilers.
The list format is a proposal and the final version will not be a document but a dynamic table on the website.

Source: TCO Development (2014)

However, a full scale integrated alternative assessment has often been hindered due to the lack of data on life-cycle impacts, as shown in the example below on the assessment of alternatives to the flame retardant Hexabromocyclododecane (HBCDD) to be used in HIPS.[87]

85 Please refer to: http://tcodevelopment.com/news/criteria-review-non-halogenated-substances-pre-draft-open-for-comment/

86 This list is dynamic and will be continuously updated as soon as this criterion comes into force

87 High Impact Polystyrene (thermoplastic polymer)

Table 5-7: Summary of an integrated alternative assessment of alternatives to HBCDD for use in HIPS

Alternative Substance	Pros (Compared to HBCDD)	Cons (Compared to HBCDD)
Resorcinol bis (biphenyl phosphate)	• Not a PBT or vPvB substance • Likely to be technically and economically feasible, and commercially available	• Toxic to aquatic life with long lasting effects • Lacks data to assess other hazard characteristics • Lacks data to assess life cycle impacts
Bis phenol A bis (biphenyl phosphate)	• Not a PBT or vPvB substance • Likely to be technically and economically feasible, and commercially available	• Degrades to bisphenol A, an endocrine disruptor • May cause long lasting effects to aquatic life • Lacks data to assess other hazard characteristics • Lacks data to assess life cycle impacts
Diphenyl cresyl phosphate	• Not a PBT or vPvB substance (however, considered not readily biodegradable) • Likely to be technically and economically feasible, and commercially available	• May impair fertility and cause damage to organs • Very toxic to aquatic life with long lasting effects • Lacks data to assess other hazard characteristics • Lacks data to assess life cycle impacts
Alloys of PPE/HIPS with halogen free flame retardant alternatives	• Technically feasible (used by major European TV set manufacturers) • Commercially available • Probably economically feasible (currently being used in the commercial market)	• Lacks comprehensive hazard data • Lacks data to assess life cycle impacts of PPE

Source: SUBSPORT (2013)

5.2.1.5. Operational data

In terms of estimating the environmental and health-related benefits of substituting hazardous substances with comparatively safer alternatives, few results of the GreenScreen® assessment method are available[88]. For instance, a GC3 Innovators Roundtable was initiated in 2010 to develop and pilot a new type of collaboration between companies and universities to evaluate safer alternatives to toxic chemicals. The goal was to generate robust assessments of alternatives to support chemical substitution decision-making by GC3 companies and their supply chain partners, through pooling of knowledge, data and funds (GC3 2013).

The model was developed through a pilot project focused on identifying and evaluating alternatives to a phthalate plasticizer of concern in wire & cable applications -- DEHP (Di(2-ethylhexyl)-phthalate) (GC3 2013).

This report contains the results of hazard assessments of nine plasticizers, conducted as part of this collaborative effort. The hazard assessments were conducted using Clean Production Action's (CPA) GreenScreen® for Safer Chemicals chemical hazard assessment method, and were conducted by the toxicology and risk assessment firm ToxServices. ToxServices is licensed by CPA to conduct GreenScreen® assessments. The GC3 project group offered comments and additional data in response to draft assessments produced by ToxServices, and ToxServices considered this input when developing final versions of each assessment.

Four of the nine assessments — for DEHT, DOZ, Hexamoll® DINCH®, and TEHTM — were subjected to a verification process (i.e., a rigorous peer review) by CPA, which entailed a review by

[88] See: http://www.greenscreenchemicals.org/gs-assessments/chemicals. The Clean Production Action (CPA) recently launched the GreenScreen® Store where publicly available GS assessments may be searched by chemical application and downloaded either for free or for purchase at relatively low cost. (~US$ 250)

a CPA-contracted toxicologist and further refinements to the GreenScreens® by ToxServices. The other five assessments have not been verified and are considered draft assessments.

GreenScreen® assessments of Dow's Ecolibrium™ and HallStar's Dioplex™ and Paraplex™ plasticizers have not been verified and the reports are redacted. Unlike the other six plasticizers assessed in this project – which consist of a single chemical – these three products are formulations of multiple chemical ingredients. The manufacturers did not disclose the identities of the ingredients to the GC3 project group. Instead, the manufacturers provided chemical ingredient information to ToxServices under a non-disclosure agreement (NDA) and ToxServices issued redacted assessment reports.

Table 5-8 and Table 5-9 below list the plasticizers evaluated, the GreenScreen® benchmark scores and provide links to the full GreenScreen® assessments[89]. Table 5-8 lists the verified assessments; Table 5-9 the draft assessments.

These GreenScreens® are being offered publicly to inform companies' chemical substitution decisions and to other stakeholders that are interested in learning more about these plasticizers. Neither CPA nor the GC3 permit the use of these GreenScreen® results to make product marketing claims (GC3 (2013)).

Table 5-8: Results of Verified GreenScreen® assessments

Plasticizer Acronym	Chemical Name	CAS No.	GreenScreen Benchmark (see explanations below)	Notes	Link to GreenScreen Assessments
DEHT (Eastman 168)	Di(2-ethylhexyl) terephthalate	6422-86-2	3_{DG}	Data gaps for neurotoxicity and respiratory sensitization	Verified GreenScreen
Hexamoll® DINCH® (BASF)	Diisononyl cyclohexanedi carboxylate	166412-78-8 (outside the U.S.), 474919-59-0 (inside the U.S.)	2*	Moderate endocrine activity	Verified GreenScreen
DOZ	Bis(2-ethylhexyl) azelate	103-24-2	U	Data gaps for cancer and endocrine activity	Verified GreenScreen
TEHTM	Tris(2-ethylhexyl) trimellitate	3319-31-1	U	Data gaps for cancer and endocrine activity	Verified GreenScreen

*BASF toxicologists disagree with the assessment of endocrine activity for Hexamoll® DINCH®. Their assessment is that Hexamoll® DINCH® is not endocrine active, that the endpoint for endocrine activity should be scored as "Low", and that the GreenScreen Benchmark should be 3 or higher. BASF states that their assessment is supported by the published opinions of a number of government and scientific authoritative bodies, including the European Food Safety Authority (EFSA). BASF's detailed comments can be found on the GC3 website.

Source: GC3 (2013)[89]

89 http://www.greenchemistryandcommerce.org/assets/media/images/Publications/Pilot%20Project%20Full%20Report%20Oct%202%20-%20final.pdf

Table 5-9: Results of Draft (i.e., unverified) GreenScreen® assessments

Plasticizer Acronym	Chemical Name	CAS No.	GreenScreen Benchmark (see explanations below)	Notes	Link to GreenScreen Assessments
DPHP	Di(2-Propyl Heptyl) phthalate	53306-54-0	U**	Data gaps for cancer and endocrine activity	Draft GreenScreen
DINP	Diisononyl phthalate	68515-48-0	*1***	*High endocrine activity, developmental and reproductive toxicity*	Draft GreenScreen
Dow Ecolibrium™	Modified vegetable oil derivatives (confidential formulation)	Confidential	*4 Formulations* *BM 3 for 3 form.*** *BM 2 for 1 form.**	*The BM for the formulation is for the monomer with the lowest GS BM score*	Draft, **Redacted** GreenScreen
HallStar Dioplex™ and Paraplex™	Polymeric adipate (confidential formulation)	Confidential	*5 chemical ingredients* *BM 3 for 4 ingred.*** *BM 2 for 1 ingred.**	*The BM 2 chemical is a fatty alcohol monomer with moderate developmental toxicity*	Draft, **Redacted** GreenScreen

Source: GC3 (2013)[89]

The above assessment shows that DEHT could be one of the safer plasticizers to be used. Detailed GreenScreen® assessment results for DEHT can be seen for each individual hazardous endpoint in the following Figure 5-6:

Figure 5-6: GreenScreen® Hazard Ratings for Di(2-ethylhexyl) terephthalate (DEHT)

Green Screen® Hazard Ratings for Di(2-ethylhexyl) terephthalate (DEHT)

Group I Human					Group II and II*Human									Ecotox		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						single	repeated*	single	repeated*										
L	L	*L*	L	*L*	L	dg	L	dg	dg	L	dg	L	L	L	L	vL	L	*L*	L

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in italics reflect estimated values and lower confidence. Hazard levels in BOLD font reflect values based on test data (See Guidance).
Note: Please see Appendix A for a glossary of hazard acronyms.

Source: ToxServices LLC (2012)

Similarly, environment and health-related benefits for all the GreenScreen® assessed alternatives can be estimated.

Since 2007, HP has used the GreenScreen® assessment methodology on some 140 substances with focus on alternatives to halogenated flame retardants and phthalates. HP has declared to use

only those alternative substances with GreenScreen® benchmark 2 or better. The GreenScreen® Assessment of the flame retardants (FR) showed that none of them fulfilled the highest benchmark (i.e. “prefer”) and only 6 FR fulfilled benchmark 3 requirements (i.e. “Use but still opportunity for improvements”). Most FR were allocated to benchmark 2 (i.e. “Use, but search for better alternatives”), and 16 chemical should be avoided according to the GreenScreen® assessment, amongst these also 13 non-halogenated FR. It should also be highlighted that for 14 non-halogenated substances no or very little data are available, impeding an assessment of environmental and human health impacts.

Table 5-10: Results of an HP GreenScreen® Assessment of 69 flame retardants

GS rating		Br	Cl	P	Other	Total
4	Prefer	-	-	-	-	0
3	Use, still opportunity for improvements	1	-	-	5	6
2	Use, but search for safer alternatives	1	3	6	20	30
1	Avoid	3		6	7	16
	No / very little data	3	-	12	2	17
	Total	8	3	24	34	69

Source: Hewlett-Packard (2013)

Several other full GreenScreen® Assessments can be found at:

- IC2: http://www.newmoa.org/prevention/ic2/projects/resource/hazassesstool.cfm
- Techstreet: http://www.techstreet.com/searches/3638231

In IC2 database, 33 GreenScreen® assessments are publicly available (accessed: 18.06.2014).

GreenScreen Store: http://www.greenscreenchemicals.org/gs-assessments/chemicals

Detailed information on P2OASys can be found at:

- TURI: http://www.turi.org/home/hot_topics/cleaner_production/p2oasys_tool_to_compare_materials

5.2.1.6. Applicability

P2OASys can be used to compare products, processes and technologies. GreenScreen® is only used to assess and compare individual chemicals, not products, processes or alternative technologies. Tools mentioned above are publicly available and provide comprehensive guidance on accessing publicly available data for the assessment.

5.2.1.7. Economics

According to the information from Clean Production Action, it can take 18-25 hours to do a comprehensive and thorough full GreenScreen® assessment. If a Licensed GreenScreen® Profiler is used, costs can range from ~US$ 850-1500 per chemical; depending on the copyright arrangement that the client makes with the Profiler. Depending on the amount of data and whether or not

the client requests additional modelling and review of analogues, the assessment can cost more than the figure mentioned above. In such a case, the GS Store is important. It allows reselling the GS assessments performed by Profilers so that they can sell more of them at lower cost to recoup their costs.

GreenScreen® List Translator is easy to use and can be used with a subscription to Pharos (30 day free trial or around US$ 190/year). Alternatively, one could enlist a Profiler for help in ensuring that there is full knowledge of the ingredients in a formula or product; or if one wants their help in interpreting results from GreenScreen® List Translator which is kind of a "quick and dirty" full GreenScreen®. It would entail very few costs and just a couple of hours of time. Lab testing or advanced modeling would be additional if the client finds that there are critical data gaps that they want to fill. But it is not possible to know what data gaps exist until the assessment is done (Heine 2014).

For small and medium sized enterprises, a first comparison between substances based on the REACH Candidate List and classification according to the safety data sheet, which is followed by the confirmation with the help of a hazardous substance database, requires only few hours and hence entails low and affordable costs.

Information related to cost-saving potential of above-mentioned assessment tools is not available. According to the information from Hewlett-Packard, timely substitution of a hazardous substance identified in a GreenScreen® assessment leads to significant cost savings when compared to the short-term effort required to comply with an upcoming legislation (Wendschlag 2014a).

5.2.1.8. Driving force for implementation

Drivers for chemical hazard assessment include REACH regulation (EC) No 1907/2006, Directive 2011/65/ EG on the restriction of the use of certain hazardous substances in electrical and electronic equipment ('RoHS 2'),[90] preparation of Annex XV dossiers for identification of Substances of Very High Concern (SVHC) by the Member States and/or the European Chemicals Agency (ECHA) on request by the Commission, EU-Strategy for Endocrine Disruptors and ecolabels.

The US Green Building Council, for example, has recently included GreenScreen® in its LEED rating system v4 (Clean Production Action 2014c). Moreover, TCO development has started using the GreenScreen® as their preferred chemical substance assessment methodology, and have published a 'white' list of GreenScreen® assessed non-halogenated flame retardants.

According to the interviewed companies, the main factor behind their strategy to go beyond the legislation is their estimation of the economic cost-benefit ratio related to the substitution of a certain substance. As long as the costs of a certain substitution lie within the manageable budget of a company, companies go ahead with the substitution before it is regulated by the legislation. In other cases where costs for a substitution are very high, companies rather prefer to play a waiting game as mandatory implementation of legislative requirements takes several years, which gives companies more time to identify and select cost-effective alternatives.

[90] A recent report by Oeko-Institut (Gensch et al. 2014) has reviewed 21 substances that could be prioritised for addition to the Directive on the restriction of the use of certain hazardous substances (RoHS2) in electrical and electronic equipment (EEE). The report, which was contracted by the European Commission, says that the substances should be prioritised based on their quantities in both EEE production and end products, and on the possible differences in use by EU and non-EU manufacturers, in light of the REACH authorisation process (http://chemicalwatch.com/20122/eu-consultant-identifies-21-substances-for-rohs2-prioritisation).

5.2.1.9. Reference organisations

- Clean Production Action (CPA) – CPA developed the GreenScreen® for Safer Chemicals for comparative Chemical Hazard Assessment (CHA) for the purpose of identifying chemicals of high concern and safer alternatives
- Toxic Use Reduction Institute of Massachusetts (TURI) – TURI developed the Pollution Prevention Options Assessment System (P2OASys) tool to help companies determine whether the Toxic Use Reduction options they are considering may have unforeseen negative environmental, worker or public health impacts.
- Hewlett-Packard (HP) – According to HP, it has used the GreenScreen® assessment methodology on some 140 substances with focus on alternatives to halogenated flame retardants and phthalates.
- TCO Development – TCO Development published the "White List" of acceptable non-halogenated flame retardants for the TCO Certified sustainability certification for all eligible IT product categories. Acceptable flame retardants in the TCO Development are based on the GreenScreen® hazard assessment
- PINFA EU – Phosphorus, Inorganic, and Nitrogen Flame Retardants Association (PINFA) has run a pilot project of conducting GreenScreen® assessments on non-halogenated flame retardant alternatives.
- Nike: As part of Nike sustainability initiatives, the GreenScreen® is used to assess the hazards of chemicals used in products
- Pharos: The Pharos Chemical & Material Library provides easy online access to chemical hazard information for over 20,000 identified substances using the hazard lists identified by the GreenScreen List Translator.

5.2.1.10. Chapter references

BOMcheck (2013) BOMcheck List of Restricted and Declarable Substances; Version 3.2, July 2013. Available at: https://www.bomcheck.net/assets/docs/Restricted%20and%20declarable%20substances%20list.pdf

Clean Production Action (2014a) GreenScreen® for Safer Chemicals v 1.2 Benchmarks

Clean Production Action (2014b) GreenScreen® method description, http://www.greenscreenchemicals.org/method/full-greenscreen-method, last accessed in May 2014

Clean Production Action (2014c) GreenScreen® LEED Guidance, http://www.greenscreenchemicals.org/practice/leed

GC3 (2013) GC 3; Green Chemistry and Commerce Council: Chemical Hazard Assessments of Alternative Plasticizers for Wire & Cable Applications. http://www.greenchemistryandcommerce.org/assets/media/images/Publications/Pilot%20Project%20Full%20Report%20Oct%202%20-%20final.pdf

Gensch et al. (2014)	Gensch, C.-O.; Baron, Y.; Blepp, M.; Bunke, D.; Moch, K.; Study for the Review of the List of Restricted Substances under RoHS 2 - Analysis of Impacts from a Possible Restriction of Several New Substances under RoHS 2 (Final Version), Report prepared by Oeko-Institut e.V. for the European Commission. Available at: http://rohs.exemptions.oeko.info/fileadmin/user_upload/reports/20140604_Substance_Review_plus_Dossier_final.pdf
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Dell (2013)	Dell's Chemical Use Policy; May 2013. Available at: http://i.dell.com/sites/doccontent/corporate/environment/en/Documents/chemical-use-policy.pdf
Heine (2014)	Heine, L. (Clean Production Action); Personal Communication; 02.07.2014
Hewlett-Packard (2013)	Reducing Risk by Reducing Hazard, Chemical Hazard Screening as the First Step in the Assessment Process; presentation by H. Wendschlag at FRPM, Lille, July 2013
JEITA (2009)	Japan Electronics & Information Technology Industries Association (JEITA) & Japan Electrical Manufacturers' Association (JEMA) (September 2009). "Energy Efficient Products: Technology and Supply Chains."
Jepsen at al. (2009)	Jepsen, D.; Bunke, D.; Groß, R.; Assessment of alternative applications of the 0.1 % limit in REACH triggering information on Substances of Very High Concern (SVHC) in articles; Nordic Chemical Group, Environment Agency, Reykjavík, Iceland 2009
Martin (n.y.)	Martin, B.; Seagate Product Environmental Compliance: Hazardous Substance Management; Available: http://www.bizngo.org/pdf/seattle-seagate-brianmartin.pdf
Nimpuno et al. (2009)	Nimpuno, N.; McPherson, A.; Sadique, T.; Greening Consumer Electronics – moving away from bromine and chlorine; ChemSec & Clean Production Action (CPA); September 2009. http://www.cleanproduction.org/library/Greening_Consumer_Electronics.pdf
SUBSPORT (2013)	SUBSPORT; Specific Substances Alternatives Assessment – Hexabromocyclododecane. Available at: http://www.subsport.eu/wp-content/uploads/data/hexabromocyclododecane.pdf
SUBSPORT (2012)	SUBSPORT; Case Story Database: Substitution of brominated flame retardants with non-halogenated alternatives using the GreenScreen® for safer chemicals alternatives assessment tool. Available at: http://www.greenscreenchemicals.org/static/ee_images/uploads/resources/HPHBCDAAonSubsport.pdf
TCO Development (2014)	TCO Certified Accepted Substance List (as per April 2014). Available at http://tcodevelopment.com/news/criteria-review-non-halogenated-substances-pre-draft-open-for-comment/

ToxServices LLC (2012)	Di(2-ethylhexyl) terephthalate (DEHT) (CAS #6422-86-2) – GreenScreen® Assessment. Report dated October 11, 2012. Available at: http://www.greenchemistryandcommerce.org/documents/DEHTVERIFIEDASSESSMENT_final.pdf
Wendschlag (2014a)	Wendschlag, H. (Hewlett-Packard): Personal communication; 18.06.2014
Wendschlag (2014b)	Wendschlag, H. (Hewlett-Packard): Personal communication; 28.05.2014
Wood & Tetlow (2013)	Wood, C.; Tetlow, J.; Global Supply Chain Operation in the APEC Region: Case Study of the electrical and electronics industry; APEC Policy Support Unit; July 2013

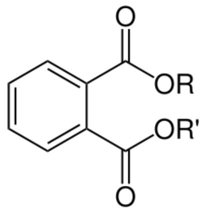
5.2.2. Elimination of certain phthalates

5.2.2.1. Description

Phthalates (ortho-phthalates) are a group of organic substances with the same general chemical structure. They are esters of the ortho-phthalic acid (chemical name 1,2-benzenedicarboxylic acid) with two carbon (alkyl) chains of different lengths (see Figure 5-7).

Phthalates are the most commonly used plasticisers (or softeners) in flexible polyvinyl chloride PVC.[91] In the EEE sector, the most common application of phthalates is related to PVC insulation of cables and wires (ECHA RAC SEAC 2012). Other applications in electrical and electronic equipment (EEE) are in adhesive applications, rubber products and sealants (Groß et al. 2008).

Figure 5-7: Chemical structure of ortho-phthalates: R and R' indicates an alkyl chain



Source: http://en.wikipedia.org/wiki/File:Phthalates.svg

So far, many phthalates have been assessed as being toxic for reproduction[92]: Besides DEHP, DBP, BBP and DIBP, further nine phthalates are included as Substances of Very High Concern in the REACH Candidate List because have been assessed as being toxic for reproduction (Article 57 c) (as of August 2014; cf. Annex 2, section 8.2). Additionally, the endocrine disrupting effects of phthalates have increasingly been assessed in the last years[93]. Thus, more comprehensive legal restrictions of the phthalates in the future can be expected. At present (August 2014), six different phthalates (see Table 5-11 for full names and CAS numbers) are taken up in REACH Annex XIV and REACH Annex XVII

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91 European Council for Plasticisers and Intermediates (ECPI): Plasticisers and flexible PVC Information Center; http://www.plasticisers.org/en_GB/plasticisers

92 http://echa.europa.eu/candidate-list-table

93 Endocrine disruptors interfere in some way with hormone action and can thereby produce adverse effects on human and wildlife health.

In June 2014, Denmark submitted intentions to evaluate the four phthalates DEHP, DBP, BBP and DIBP as endocrine disrupters (http://echa.europa.eu/de/registry-of-current-svhc-intentions;jsessionid=821538002C70C38153D47D0A2E2DCCE6.live1).

According to the EU COM Endocrine Disruptors strategy, also DINP and DIDP are in Category 2 – at least some in vitro evidence of biological activity related to endocrine disruption (http://ec.europa.eu/environment/chemicals/endocrine/index_en.htm; http://ec.europa.eu/environment/archives/docum/pdf/bkh_annex_10.pdf)

- DEHP, DBP, BBP, and DIBP are listed in REACH Annex XIV[94], meaning that after 21st February 2015 they cannot be manufactured or placed on the EU market in substance form.[95] In practice, for the EEE sector, this means that they cannot be applied in the manufacturing of EEE components and products in the EU. However imported articles are not affected by this ban.
  Yet, suppliers of an article containing these phthalates have to communicate the presence of the substances, and provide the recipient of the article with sufficient information (REACH Article 33).[96] They also have to notify to ECHA for SVHC in articles.[97]
- The restrictions under REACH Annex XVII for a number of phthalates (DEHP, DBP, BBP, DINP, DIDP and DNOP, see Table 5-11) do not affect the use in EEE as these restrictions apply for use in toys and childcare articles. [98]
- DEHP, BBP, DBP and DIBP were investigated in 2013-2014 as possible candidates to be added to the list of substances restricted under Directive 2011/65/EU (RoHS 2)[99], which is contained in Annex II of the Directive. The RoHS Delegated Act Decision on these phthalates is expected by the end of 2014. If the phthalates are added to RoHS Annex II, this shall call for complete phase-out in all EEE, albeit with a transition period to allow for implementation.

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94 Annex XIV – the list of substances subject to authorisation by the REACH Regulation, No. 1907/2006

95 For DEHP, DBP and BBP, there are exempted uses in the immediate packaging of medicinal products. There are other applications for authorisations for exempted uses for DEHP (11 applications) and DBP (six applications), which, however, are not relevant for the EEE sector (August 2014); http://echa.europa.eu/addressing-chemicals-of-concern/authorisation/applications-for-authorisation-previous-consultations

96 Article 33 stipulates that any supplier of an article containing a substance meeting the criteria in Article 57 and identified in accordance with Article 59(1) in a concentration above 0.1% weight by weight (w/w) shall provide the recipient of the article with sufficient information, available to the supplier, to allow safe use of the article including, as a minimum, the name of that substance.
On request by a consumer, any supplier of an article containing a substance meeting the criteria in Article 57 and identified in accordance with Article 59(1) in a concentration above 0.1% weight by weight (w/w) shall provide the consumer with sufficient information, available to the supplier, to allow safe use of the article including, as a minimum, the name of that substance.

97 According to Article 7(2), producers and importers have to notify to ECHA the substances listed on the Candidate list which are present in their articles, if both the following conditions are met: The substance is present in their relevant articles above a concentration of 0.1% weight by weight and the substance is present in these relevant articles in quantities totalling over one tonne per year.

98 See entry 51 of REACH Annex XVII and entry 52 of REACH Annex XVII; http://old.eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2006R1907:20140410:EN:HTML

99 RoHS 2: Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast); http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011L0065&from=EN

Table 5-11: DEHP, DBP BBP and DIBP relevant for elimination and their current main alternatives DINP and DIDP that should be eliminated in the long term

Name	CAS	Legal status	Comments
Bis (2-ethylhexyl) phthalate (DEHP)	117-81-7	REACH Annex XIV; sunset date: 21st February 2015 Restricted by entry 51 REACH Annex XVII for the use in concentrations greater than 0,1% in toys and childcare articles	Also restricted for use in food contact material and prohibited in the production of cosmetic products Potential to bioaccumulate
Butyl benzyl phthalate (BBP)	85-68-7		Very toxic to aquatic life (Aquatic Acute 1, H400); very toxic to aquatic life with long lasting effects (Aquatic Chronic 1, H410)
Dibutylphthalate (DBP)	84-74-2		Very toxic to aquatic life (Aquatic Acute 1, H400)
Diisobutyl phthalate (DIBP)	84-69-5	REACH Annex XIV; sunset date: 21st February 2015	All-round alternatives for DBP
Diisononyl phthalate[100] (DINP)	28553-12-0 and 68515-48-0	DINP, DIDP, DNOP have no harmonized classification Restricted by entry 52 REACH Annex XVII for the use in concentrations greater than 0.1% in toys and childcare articles which can be placed in the mouth by children. Banned by EU Eco-Label for personal computers and notebook computers	Evidence of biological activity related to endocrine disruption according to EU COM EDC database Reprotoxic effects and effects on development have been reported; suspected endocrine disruptor; detected in the environment and humans (SIN list[101])
Di-'isodecyl' phthalate (DIDP)	26761-40-0 and 68515-49-1		Evidence of biological activity related to endocrine disruption according to EU COM EDC database. Potential to bioaccumulate
(di-n-octyl phthalate) DNOP	117-84-0		Information on current uses of DNOP in EU very limited and contradictory.

To summarize: as EEE components are often acquired from the supply chain, the four phthalates DEHP, DBP, BBP and DIBP can still be used in EEE if the components are manufactured in non-EU countries. It is difficult to estimate the amount of the four phthalates brought into the EU market with EEE products. However, the following estimates for DEHP - the most commonly used phthalate in EEE – gives an indication of the high usage amount:

100 1,2-benzenedicarboxylic acid, di-C8-10- branched alkyl esters, C9-rich

101 The SIN (Substitute It Now!) List is an NGO driven project to speed up the transition to a world free of hazardous chemicals. The SIN List 2.1 consists of 626 chemicals that the NGO ChemSec has identified as SVHC based on the criteria established by REACH. These are substances that can cause cancer, alter DNA or damage reproductive systems. It also includes toxic substances that do not easily break down, but instead build up in nature - with a potential to cause serious and long-term irreversible effects. The SIN List also contains substances that are identified to give raise on an equivalent level of concern (endocrine disrupters) (http://www.chemsec.org/what-we-do/sin-list).

- The ECHA (2012) estimates the tonnage of DEHP applied in flexible PVC for insulation on wires and cables to 6,200 tons in 2007 (end-products used in the EU)[102].
- The Austrian UBA assumed an amount of 7,444 to 22,334 tonnes DEHP in 2010 in EEE placed in the EU market (Austrian UBA 2014).[103]

Thus, it can be concluded that the total quantity of the four phthalates for all applications in EEE products in the EU is much higher. A few frontrunner companies have in recent years increasingly attempted to eliminate the four phthalates DEHP, DBP, BBP and DIBP from their products.

Some frontrunner companies go beyond the ban of the above-mentioned four phthalates by going completely phthalate-free. The shift from a restricted phthalate to a non-restricted one might be easier to apply from a manufacturing perspective, as it might require significantly less changes in the manufacturing process in light of substance similarities. However, from an environmental perspective, an alternative from the same substance group might have a somewhat lower environmental impact. The main alternatives for DEHP in cables and wire insulation, for example, are DINP and DIDP. Though a harmonized classification for DIDP and DINP does not exist yet[104], there are certain concerns relating to human health, which are presented in greater detail in section 5.2.2.4, Cross-media effects. Thus, Best Environmental Management Practice should be a complete phase out of all phthalates.

5.2.2.2. Environmental benefits

The elimination of phthalates has a high environmental and health benefit due to the large quantities used in the respective applications. The environmental impact in this case can be defined as a minimization of the environmental exposure: Phthalates are not chemically bound to PVC, but dispersed in the matrix. Thus, they are released from the material during the lifetime of products and during their disposal. Leaching out from certain applications and transportation in the air are the major routes of environmental releases of phthalates from PVC (UBA 2007; Groß et al. 2008, Danish EPA 2013a).

The latest evaluations of the four phthalates show that little data is available on the environmental effects of the phthalates. The assessment of the phthalates often focused on the human health effects (toxic for reproduction and endocrine disrupting effects) (Danish EPA 2013a and b).

The main sources of exposure to the four phthalates resulting from EEE are articles via dermal contact and indoor environment via inhalation, as the phthalates leach out from the PVC and are then found in the indoor air and in indoor dust.

Especially, DEHP is found to be diffusely spread in the environment due to the large amount used in the last years and the wide dispersive use. AS DEHP is found in all environmental compart-

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102 The article group consists of isolated electrical wires and cables, as well as optical fibre cables, of types used indoor in homes and offices (ECHA RAC SEAC 2012).

103 In 2010, 9.4 Mio tonnes of EEE were placed on the market in the EU; assuming a plastic content in EEE of 30% of the appliances' weight, a 12% share of the EEE plastics being PVC, a plasticiser content in PVC of 20-60%, and a 11% share of DEHP within used plasticizers would lead to an assumption of 7,444 to 22,334 tonnes (Austrian UBA 2014).

104 Regulation No 1272/2008 on Classification, Labelling and Packaging of substances and mixtures ensures that the hazards presented by chemicals are clearly communicated to workers and consumers in the European Union through classification and labelling of chemicals. If a decision on the classification of a chemical is taken at Community level, it is called a harmonized classification.

ments, also in remote areas, DEHP has to be considered a widespread environmental pollutant (Groß et al. 2008).

An additional benefit of switching to PVC-free cable, resulting in a complete elimination of phthalates, would be derived from halogen-free products (see section 5.2.3). While elimination of PVC would automatically lead to elimination of all phthalates, it has to be understood that requirements for the PVC phase-out are currently met only by few companies and few products. An overview of companies and their products with a PVC phase-out plan is provided under section 5.2.3.9.

5.2.2.3. Appropriate environmental performance indicators

Appropriate indicators for monitoring the implementation of the BEMP and/ or its environmental benefits would be:

- Major OEM suppliers (in terms of % of supply chain expenditure) issue a Supplier Declaration of Conformity for company-specific list of restrictions, complemented by a certification (preferably third-party) based on laboratory testing
- OEM publishes the information on its web-site and annual sustainability reports disclosing the % of suppliers (in terms of % of supply chain expenditure) that have phased-out four phthalates DEHP, DBP, BBP and DIBP

5.2.2.4. Cross-media effects

DIDP and DINP are the dominant alternatives to DEHP in wires and cables because of closeness in performance, availability and only moderately higher costs. Though a harmonized classification for DIDP and DINP does not exist yet, restrictions under REACH Annex XVII for toys and childcare articles reflect their hazardous potential. As regards DINP, health effects due to endocrine disrupting (anti-androgenic) effects are discussed, since DINP is present in much higher concentrations compared to the four phthalates DEHP, DBP, DIBP and BBP. Besides those negative developmental effects, DINP has shown negative effects on the liver (ECHA 2012). The ECHA recommends looking at the anti-androgenic potential in more depth. Thus, substitution by shifting within the group of phthalates also entails health risks, however, possibly at a lower level.

There is no data available on the effect of the elimination of phthalates on other environmental pressures, such as energy consumption during manufacturing, greenhouse gas emissions etc.

5.2.2.5. Operational data

The supply chain management for the elimination of the four phthalates takes place by a restriction or ban by the company of (specific) phthalates which is laid down in a company-specific document. This document generally specifies a threshold value that is mostly a specification of 0.1% by weight for homogeneous materials or components. It is assumed that any presence of substance below this threshold would be a result on unintentional addition.

The percentage of 0.1% per weight is also applied as usual maximum concentration value in RoHS and as threshold concentration under REACH for the before-mentioned communication and notification duties (REACH Article 7(2) and Article 33).

As for the reference level for the concentration limit of 0.1%, the RoHS Directive refers to homogeneous material specified as one material of uniform composition or a combination of materials that cannot be disjointed or separated into different materials.[105] The REACH Regulation does not indicate a reference level for the concentration limit of 0.1% weight by weight (w/w) (see footnotes 96 and 97); on the basis of the interpretation given by the European Commission and a majority of the Member States,[106] the concentration limits are to be applied to the entire article. The reference level for components is somewhat in between, but basically less strict then homogenous material, as a component can consist of different materials that can be separated. As for phthalates, however, the different reference level is negligible, since plasticizer concentrations generally range between 10 and 30% (ECHA RAC SEAC 2012).

Suppliers receive these specifications which must be met as regards components and materials.

Independent testing of the suppliers' declaration is an important monitoring tool. As for phthalates, the testing requirements involve an extraction of the substances and a subsequent identification step. The analysis method for determination of the phthalates DIBP, DBP, BBP and DEHP in products comprises an extraction with dichloromethane (solvent suitable for liberating phthalates from polymer materials such as PVC), followed by gas chromatography of the extracts with mass spectrometric detection (GC-MS).[107] This complex analysis is usually performed by laboratories and not in-house by the companies.

The following paragraphs explain the different approaches by Apple, Fujitsu and Dell:

Apple has a comprehensive list of substances, the Apple Regulated Substances Specification, Version H (Apple 2014). According to this list, Apple restricts far more than the four phthalates (see next figure). The threshold value is indicated as < 1000 ppm per homogenous material (equal to 0.1% per weight value). As Apple phased out PVC, replacing it by the use of elastomers in cables, most phthalate applications will, as a result, also be eliminated by this switch of materials.

Additional applications of relevance that might be used in the EEE sector include adhesives that are also covered by the phthalate restrictions.

Thereby, Apple goes complete phthalate free; the mentioned cross-media effects resulting from the substitution of DEHP by DIDP and DINP are not applicable here.

Suppliers are obliged to have their components tested by independent laboratories. Apple operates its own laboratory in California to verify the information provided by suppliers.

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105 RoHS 2 Article 3 (20) defines 'homogeneous material' as "one material of uniform composition throughout or a material, consisting of a combination of materials, that cannot be disjointed or separated into different materials by mechanical actions such as unscrewing, cutting, crushing, grinding and abrasive processes".

106 http://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/opinion_of_the_german_federal_environment_agency_revision_rohsdirective.pdf

107 For further information and examples of analysis results, see Tønning, K.; Jacobsen, E.; Pedersen, E. Nilsson, N. H. (2010): Phthalates in products with large surfaces, Danish Technological Institute, Survey of Chemical Substances in Consumer Products, No. 108 2010; http://www2.mst.dk/udgiv/publications/2010/978-87-92708-71-7/pdf/978-87-92708-70-0.pdf

Figure 5-8: Section on phthalates in the Apple Regulated Substances Specification, Version H

3.26 Phthalates

The restriction is applicable to the following phthalates:

- 1,2-Benzenedicarboxylic acid, di-C6-8-branched alkyl esters, C7-rich (DIHP), CAS No. 71888-89-6
- 1,2-Benzenedicarboxylic acid, di-C7-11-branched and linear alkyl esters (DHNUP), CAS No. 68515-42-4
- 1,2-Benzenedicarboxylic acid, dipentylester, branched and linear (DPP), CAS No. 84777-06-0
- Benzyl butyl phthalate (BBP), CAS No. 85-68-7
- Bis(2-ethylhexyl)phthalate (DEHP), CAS No. 117-81-7
- Bis(2-methoxyethyl) phthalate (DMEP), CAS No. 117-82-8
- Di-iso-pentyl phthalate (DIPP), CAS No. 605-50-5
- Di-isodecyl phthalate (DIDP), CAS Nos. 68515-49-1 and 26761-40-0
- Di-n-hexyl phthalate (DnHP), CAS No. 84-75-3
- Di-n-octyl phthalate (DnOP), CAS No. 117-84-0
- Di-n-pentyl phthalate (DnPP), CAS No. 131-18-0
- Dibutyl phthalate (DBP), CAS Nos. 84-74-2 and 201-557-4
- Diethyl phthalate (DEP), CAS No. 84-66-2
- Diisobutyl phthalate (DIBP), CAS No. 84-69-5
- Diisononyl phthalate (DINP), CAS Nos. 68515-48-0 and 28553-12-0
- Dimethyl phthalate (DMP), CAS No. 131-11-3
- n-Pentyl-isopentyl phthalate (nPIPP), CAS No. 776297-69-9

Restriction	Reference	Application Examples
≤ 1000 ppm	CA Proposition 65, REACH 1907/2006 and amendments	Plasticizer

Source: Apple (2014)

The Fujitsu Group eliminated the four phthalates DEHP, DBP, BBP and DIBP from their IT products. This restriction is specified in a list of prohibited hazardous substances that are part of the suppliers' confirmation. The limit value for all applications is 0.1% by weight per purchased part, component or module. Fujitsu requests test reports proving the suppliers' confirmation in selected cases. Fujitsu commissions an independent testing of phthalates by a laboratory, however only in the case of suspicion.

A number of IT products of Fujitsu are labelled with the Blue Angel (primarily desktops computers and keyboards).[108] One requirement to obtain the Blue Angel for Personal Computers is that no substances may be added to the plastics used in housings and housing parts as constituent parts classified as carcinogenic, mutagenic or toxic to reproduction in category 1, 2 or 3.[109] This comprises the four phthalates DEHP, DBP, BBP and DIBP.

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108 http://www.blauer-engel.de/en/get/brand_products/Fujitsu

109 See Basic Criteria for Award of the Environmental Label, Personal Computers (Desktop Computers, Integrated Desktop Computers, Workstations, Thin Clients) RAL-UZ 78a, Edition March 2012; under: http://www.blauer-engel.de/en/companies/basic-award-criteria.

Secondly, Fujitsu has additional reporting requirements for suppliers that cover all non-SVHC-phthalates. However, compliance in the reporting of these phthalates is so far not critical which means that Fujitsu does not reject the components/products if suppliers do not fulfil the reporting requirements. Thereby, Fujitsu has the possibility to monitor the substances used for substitution.

Dell stipulates the substance specification in the Dell Specification Materials Restricted for Use. The threshold limit is 1000 ppm per homogenous material. The phthalates DEHP, DBP and BBP have been restricted in all newly designed products since 2010. The restriction for DIBP is effective by January 1, 2014 for newly launched Dell parts and products, and by July 1, 2015 for all sustaining products. The suppliers provide a Supplier Declaration of Conformity (Dell 2013). At Dell's request, suppliers have to provide analytical data. Suppliers do not have to report the alternative used to substitute the four phthalates. A recent survey conducted by Dell for the Canadian market showed that mainly DIDP and, to a smaller extent, DINP are mostly used in cables insulation/jacketing.

Dell performs audits where randomly selected parts are tested for the presence of restricted material. The audits are carried out on a quarterly basis.

Furthermore, third party testing plays an important role in monitoring the environmental performance. Surveys on the content of phthalates in different product groups are periodically carried out by some public agencies (e.g. the Swedish Chemicals Agency KEMI)[110] and additionnally by NGOs (e.g. Greenpeace).[111]

LG Electronics (LGE) grouped the phthalates in Level B-I list (Voluntary phase-out substances) – "Level B-II are substances considered harmful to human being and environment that are not currently prohibited of use, but are scheduled for the information provision in REACH and/or for prohibition by the law and regulation in the future" (LGE 2014, pg. 12). The detailed approach of LGE is described in section 5.2.3, Elimination of brominated flame retardants (BFR) and polyvinyl chloride (PVC). LGE has phased-out a number of phthalates in new models of mobile phones manufactured from 2011.

The voluntary phase out of LGE limits the use of various phthalates above a level of 1,000 mg/kg on a voluntary basis, including DEHP, DBP, BBP, but also among others the main alternatives for DEHP: DINP and DIDP (see Table 5-12). The approach can be considered as a complete phase out approach and is understood to be performed by a material shift away from PVC polymers.

[110] See e.g. https://www.kemi.se/en/Content/News/Mapping-of-phthalates-in-products-in-Sweden/

[111] http://www.greenpeace.org/international/en/System-templates/Search-results/?all=phthalate

Table 5-12: Section on phthalates defined as voluntary phase-out substances by LGE

Name	Chemical symbol	CAS No.
Dimethyl phthalate (DMP)	$C_{10}H_{10}O_4$	131-11-3
Diethyl phthalate (DEP)	$C_{12}H_{14}O_4$	84-66-2
Bis(2-ethyl-hexyl) phthalate(DEHP)	$C_{24}H_{38}O_4$	117-81-7
Dibutyl phthalate(DBP)	$C_{16}H_{22}O_4$	84-74-2
Benzyl butyl phthalate(BBP)	$C_{19}H_{20}O_4$	85-68-7
Di-"isononyl" phthalate(DINP)	$C_{26}H_{42}O_4$	28553-12-1 / 68515-48-0
di-"isodecyl" phthalate(DIDP)	$C_{28}H_{46}O_4$	26761-40-0 / 68515-49-1
di-n-octyl phthalate(DNOP)	$C_{24}H_{38}O_4$	117-84-0
1,2-Benzenedicarboxylic acid, di-C7-11-branched and linear alkyl esters		68515-42-4
1,2-Benzenedicarboxylic acid, di-C6-8-branched alkyl esters, C7-rich (DIHP)		71888-89-6
Other Phthalates compounds	-	-

Source: LG Electronics (2014)

5.2.2.6. Applicability

To date, the applicability of the proactive elimination of certain phthalates is limited to the ICT sector. Within the ICT sector, companies may influence the chemical composition of standard commodity articles such as cables and wires as shown in the examples of Apple, Fujitsu and Dell. However, the elimination of certain phthalates in other sectors such as domestic appliances and white goods is less common. LG Electronics is promoting voluntary phase-out of phthalates from all products, also including household appliances, though it is not known at this time in what product groups (or components) phase-out is to begin.

As regards the introduction of substance restriction in combination with declaration requirements, cooperation with specific suppliers proved advantageous for the implementation.

In most cases, an independent testing of phthalates is not performed in-house by companies, but by external laboratories. This might be an obstacle for independent testing of the supply chain's declarations, which can, however, be compensated by cooperation with specific suppliers.

A threshold value of 0.1% by weight is applicable as this is the usual value given for restricted substances under the RoHS Directive.

5.2.2.7. Economics

One respondent company stated that the ban of the four phthalates would not be associated with higher costs. A ban of all phthalates respectively a switch to PVC-free cables, however, has a high cost impact. Another interviewee could not provide information regarding the associated costs of the elimination of the four phthalates arguing that costs were borne by the various levels of the supply chain.

Costs can arise at the level of the formulator[112] if there are changes in costs of the substances applied. Possible additional costs may arise if additional additives become necessary due to different chemical characteristics of the substitute. Costs can also occur at the level of the component manufacturer, resulting from changes in design, testing etc. According to the Danish EPA (2013), the costs of research and development (R&D) and investments in equipment is generally low compared to the costs of the plasticizers for the substitution in cables. Though some adjustment is often necessary when replacing the plasticizers, this is typically done by means of close cooperation between the manufacturer and the downstream user; the costs of R&D per manufacturing site is estimated at 60,000 €.

The ECHA RC SEAC (2012) estimated the costs for the substitution of DEHP by DIDP. It has to be noted that the substitution of DEHP by DIDP can easily be achieved from a manufacturing perspective, since it requires significantly less changes in the manufacturing process in light of substance similarities. The additional raw material costs of DIDP are only slightly higher (approx. € 0.026 per kg cable[113]), which accounts for 0.005% of the value of the cables.[114] As the content of DEHP in imported cables and wires was estimated to be 6,200 tons in 2007, ECHA RAC SEAC (2012) estimated the additional cost relating to the substitution by DIDP to be in the magnitude of € 1,300,000.[115] ECHA RAC SEAC estimates the potentially higher price for articles as follows: If all costs are passed on to the end-user, the increase in costs incurred for cables have been estimated at 0.5% in the beginning of the substitution of DEHP, as suppliers had to change the production. The costs for end-user decreased to 0.05% when substitution has taken place.

The costs for switching to PVC free cables are significantly higher. Details are presented in section 5.2.3, Elimination of brominated flame retardants (BFR) and polyvinyl chloride (PVC).

5.2.2.8. Driving force for implementation

The interviewed companies stated different driving forces; however, in the beginning, legal requirements were the starting point.

The communication and notification duties under REACH for substances that apply for substances on the REACH Candidate List of substances of very high concern and REACH Annex XIV were mentioned by one company as an initial point to consider the restriction of the phthalates. Another company stated that the restrictions under REACH Annex XVII for certain phthalates was the reason to focus on phthalates.

However, as the mentioned legal restriction did not apply to EEE respectively the imported EEE articles, the main driving force behind is a certain corporate responsibility aiming to proactively anticipate specific legal restrictions while having no or little changes in costs. Companies paraphrase this differently, i.e. as ‘signs of the time’, as a modest way or precautionary principle and general personal commitment as well as means that is more effective in advertising.

In some cases, a specific market visibility was achieved.

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112 Formulation is the process by which chemical products composed of one or more ingredients are prepared according to the product formula.

113 Assuming an average plasticiser concentration of 25% and an average weight of insulation of 50% of the total cable/wire, the weight of plasticisers accounts for 12.5% of the weight of cables and wires.

114 The average value of cables produced within the EU was calculated to 5.4 € per kg cable.

115 Using the price of 1€ per kg DEHP, ECHA RAC SEAC (2012) estimated the cost for using DEHP to be €6.2 million.

Though not mentioned by the companies, a driving force behind the elimination of the four phthalates was certainly public concerns raised by NGOs (e.g. Greenpeace).

5.2.2.9. Reference organisations

- Apple – Apple restricts more than the four phthalates addressed in this BEMP. The threshold value is indicated as < 1000 ppm per homogenous material (equal to 0.1% per weight value). As Apple phased out PVC, most phthalate applications will, also be eliminated by this switch of materials.
- Fujitsu – The Fujitsu Group eliminated the four phthalates DEHP, DBP, BBP and DIBP from their IT products. This restriction is specified in a list of prohibited hazardous substances that are part of the suppliers' confirmation. The limit value for all applications is 0.1% by weight per purchased part, component or module.
- Dell GmbH – Dell has restricted DEHP, DBP and BBP in all newly designed products since 2010. The restriction for DIBP is effective by January 1, 2014 for newly launched Dell parts and products, and by July 1, 2015 for all sustaining products.

5.2.2.10. Chapter references

Apple (2014)	Apple Regulated Substances Specification, Version H; https://www.apple.com/environment/reports/docs/apple_regulated_substances_specification_sept2014.pdf
Austrian UBA (2014)	Environment Agency Austria; ROHS Annex II dossier for DEHP; January 2014; http://www.umweltbundesamt.at/fileadmin/site/umweltthemen/abfall/ROHS/finalresults/Annex6_RoHS_AnnexII_Dossier_DEHP.pdf
Danish EPA (2013a)	Danish Environmental Protection Agency; Phthalate strategy; http://eng.mst.dk/about-the-danish-epa/news/denmark-at-the-leading-edge-regarding-phthalates/ and http://eng.mst.dk/media/mst/Attachments/strategiUK.pdf
Danish EPA (2013b)	Danish Environmental Protection Agency; Survey of selected phthalates, Part of the LOUS-review, Version of Public Hearing; October 2013. http://www.mst.dk/media/mst/Attachments/LOUS2013HoeringPhthalates.pdf
Dell (2013)	Dell Inc.; Dell's Chemical Use Policy; May 2013; http://www.dell.com/downloads/global/corporate/environ/Chemical_Use_Policy.pdf
ECHA (2012)	European Chemicals Agency ECHA;: Evaluation of new scientific evidence concerning the phthalates DINP and DIDP; 2012; http://echa.europa.eu/documents/10162/13641/information_note_dinp_didp_en.pdf
ECHA RAC SEAC (2012)	ECHA RAC/SEAC Committee for Risk Assessment (RAC) Committee for Socioeconomic Analysis (SEAC); Background document to the Opinion on the Annex XV dossier proposing restrictions on four phthalates; December 2012; http://echa.europa.eu/documents/10162/3bc5088a-a231-498e-86e6-8451884c6a4f

Groß et al. (2008)	Groß, R.; Bunke, D.; Gensch, C.-O.; Zangl, S.; Manhart, A.; Study on Hazardous Substances in Electrical and Electronic Equipment not Regulated by the RoHS Directive; Final Report, October 2008. http://hse-rohs.oeko.info/fileadmin/user_upload/Documents/RoHS_Hazardous_Substances_Final_Report.pdf
LGE (2014),	LG Electronics, LG Electronics Manual for hazardous substance management – 7.0 edition, Copyright 2014 LG Electronics Inc., available under: http://www.lg.com/global/pdf/Management-of-Hazardous-Substance_140619.pdf
LGE (2015)	LG Electronics, Voluntary Replacement of Hazardous Substances, avalable under: http://www.lg.com/global/pdf/Voluntarily-Replacement-of-Hazardous-Substances_v1.pdf
UBA (2007)	German Federal Environment Agency Umweltbundesamt UBA; Phthalate – Die nützlichen Weichmacher mit unerwünschten Eigenschaften; Februar 2007; http://www.umweltbundesamt.de/publikationen/phthalate

5.2.3. Elimination of brominated flame retardants (BFR) and polyvinyl chloride (PVC)

5.2.3.1. Description

Brominated and chlorinated compounds are the most common halogens in electronic products, and are the most likely to be used to achieve flame retardancy (iNEMI 2009a).

Chlorine-containing plastics, and in particular polyvinyl chloride (PVC), involve risks associated with their production, processing and especially with their disposal and incineration. The crucial potential for danger in this context regards the emissions of substances such as organic chlorine compounds and the associated emissions of dioxins and furans, especially when PVC is disposed of and incinerated. PVC is a chlorinated polymer that is commonly used as an insulation material for electronic components and assemblies, particularly cables and wires (iNEMI 2009a, Groß et al. 2008).

PVC polymer is not used as a pure resin in EEE applications, but rather mainly in the form of flexible PVC material that contains various additives. Many of the additives, e.g. plasticizers such as the phthalate di-(2-ethylhexyl)phthalate (DEHP) or flame retardants such as medium-chain chlorinated paraffin's (MCCPs), are classified as dangerous and are included in Annex I to Directive 67/548/EEC (now Regulation (EC) 1272/ 2008). The plasticizers content varies between 15-60% with typical ranges for most flexible applications around 35-40%. Thus, the PVC material that is used in EEE applications contains significant amounts of hazardous substances classified as dangerous in accordance with Directive 67/548/EEC (now Regulation (EC) 1272/ 2008) (Groß et al. 2008).

Brominated flame retardants (BFRs)[116] have in common that they contain bromine and are used to prevent the ignition of plastic materials and textiles. They all act by the same mechanism: through the release of hydrogen bromine when the material is ignited, which interrupts the further combustion process. Otherwise, the brominated flame retardants form a complex group of substances: aromatic, cycloaliphatic, aliphatic, polymeric and inorganic substances, all containing bromine. Some of the substances are used as additives, where the substances are not chemically bound in the polymer material, while others are used as reactive substances built into the polymer structure and not present as the original substance in the final polymer (except for trace amounts of un-reacted substances). Certain brominated flame retardants are either persistent or can be degraded to persistent compounds, either bioaccumulative or toxic (Lassen et al. 2014).

- On the basis of the above, brominated and chlorinated compounds have been the subject of various substance assessments, resulting in the regulation of specific substances in EU legislation. Current regulation already restricts the use of some of these substances, for example: The RoHS Directive restricts the application of poly-brominated biphenyls and poly-brominated diphenyl ethers in EEE, and has led to a virtual phase-out of these substances in EEE.
- Annex XIV of the REACH Regulation does not allow hexabromocyclododecane (HBCDD) to be manufactured or used in manufacture of articles that takes place within the EU without a specific

[116] Flame retardants are added to polymeric materials, both natural and synthetic, to enhance the flame retardancy properties of the polymers. Fire safety regulations are to a large extent the driver for the use of flame retardants. Fire safety regulations in general do not include any specific requirements for the use of brominated flame retardants or other flame retardants. The regulations typically define some fire tests which the materials, articles or building components should pass, but it is up to the manufacturer or the builder to decide how the requirements are to be met Lassen et al. (2014).

authorization: Annex XVII of the REACH Regulation restricts the use of monomethyl-dibromo-diphenyl methane bromobenzylbromotoluene (DBBT) and mixtures of isomers, in articles to be placed on the European market.

- The Stockholm Convention on Persistent Organic Pollutants (POPs), restricts the use and manufacture of certain substances, calling parties (who have signed the convention) to either eliminate production and use of substances (Annex A) to restrict manufacture and use (Annex B) or to reduce unintentional releases of substances (Annex C). Among others, the following brominated flame retardants are listed in this regard under Annex A: hexabromobiphenyl, hexabromodiphenyl ether, heptabromodiphenyl ether, tetrabromodiphenyl ether and pentabromodiphenyl ether;[117] It has further been recommended to add hexabromocyclododecane to Annex A of the convention.

The presence of a certain material or substance in a product is in general a result of the product design. The choice of materials largely depends on the various performance parameters that a certain component must exhibit in the end-product. For example, PINFA (2010) lists a number of criteria which need to be met by polymer resins, used for manufacturing many components in EEE:

- Flame retardancy – to ensure a proper level of fire safety, specific components need to be manufactured to comply with high fire safety standards;
- Processability – Important for a good processability is a high melt flow, which allows a high throughput;
- Thermal stability – Especially a high Heat Deflection Temperature (HDT) is required;
- Mechanical properties – In particular a high impact strength is requested;
- Hydrolytic stability – A high resistance against degradation caused by moisture is stipulated;
- Recyclability – The used polymer resins must be suitable for easy separation and they should be recyclable using standard processes;
- RoHS and WEEE directives – The polymer resins have to comply with the RoHS and WEEE directives.

Since some parts of manufacture may be performed by suppliers (manufacture of components and sub-assemblies), requirements for such criteria are established at the various stages of product design, and are communicated to suppliers as a condition to procurement. Product specifications will therefore include all relevant aspects, to ensure that the delivered components are compatible with the design of the finished product. To ensure compliance with legislation, OEMs will also use such specifications to address cases where the use of a substance is restricted, limited to certain applications or requires documentation of use. Such specifications are drawn up on the basis of chemical legislation (such as REACH and RoHS in the EU), but also incorporate independent initiatives such as in the case of OEMs who have decided to phase out certain substances voluntarily. Such lists are referred to differently by manufacturers, but shall be referred to in this report using the term Restricted Substances List (RSL). Some manufacturers have made their RSLs public (for example Apple and Dell as shown in section 5.2.3.5), however, at present, it is still not standard practice for manufacturers to publish such lists openly. Greenpeace (2014) have identified the publication of such RSLs on the use of hazardous chemicals in manufacturing, as the critical first step to addressing the problem in a credible manner.

[117] See Stockholm Convention on Persistent Organic Pollutants (POPs) as amended in 2009 under: http://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx

Examples have shown that most manufacturers shall specify restrictions of substances as is stipulated in the respective regulation, communicating the legal obligation to comply with substance thresholds as required by law. The brominated flame retardants PBB and PBDE, for example, restricted by RoHS, are thus assumed to appear on the RSLs of all EEE OEMs who market their products in the EU, as this is a legislative obligation, and at present, there are no exemptions for these substances in Annexes III and IV of RoHS, allowing derogations. Likewise, substances restricted through REACH Annex XVII, or listed in Annex A of the Stockholm POPs Convention are likely to be addressed similarly be OEMs in RSLs. As for hexabromocyclo-dodecane (HBCDD) and other substances listed in REACH Annex XIV, at present or in the future, the limitation of use does not apply to imported articles and thus its reference in OEM RSLs may differ, as articles imported to the EU can still use this substance. Some manufacturers may have decided to be more stringent in this respect, restricting the use/presence of such substances in all articles provided by suppliers, others may only require documentation of such use in cases where components are expected to be imported to the EU and thus not fall under the scope of this Regulation. However, reference to additional hazardous substances differs between manu-facturers, and BFRs and PVC are an interesting example in this regard. Whereas for other substances, the manufacturers' commitments can be compared by checking what substances are referred to in RSLs and what thresholds are given to establish that phase-out has been implemented, in case of brominated and chlorinated compounds, the product or application is also of relevance for most manufacturers.

In this regard it is important to understand that manufacturers have shown different approaches where the phase-out of brominated and chlorinated compounds is concerned. For example, Groß et al. (2008) mentions a number of approaches for phasing out of restricted flame retardants:

- **Substitution of flame retardants** – The halogenated flame retardants are replaced in the poly-mer material by a drop-in chemical substitute. The drop-in chemical is ideally comparable in terms of cost and performance to the halogenated flame retardant. This is the simplest approach because it typically does not require changes to the polymer material or to the design of the product. This change can be implemented by the polymer processor or compounder. In this regard, three different types of halogen-free flame retardants exist that can be used to substitute brominated and chlorinated flame retardants including inorganic substances (such as metal hydroxides), phosphorus-based flame retardants and nitrogen-based flame retardants.
- **Substitution of polymer material or resin** – Both the chemical used as flame retardant and the polymer material or resin system are changed. This is a more complex approach than simple flame retardant substitution, because it has a greater effect on the overall cost of the product and on performance. This change can be implemented by the polymer processor/compounder or by the end-product manufacturer.
- **Redesign of the product** – The actual product design is changed to minimize or eliminate the need for flame retardant chemicals. Examples of product redesign include using fire barrier material, as well as separating or reducing the source of heat from the product. This change can be implemented by the end-product manufacturer.

In the case of brominated flame retardants, for which manufacture and use have been restricted, compounders and manufacturers have often opted to replace substances with other brominated flame retardants, for which no restrictions exist. Such replacement has been regarded as pre-ferable, as in many cases, "drop-in" substitutes could not be found, which provided the same qualities in the end product, without requiring significant changes to manufacture and design. However, such substitutes may often also exhibit certain hazardous properties, and in this sense such substitution is not ideal. This is also reflected in the fact that additional brominated flame retardants have been and are being considered for future restrictions under various legislations.

The last decade has shown that there is a risk that the list of restricted brominated flame retardants could gradually grow (a few new substances could be added to the list every few years), creating uncertainty for the development of businesses tied to the manufacture or use of such chemicals. This background has supported the decisions of some enterprises which have started to look into the phase-out of such substances where this is possible. Several manufacturers of EEE have been committed to achieving a phase-out of brominated and chlorinated compounds in their product applications over the last few years, proving that substitution of these substances in EEE is possible at least for a large number of applications, and should be considered for application over a wider range of products. This BEMP therefore looks at the various phase-out practices of brominated and chlorinated compounds in the EEE sector.

5.2.3.2. Environmental benefits

As brominated and chlorinated compounds are associated with various hazardous aspects, the environmental benefit of their phase-out is related to the elimination of risks for human health and the environment tied to their use and their dispersion in the environment.

A main concern related to both groups of compounds is tied to the incineration of plastics, in which they are contained, at end-of-life. Lassen et al. (2014) mentions the risk of formation of brominated and mixed brominated/chlorinated dioxins and furans in this regard. Groß et al. (2008) makes reference to similar risks tied to the disposal and incineration of chlorine-containing plastics, and in particular of PVC.

Available information as to the environmental and toxic aspects of BFRs is limited, and mainly based on experience with the few BFRs which have already been addressed through legislation. However, BFRs have been associated with various toxicity properties, having been identified to be potentially bio-accumulative, relatively persistent and as having, in some cases, degradation products that are more toxic and accumulative than the original substance. Where human health effects are concerned, there is further concern that simultaneous occurrence of multiple brominated flame retardants with similar toxicological mechanisms will result in additive effects and in some cases in synergistic effects.

In this sense, the substitution of BFRs with non-brominated substances is considered to be beneficial in light of the elimination or at least the reduction of impacts associated with hazardous aspects of BFRs. Though some substitutes will also exhibit problematic aspects in light of toxicity and negative environmental impacts, a range of substitutes exist where this is not the case.

The European Commission-funded project ENFIRO (Leonards 2012) investigated substitution options for some BFRs and compared the hazard, exposure, fire, and application performances. The study followed a practical approach in which halogen-free flame retardants (HFFRs) were evaluated and compared to BFRs regarding their flame retardant properties, their influence on the function of products once incorporated, and their environmental and toxicological properties. In total, 14 HFFRs as alternatives for decabromodiphenyl ether (decaBDE), tetrabromobisphenol A (TBBP-A), and brominated polystyrenes were selected. These flame retardants were studied in five applications - printed circuit boards (PCBs), electronic components, injection molded products, textile coatings and intumescent paint. ENFIRO showed that all of the selected alternative flame retardants fulfil regulatory fire test requirements. An important finding was that halogen free systems have clear benefits, e.g. less visible smoke, in some cases lower peak heat release rates with halogen free products, and less toxic components in smoke. Both polymers with brominated and halogen-free flame retardants showed similar loss in mechanical properties compared to the polymer alone. All formulations (HFFR and BFR) showed equal or better performance regarding processability for injection molding. For all polymer systems investigated, a HFFR option was

found. The results for the PCBs showed that the HFFRs were as good as or better than the reference PCBs produced using BFRs. From the initial selection of 14 alternative flame retardants, seven were found to be less toxic and also accumulated less in the food chain than the BFRs. Environmental fate models predicted that the organic HFFRs would be found primarily in soils, sediments and dust and to a lesser extent in water and air. Controlled air emission experiments showed that all organic HFFRs emitted from polymers at elevated temperature but not at lower temperatures. Leaching experiments showed that both HFFRs and BFRs can leach to water. For some polymers, no differences in leaching behavior were found between BFRs and HFFRs, but some HFFR systems had higher leaching properties than polymeric-based BFRs. The type of polymer is the main parameter determining the leaching behaviour.

The US EPA (USEPA 2014) is also concerned with certain polybrominated diphenyl ethers (PBDEs – including decaBDE), in light of their being persistent, bioaccumulative, and toxic to both humans and the environment. As part of its Design for the Environment (DfE) Program, the U.S. Environmental Protection Agency initiated a multi-stakeholder partnership to assess flame retardant alternatives for Decabromodiphenyl Ether (decaBDE). The assessment has been aimed at providing a basis for informed decision-making, by developing an in-depth comparison of potential human health and environmental impacts of chemical alternatives. The final report, published in 2014, as well as further information concerning this partnership is available at http://www.epa.gov/dfe/pubs/projects/decaBDE/about.htm.

There is much discussion concerning the assessment of PVC for inclusion in various chemical legislations. A number of stakeholders have made various statements in this regard in a recent RoHS Stakeholder Consultation[118]. In summary, it is explained that PVC is not classified to be hazardous according to the EU Regulation on the Classification and Labelling of substances and mixtures, nor is it classified as a Persistent Bio-accumulative and Toxic (PBT) substance or a Substance of Very High Concern (SVHC). Toxicity aspects are explained to be related with the use of a number of restricted additives (plasticizers, namely the phthalates DEHP, DBP, BBP) and thus some stakeholder state that additives rather than PVC should be investigated (CEOE 2014; BEAMA 2014; CECAPI 2014).

Thus, for PVC it should be kept in mind that regardless of the question if environmental and health impacts are to be related to PVC content or to additive content, the substitution of PVC allows eliminating the need for using various plasticizers. In this sense, environmental benefits are expected, at a minimum in relation to the possible elimination of problematic additives.

Though additional environmental pressures should be considered, when comparing specific alternatives with brominated and chlorinated compounds, the main benefit of substitution relates to the reduced hazardous and toxic properties of alternatives. In such cases, benefits are understood to mainly be relevant at the manufacturing stage and relate to reduction of costs and resources needed to eliminate emissions and protect workers. More importantly, risks tied with treatment of WEEE at end-of-life can be reduced, in terms of the costs of sufficient treatment, but also in terms of emissions and impacts tied to less optimal treatment of waste. This aspect is of higher importance in cases where WEEE is exported (especially when this done illegally) as well as when second-hand products are exported for further use in developing countries. A socio-economic assessment and feasibility study on sustainable e-waste management in Ghana found that health and environment risks are related among others to the open incineration of cables and wires

[118] For further details see RoHS Substance Review Stakeholder Consultation Page under: http://rohs.exemptions.oeko.info/index.php?id=211

(Prakash & Manhart 2010). In this sense, substituting brominated and chlorinated compounds with substances of with lower hazardous properties would also contribute to reducing such impacts.

5.2.3.3. Appropriate environmental performance indicators

Referring to section 5.2.3.5, following thresholds for phasing-out chlorinated and brominated compounds are proposed:

- Br < 900 ppm (or mg substance per kg homogenous material);
- Cl < 900 ppm (or mg substance per kg homogenous material);
- paired with a total threshold of Br+Cl < 1500 ppm (or mg substance per kg homogenous material).

Appropriate indicators for monitoring the implementation of the BEMP and/ or its environmental benefits would be:

- Major OEM suppliers (in terms of % of supply chain expenditure) issue a Supplier Declaration of Conformity for company-specific list of restrictions, complemented by a certification (preferably third-party) based on laboratory testing.
- OEM publishes the information on its web-site and annual sustainability reports disclosing the % of suppliers (in terms of % of supply chain expenditure) that have phased-out BFR and PVC.

5.2.3.4. Cross-media effects

Cross-media effects of concern are related to the application of various alternatives to achieve the substitution of brominated and chlorinated compounds.

On the surface, this is related to the possibility of an alternative to also have certain hazardous properties which may not completely eliminate impacts which have been the cause for substitution. According to Beard (2014), it needs to be clear that not every flame retardant alternative is safer per se, however, many phosphorus-based alternatives have a better performance in terms of environmental impacts. Aryl phosphates like Tri Phenyl Phosphate (TPP), for instance, are problematic in terms of aquatic toxicity. For each alternative, the various endpoints and parameters need to be considered. Red phosphorus, for instance, is problematic from the processing perspective, and many compounders prefer to avoid its use, however there are alternatives that are unproblematic in this respect. A further aspect of importance, however, is how alternatives are applied. Beard (2014) explains that most alternatives are not drop-in and will require changes in the formulation of the material and possibly in the design (e.g. appearance) of a certain component. Usually, the recipe of the formulation needs to be adapted, often by using additional additives for adjusting material properties or other aspects which may change once a BFR is replaced with an alternative.

Additional resources and changes in processes shall translate into costs, but more importantly, other environmental pressures may become apparent that are important for choosing between alternatives. Changes in emissions and energy consumption related with manufacture of materials and components production are one aspect of importance; however, additional aspects may become relevant once the substances are considered for a specific case. In this sense, it is important to keep in mind that each case needs to be assessed before implementing substitutes.

For example, for substances that are restricted or regulated and have been replaced with an alternative substance, Apple (2014a, pg. 21) requires suppliers "*to ensure the alternative sub-*

stance is an environmentally responsible substitution. Substitutions should be selected based on minimizing unintended consequences that might occur in phasing out a potentially hazardous substance. Suppliers shall conduct alternatives assessments or obtain these assessments from their raw materials suppliers prior to making a replacement." See also substance assessment tool BEMP, section 5.2.1, in this regard.

5.2.3.5. Operational Data

Greenpeace (2014, pg. 24) explains that in some cases, electronic products described as "PVC/BFR-free" and "halogen-free" could contain BFRs and chlorinated chemicals at unacceptably high levels. Greenpeace elaborate that "Although these are considered to be "low" levels, significant quantities of halogenated chemicals will ultimately be released to the environment – both from products and in the production process – when they are multiplied many times over by the large volume of consumer electronics that are produced and disposed of…" further explaining that "Zero is the goal and zero also needs to be implemented and verified, to the lowest possible detection limit".

Where low-halogen or halogen-free practices in the EEE sector are concerned, it is important to clarify what maximum levels or threshold levels of bromine (Br) and chlorine (Cl) are to be tolerated, where electronic materials and systems are identified as "low halogen" or "halogen-free" (and/or as "BFR/CFR/PVC-free"). iNEMI (2009b) points out the importance of reaching a common definition of maximum halogen levels for low-halogen components and materials, for the alignment of the supply chain in the development of new materials and components.

The iNEMI (2009a) position paper[119] supports the following definition of "low halogen" (BFR-/CFR-/ PVC-free) electronics:

A component* must meet all of the following requirements to be Low Halogen ("BFR/CFR/PVC-Free"):

1) "*All printed board (PB) and substrate laminates shall meet Br and Cl requirements for low halogen as defined in IEC 61249-2-21 and IPC-4101B per 1a below (refer to IEC and IPC standards for actual requirements).*
    a. *Non-halogenated epoxide with a glass transition temperature of 120°C minimum. The maximum total halogens contained in the resin plus reinforcement matrix is 1500 ppm with a maximum chlorine of 900 ppm and maximum bromine being 900 ppm.*
2) *For components* other than printed board and substrate laminates: Each plastic within the component contains < 1000 ppm (0.1%) of bromine [if the Br source is from BFRs] and < 1000 ppm (0.1%) of chlorine [if the Cl source is from CFRs or PVC or PVC copolymers].*"

The assumptions behind these thresholds are that brominated and chlorinated compounds need to be present in much higher quantities to be effective, and thus that most materials containing less than the above concentrations of bromine and chlorine will not have any detectable levels of bromine or chlorine present.

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[119] iNEMI member companies supporting this definition include: Cisco, Dell Inc., Doosan Corporation, HP, Intel Corporation, Lenovo, Nan Ya Plastics Corporation, Senju Comtek Corp. Sun Microsystems, Inc. and Tyco Electronics.

The Blue Angel Label requirements differ from product to product where brominated and chlorinated compounds are concerned. In hand dryers, for example, neither polybrominated diphenyls nor polybrominated diphenyl ethers may be used for the flame protection of the plastic parts (Blue Angel 2010). For hair dryers and TV sets, the criterion is that "halogenated polymers shall not be permitted. Neither may halogenated organic compounds be added as flame retardants. Moreover, no flame retardants may be added which are classified pursuant to Table 3.1 or 3.2 in Annex VI to Regulation (EC) 1272/2008 as very toxic to aquatic organisms with long-term adverse effect and labelled with Hazard Statement H 410 or Risk Statement R 50/53." Process-related, technically unavoidable impurities; fluoroorganic additives used to improve the physical properties of plastics (provided that they do not exceed 0.5 weight percent) and plastic parts less than 25 grams in mass are exempt from this rule (Blue Angel 2012).

From a comparison prepared by Osmani et al. (2014) of various labelling mechanisms it is understood that the EU Ecolabel criteria do not allow the use of BFRs restricted under RoHS (PBB and PBDE) in TVs, desktops and notebook computers. In these products, the EU Ecolabel criteria require that plastic parts shall not contain a chlorine content greater than 50% by weight and that only biocidal products containing biocidal active substances included in Annex IA to Directive 98/8/EC of the European Parliament and of the Council (1), and authorized for use in computers, shall be allowed for use. In comparison, Nordic Swan requires that:

- The flame retardants HBCDD, TCEP and SCCP/MCCP must not be added;
- The flame retardant TBBP-A must not be added except in PWB;
- Other organic halogenated flame retardants and other flame retardants assigned one or more of the following risk phrases, or combinations, must not be added: H350, H350i, H340, H360F, H360D, H360Fd, H360Df;
- Plastic parts >25 g must not contain chlorinated polymers such as PVC.

It is apparent that there are different ways to address phase-out of BFRs and PVC, ranging from the restriction of certain compounds to broader restrictions for example of halogenated organic compounds, in which case some exclusions are usually provided. It seems that the thresholds used by most frontrunner manufacturers in specifications, which suppliers must comply with, have the benefit that they address the various compounds as a group, through the reference to the elimination of the element and not of a specific compound. The full implementation of such an approach shall assist in avoiding situations in which suppliers shift between compounds of a substance group (e.g., shift from a restricted BFR to a non-restricted one).

Apple began the phase-out of PVC in 1995. For example, PVC has been replaced with non‑chlorinated and non‑brominated thermoplastic elastomers in power leads and headphone cables. Metal hydroxides and phosphorus compounds are applied in circuit boards, cases and enclosures to replace BFRs (Apple 2014b).

Apple's phase-out of BFRs and PVC covers all parts of new product designs manufactured after 31 December 2008. While Apple's phase-out will cover the vast majority of products and components, older product designs, replacement parts and accessories for older product designs may not be fully BFR‑free and PVC‑free (Apple 2014c).

Apple recently published their specifications for regulated substances. Restrictions are said to be derived from international laws or directives, agency or eco-label requirements, and Apple policies. To ensure that these requirements are implemented by suppliers, Apple conducts factory audits, performs components testing with independent laboratories, and further verifies the results in an in-house laboratory located at the Cupertino headquarters in California (Apple 2014a).

Further communication clarifies that in analysis of supplied components, reference is made to detectable quantities of bromine and chloride on an elemental basis. Throughout stages of the research and development of new products, prototypes are provided by suppliers, which are submitted to analysis to ensure that the bromine and chloride limits are ensured. Testing is performed on the homogenous material level, and presence of elements is analysed on a total basis and not per specific substance. Specific substances and compounds are not referred to in this sense in reference with legislation, but rather a total elimination of all compounds/substances is required and in this sense also enforced at the supplier level (Apple 2014c).

Brominated and chlorinated compounds are addressed through items 3.8 and 3.11 of the specifications as follows:

> "*3.8: Bromine (Br) and its compounds: Materials are required to be compliant with Apple specifications on the restriction of bromine and chlorine. The CAS No. for bromine is 7726-95-6".*

Table 5-13: Apple Bromine Specifications

Restriction	Reference	Application Examples
≤ 900 ppm Bromine	Apple specification	Flame retardant, flux, solder paste
≤ 1500 ppm Bromine + Chlorine cumulative		

Source: Apple (2014a)

"3.11: Chlorine (Cl) and its compounds: Materials are required to be compliant with Apple specifications on the restriction of bromine and chlorine. The CAS No. for chlorine is 7782-50-5."

Table 5-14: Apple Chlorine Specifications

Restriction	Reference	Application Examples
≤ 900 ppm Chlorine	Apple specification	Flame retardant, flux, solder paste
≤ 1500 ppm Bromine + Chlorine cumulative		

Source: Apple (2014a)

Additional specifications are included where specific compounds are restricted by legislation, such as in the case of polybrominated biphenyls (PBB), addressed in item 3.28 in reference to the RoHS Directive. To prevent discrepancies in such cases, it is clarified that the restriction is in addition to the restriction addressed in item 3.8 (Bromine restriction). PVC is specifically addressed in item 3.33 which reference to the restrictions on bromine and chlorine with PVC-specific application examples: "*Electrical insulator, wire, tape, tubing, cable enclosure, vibration dampener, films*."

The document (Apple 2014a) further refers to means for demonstrating compliance. Both brominated and chlorinated compounds are among the few substances for which Apple requires suppliers to provide "*test reports from certified labs as proof of compliance…Testing for bromine*

and chlorine must be performed according to method EN 14582:2007,[120] *EPA SW-846 5050/ 9056,*[121] *or others preapproved by Apple*".

Dell is a further example of a manufacturer who has adopted precautionary measures to eliminate brominated and chlorinated substances. For Dell, PVC and BFR phase-out means meeting the definition of BFR-/PVC-free as set forth in the iNEMI Position Statement on the 'Definition of Low-Halogen Electronics (BFR-/CFR-/PVC-free)' (referenced in this document as iNEMI (2009a). Though full phase-out is yet to be accomplished, progress towards the elimination of BFR & PVC is continuous with the identification of acceptable alternatives. Efforts are aimed at lowering possible product health and environmental impacts without compromising product performance (Dell 2013a).

Some examples of products where Dell has achieved phase-out include (Dell 2013a):

- By 2004, all BFRs and PVC were restricted from the external case plastics in Dell branded products.
- Dell has already made the transition to BFR- and PVC-free removable media storage devices, memory, notebook LCDs, and hard disk drives.
- In 2013, entire product families have transitioned completely to BFR/PVC-free including: XPS[122] Notebooks and Tablets; Mobile Precision[122] Workstations; Latitude[123] Notebooks[122]; OptiPlex 9020 USFF[122] Desktop; P-Series Flat Panel Displays[122].

To ensure that these substances are not present in supplier components, DELL has number of measures in place. As a condition to approving a part for production, Dell requires suppliers to sign a Supplier Declaration of Conformity (SDoC) to ensure that all materials comply with the company's environmental policy. This declaration is also required to document any exemptions of relevance. Upon request, suppliers need to be able to provide technical documentation in the form of internal design controls, supplier declarations or analytical test data. As a second Tier in the verification strategy, Dell has implemented a so-called "Supplier RoHS Audit Program", which is divided into two parts: a quarterly traditional audit and an in-depth supplier survey. In the traditional audit, parts are selected randomly and submitted to third party analytical testing on a quarterly basis. Samples are tested for presence of restricted materials including the RoHS Annex II substances. Dell also actively screens samples in-house by using X-Ray Flourescence (XRF) equipment (Dell 2013a).

In this regard, Dell's supplier specifications restrict brominated and chlorinate compounds among others as follows:

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[120] Defined by Apple (2014a) as EN 14582:2007: Characterization of waste. Halogen and sulfur content. Oxygen combustion in closed systems and determination methods. British Standards Institute (2007)

[121] EPA SW-846 5050/9056: Bomb preparation method for solid waste; Method 9056: Determination of inorganic anions by ion chromatography. EPA (1994)

[122] Exclude peripheral accessories

[123] Exclude Latitude 3-series

Table 5-15: Dell Bromine and Chlorine Supplier Specifications

Substance	**Threshold Limit** (mg substance/kg homogenous material = ppm)	**Exemptions**	**Reference Appendix** (usually referring to compound lists)
Polybrominated Biphenyls PBBs & their Ethers/Oxides (PBDEs, PBBEs), including deca-BDE	1000	None	Table I
Brominated/chlorinated flame retardants (excluding PBBs, PBDEs)	1000	Restriction applies to mechanical plastic parts greater than 25 grams and products designated as Halogen Free or BFR/CFR-Free. Exemption applies to internal plastic components such as circuit boards, electronic components, fans, cables, printer fuser assembly and electrical assemblies contained in Dell products unless designated as Halogen Free or BFR/CFR-Free products.	Table L
Polyvinyl chloride (PVC)	1000	Restriction applies to mechanical plastic parts, plastic parts greater than 25 grams and products designated as Halogen Free or PVC free products. Cables, connectors, electronic components, battery trays, magnetic tape, and similar non-mechanical plastic parts are exempt unless designated as Halogen Free of PVC-Free products	CAS#: 9002-86-2
Additional requirements in Item 3.2 concerning BFR/CFR/PVC-Free "Halogen Free" Requirements		All parts and/or products designed to satisfy "halogen-free" requirements must satisfy Dell's BFR/CFR/PVC-Free Specification "Halogen-Free Specification", p/n ENV0199 (in Agile) in addition to this specification. Parts and/or products without a "halogen-free" requirement are not required to comply with ENV0199. ENV0199 specification is not applicable to Dell Enterprise products.	(Requirements not in table form, therefore aspect is not applicable)

It should be noted that specified specifications do not necessarily cover all DELL brominated and chlorinated compound restrictions, but rather provide an overview.

Source: Dell (2013b), Dell Specification: Materials Restricted for Use, Document Number: 6T198, approved 08/19/2013, available at: http://www.dell.com/downloads/global/corporate/environ/restricted_materials_guid.pdf

Though it seems that manufacturers of EEE from other than the ICT sector have been slower to make commitments regarding BFR and PVC phase-out, first examples can already be found. According to Greenpeace (2014, Table 1, pg. 38), LGE is gradually replacing BFR and PVC in its products. It is further detailed that in over 1,700 LGE refrigerator models the PVC "lower skirt" has been replaced with a TPE alternative, representing the substitution of 24.59 tons of PVC. Additionally, 144 top loader washing machines use PVC-free exterior film as from 2013, representing the substitution of 1,410 tons of PVC.

The LG RSL (LG Electronics Manual for hazardous substance management – 7.0 edition - LGE 2014) specifies requirements for suppliers concerning among others the voluntary phase-out of BFRs, CFRs and PVC. Substances are classified into two groups (or four sub-groups) as follows:

- Level A (Prohibited substance): Level A substances are prohibited for intentional use in all products, parts, raw materials, subsidiary materials and packaging materials supplied from cooperating suppliers to LG Electronics. In the case of impurities, which cannot be completely removed due to technical problems, maximum allowable concentration levels are specified.
  - Level A-I: Level A-I substances are the six substances currently restricted by the RoHS Directive, including PBDEs, PBBs; the maximum allowable concentration level for both substances is 800 mg/kg (i.e. 800 ppm or 0.08 % weight);
  - Level A-II: Level A-II substances are substances restricted by international / local laws or international conventions, except the RoHS Directive. This list includes: Polychlorinated biphenyls (PCBs), Polychlorinated naphthalenes (PCNs), Polychlorinated terhphenyls (PCTs), short chained chlorinated paraffins (SCCP) and Monomethyl dibromo/dichloro/tetrachloro diphenyl methane (Ugilec 121, 141, DBBT). The maximum allowable concentration level for PCBs, PCNs and PCTs is 50 mg/kg (i.e. 50 ppm or 0.005 % weight); for SCCPs it is 1000 mg/kg (i.e. 1000 ppm or 0.1 % weight); for DBBT a not detected level is specified;
- Level B Substances (Voluntary phase-out substances and Monitored substances):
  - Level B-I: Level B-I substances are substances that LG has decided to voluntarily phase-out of LG Electronics. Substances of relevance for this BEMP include PVC, BFRs and CFRs, for which specific compounds are detailed in Table 5-16 below. It is understood that LG Electronics will gradually replace these substances in products with alternatives according to the product characteristics.
  - Level B-II: Level B-II substances are substances with regard to which LG has decided to monitor their presence in LG Electronics. Medium chained chlorinated paraffins (MMCPs) are specified in this list.

Table 5-16: Level B-I list (Voluntary phase-out substances)

Name	Chemical symbol	CAS No.
Poly vinyl chloride	$H(CH_2CHCl)_nH$	9002-86-2 / 93050-82-9
Tetrabromobisphenol A	$C_{15}H_{12}Br_4O_2$	79-94-7
Tetrabromobisphenol A dimethylether	$C_{17}H_{16}Br_4O_2$	37853-61-5
Tetrabromobisphenol A dibromopropyl ether	$C_{21}H_{20}Br_8O_2$	21850-44-2
Tetrabromobisphenol A bisallylether	$C_{21}H_{20}Br_4O_2$	25327-89-3
Tetrabromobisphenol A bis(2-hydroxyethyl ether)	$C_{19}H_{20}Br_4O_4$	4162-45-2
Tri(2, 3-dibromopropyl) phosphate	$C_9H_{15}Br_6O_4P$	126-72-7
Bis(2, 3-dibromopropyl) phosphate	$C_6H_{11}Br_4O_4P$	5412-25-9
Tetradecabromo (p-diphenoxybenzene)	$C_{18}Br_{14}O_2$	58965-66-5

Bis(2, 4, 6-tribromophenyl) carbonate	$C_{13}H_4Br_6O_3$	67990-32-3
2-Propenoic acid (pentabromophenylmethyl) ester, homopolymer	$(C_{10}H_5Br_5O_2)_n$	59447-57-3
Polystyrene, brominated	$(C_8H_5Br_3)_n$	88497-56-7
1, 2-Bis (2, 4, 6-tribromophenoxy) ethane	$C_{14}H_8Br_6O_2$	37853-59-1
Disodium tetrabromophthalate	$C_8H_2Br_4O_4.2Na$	25357-79-3
TBBPA bis (2, 3-dibromopropyl) ether	$C_{21}H_{20}Br_8O_2$	21850-44-2
1H-Isoindole-1, 3(2H)-dione-2,2'-(1,2-ethanediyl)bis[4,5,6,7-tetrabromo]	$C_{18}H_4Br_8N_2O_4$	32588-76-4
Hexabromocyclododecane	$C_{12}H_{18}Br_6$	25637-99-4
3,4,5,6-Tetrabromo-1,2-benzenedicarboylic mixed esters acid, propylene with diethylene glycol and glycol	-	77098-07-8
Polymer of TBBPA, phosgene, and phenol	$(C_7H_5O_2).(C_{16}H_{10}Br_4O_3)_n.(C_6H_5O)$	94334-64-2
Tris(tribromoneopentyl) phosphate	$C_{15}H_{24}Br_9O_4P$	19186-97-1
TBBPA, 2,2-bis[4-(2,3-epoxypropyloxy) dibromo Phenyl]propane polymer	$(C_{21}H_{20}B_{r4}O_4)_n.(C_{15}H_{12}Br_4O_2)_n$	68928-70-1
Phosphoric acid, mixed 3-bromo-2,2-dimethylpropyl and 2-bromoethyl and 2-chloroethyl esters	-	125997-20-8
2,4,6-Tribromophenyl terminated carbonate oligomer	$(C_7H_2Br_3O_2).(C_{16}H_{10}Br_4O_3)_n.(C_6H_2Br_3O)$	71342-77-3
Tetrabromocyclooctane	$C_8H_{12}Br_4$	31454-48-5
Brominated aliphatic Compounds	-	-
Dibromoethyl dibromo cyclohexane	$C_8H_{12}Br_4$	3322-93-8
N,N-Ethylene-bis(tetrabromophthalimide)	$C_{18}H_4Br_8N_2O_4$	32588-76-4
Brominated polystylene	$(C_8H_5Br_3)_n$	57137-10-7
Tetrabromophthalic anhydride	$C_8Br_4O_3$	632-79-1
Ethylenebis(Tetrabromophthalimide)	$C_{18}H_4Br_8N_2O_4$	32588-76-4
Other BFRs compounds	-	-
Chlorinated paraffin	-	-
Chlorinated polyethylene	-	-

Source: LG Electronics Manual for hazardous substance management – 7.0 edition, 2014, available at: http://www.lg.com/global/pdf/6th_edition_Hazardous_substance_management_manual_for_the_supplier_Ver1.3.pdf

LGE specifies the following maximum allowable concentration levels for the above Level B-I substances (it is understood that this threshold shall gradually apply in components/products supplied):

- PVC – Not detected;
- BFRs (except PBBs, PBDEs) – for HBCDD 1000 mg/kg, for others: 900 mg/kg (Total Br);
- CFRs – for TCEP 1000 mg/kg, for others: 900 mg/kg (Total Cl).

LGE (2015) has made progress with the phase-out of these substances in:

- Mobile phones (no BFRs or PVC used in new models since 2010);
- LCD/OLED televisions (various BFR and/or PVC free components including housings, LCD panels, insulation sheets and internal cables of all/some models – for more details see source);
- Monitors, PCs, Laptops (replaced PVC and BFR in various components - for more details see source);
- Air conditioner (Replaced PVC from drain pipes for the indoor unit of residential air conditioners developed in 2011);
- Vacuum cleaners (PVC free for hose of vacuum cleaners for 6 series, BFRs free for steam pipe in all steam cleaners, charger and battery and EPS packing in 4 models);

5.2.3.6. Applicability

Various reasons have been raised by industry objecting to the complete phase-out of BFRs and PVC. Aside from the higher costs that substitution creates for design and manufacture, the opposition often also refers to the difficulty of phase-out of halogenated substances from all applications in light of the need to obtain comparable performance and reliability of products.

The time and resources needed to develop and implement the use of substitutes is an important factor, well reflected in exemptions still available for some restricted substances, such as those listed in annexes III and IV of the RoHS Directive. However, in this respect, experience also shows that where OEMs have engaged themselves actively in phase-out of certain substances, more progress has been made. In the EEE sector, such differences are apparent between the various sub-sectors. For example, the pressure created by initiatives such as those set up by Greenpeace have had a substantial impact on manufacturers in the ICT sector. The range of products in this sub-sector which are already manufactured in halogen-free versions is more diverse, meaning that applicability is not just wider but can also be assumed to require less time, as substitutes for a wider range of applications are already available. In relation with other sub-sectors such as the household appliance sector, it seems that development is slower; however, here too, first examples can be found.

In its 2014 report (Table 1, pg. 38), Greenpeace provides a comparison of the achievements of various OEMs in this regard, referring to various products. Fifteen companies have been included in this comparison. Some manufacturers have established complete phase-out in certain products and some are still phasing out BFRs and PVC from certain components. Though differences can be seen for different products, it is worth noting that the following products are already mentioned at least in relation with partial phase-out (from some product models or from certain components of named products), their range of applicability being clarified to some extent: mobile phones; desktop and laptop computers and monitors; media storage devices, memory and hard drives; LCD, UHD and OLED TVs; refrigerators; washing machines; shaving and grooming products; lighting products; MP3 players, digital cameras and camcorders, and home theatres; and more. It should be noted that companies appearing in this list have various phase-out commitments in relation to phase-out, time-line and product relevance. In this sense, though the list of products is promising in

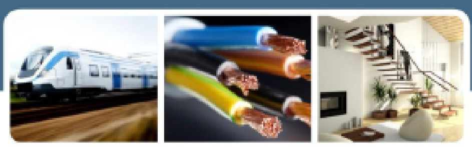
terms of the range of applicability, it does not allow understanding how much time and how much resources are needed for phase-out to be realistic in a substantial part of the EEE sector.

It can be concluded that substitutes are still being researched and that a full phase-out also needs to be coordinated in light of the ability of the supply chain to adapt to OEM requirements in this respect. However, a broad range of EEE products and components are already manufactured in BFR and PVC free versions. It should be noted, however, that the range of applicability in the EEE sector is very wide.

Apple (2014c) also notes that, though in the past it was more complicated to find suppliers to provide halogen-free components, at present it seems that this is no longer a limiting factor for implementing substitution.

A wide range of substitutes exist for various applications. The Phosphorus, Inorganic and Nitrogen Flame Retardants Association (PINFA) provide various sources of information on their website as to the technical properties and advantages of halogen-free flame retardants (FRs) for use in various sectors including the EEE sector (see http://www.pinfa-na.org/). A presentation also prepared by PINFA in 2010 provides a summary in this respect (see Figure 5-9 below). First experiences have also been made by manufacturers such as Apple, Dell, and other frontrunners (see detail in section 5.2.3.9).

Figure 5-9: Availability, Reliability, Cost & Safety of PIN FRs



Availability, reliability, cost & safety of PIN FRs

	Availability		Safety	Cost differential		Technology
Component categories	Do products exist?	Meet fire safety standard?	Health & environment	on material level	in finished product	Remaining issues to be resolved for shift (e.g.)
Wire & cable	✓	✓	Nordic & German gov't studies concluded there are sufficient PIN FRs of a good health & envi. profile to provide replacements; REACH registrations	~ 20%	Represents 1% ... 5% of the retail price of end product (fridge, TV...)	Some cable standards geared to certain materials
Enclosures	✓	✓		~ 20%		Need to shift from HIPS and ABS to polymer blends (e.g. PC-ABS)
Components	✓	✓		10% ... 20%		Some technical challenges, e.g. very thin parts, glow wire test
Wiring boards	✓	✓		10% ... 30%		Capacity build-up for alternatives; tests for long-term reliability

Source: PINFA (2010), RoHS Directive recast: Alternatives to brominated flame retardants – Presentation for Meetings in the European Parliament 23 March 2010, available at: http://www.endseurope.com/docs/100412b.pdf

Dell (2013a) provides some additional input in this regard, specifying some of the remaining challenges of full phase-out:

- Electrical performance issues above 1 GHz in halogen-free printed circuit boards
- Dielectric loss
- Unpredictability of technical performance
- Potential safety concerns in high temperature areas
- Availability issues for environmentally-preferable alternatives
- Transition to new substances for high performance products with long life-cycles
- Ability to maintain a high ratio of recycled content as substances are restricted.
- Lack of safety standards for BFR/PVC-free materials such as power cables

Despite the remaining challenges, Dell believes that legislation, such as the EU RoHS Directive, plays an important role in promoting industry-wide transition to restrict substances of concern. Dell continues to support the inclusion of BFRs and PVC in future EU RoHS Recasts, provided that some critical issues can be overcome or addressed by specific exemptions.

It is thus also expected that additional manufacturers working with the same suppliers may already to some degree benefit from phase-out as an unintentional positive rebound affect.

5.2.3.7. Economics

It is difficult to talk about costs on a general basis, as the cost of substitution is closely related to the compound to be substituted, to its exact application and to how substitution (elimination) can be carried out (i.e. drop-in, change of resin, change of design).

Beard (2014) provides some insight into the various factors that should be considered in this regard. To begin with, the comparison of costs is not just a comparison of the price of a BFR with an alternative substance (the final recipe cost needs to be compared taking into account the required dosage as well), but one also has to take into account one-time switching costs, i.e. all changes needed for the substitution – this will include costs for developing a new recipe for the formulation, costs needed for additional additives etc. These are classified as transitional costs for adjusting the recipe. Certification of materials is also important in the EEE sector, and once the recipe changes, a recertification is needed before the material can be applied in new products. Besides costs tied to certification, the process also requires time and can result in 1-2 years of time, since the process includes testing of the material for certain properties and often for long-term reliability. This testing, however, requires a minimal period of time to be completed. The certification aspect is an important factor in terms of applicability for different EEE sub-sectors. In the **IT sector** (ICT products), it is the compounder who deals with the certification, and so substitution is an aspect that mainly affects the supply chain. The OEMs will mainly be affected in terms of deciding if to phase a certain material out, in which case supply-chain specifications are adapted resulting in a possibly more narrow range of suppliers to choose from, as well as a change in costs of supplied materials and components. In the white goods sector, the option to use certified materials exists (certified by the supplier), however, the approach of most manufacturers is that the manufacturer certifies prototypes of a product or of its components, so that the manufacturer is affected more directly by the certification requirement (Beard 2014).

Beard (2014) further states that claims have been made that often a larger dosage of flame retardants is needed when shifting to non-brominated alternatives, which leads to increased costs. This is not always true, however. In cases where non-brominated flame retardants were cheaper, they have usually been used to begin with for financial reasons. Aluminium hydroxide (ATH) for instance is cheaper and allows reducing the cost of the formation of a material, but it has several technical limitations (due to its limited heat stability and inorganic nature).

When using halogen-free alternatives, in light of the development of the last few years and the growing use, today, most substances will result in additional costs of 10-30% of the material (in the past the difference was larger). The substance can be more expensive than a BFR, however, the final impact on the cost of the product will be much lower. In a notebook marketed at 500€, for example, a shift to a halogen-free alternative may result in an increase of 2-5€. This is a very small change in comparison with the total price, however when procurers look at sourcing for materials this is regarded as a large difference (Beard 2014). As also shown in Figure 5-9, the cost differential related to using halogen-free alternatives at the material level is about 20% for wires, cables and enclosures, between 10-20% for components and between 10-30% for wiring boards. Cost differential in the finished product is, however, only 1-5% of the retail price of end product.

Whereas for flame retardants, cost differences tied to substitution by halogen-free FRs may result in 10-30% higher costs on the material level, PVC alternatives are about twice as expensive, whereas a few years ago the difference was factor 3 or 4. This is due to the fact that PVC is a very cheap commodity polymer, and alternatives are more sophisticated (= expensive) polymers or inexpensive polyolefins, which have to be adapted to PVC performance by adding e.g. flame retardants. In most cases substitution results in a higher cost, however, this cost is associated with

environmental benefits. When you look, however, at the final price of the product, the difference is usually very small. (Beard 2014)

Some additional detail is provided (see Figure 5-9 above), though it should be kept in mind that data is from 2010 and that developments have allowed reducing the costs of substitutes to some degree.

Though quantitative data was not available, Apple (2014c) provides some insight where costs are concerned. When Apple decided to initiate the phase-out of brominated and chlorinated substances, application of substitutes was considerably more expensive than using the original substances. Over time, this has changed to some degree, costs are dependent on the scale of application, and substitution is at present more "affordable" for manufacturers.

5.2.3.8. Driving force for implementation

The reference to certain brominated and/or chlorinated compounds in legislation, which restricts the presence of substances in EEE such as RoHS, or their use in manufacture in general such as REACH, has been an important driving force for the phase-out of these substances. Additional assessments of substances from these groups regarding possible future substance restrictions in such legislation are also important in this concern. For some manufacturers, from a business perspective, the risk that further halogenated compounds (Br/Cl based) may be restricted in the near future has sufficed to motivate pro-active phase-out commitments, leading in the course of time to substitution of these materials.

Various labelling schemes and the public image associated with their use may also play a role in this regard, as some of these are more stringent than RoHS and REACH in their restriction of halogenated compounds (Br/Cl based).

In the IT sector, there has also been more pressure from NGOs (e.g. Greenpeace) to phase out various hazardous substances, posing an important driving force to phase out certain substances in this sector.

PINFA (2010) provide insight as to some additional drivers: In the last 30+ years the usage of so-called HFFR compounds in Wire & Cable applications have been driven by several major incidents, in which mostly the smoke density and the smoke toxicity in case of a fire in a highly populated area caused numerous casualties. In addition, the awareness of the impact of flame retardant polymers on our environment, especially in case of "end-of-life" scenarios has become an additional aspect of the design of flame retardant cables. The WEEE directive bans recycling of composites containing hazardous heavy metals and brominated flame retardants back into the feed stream. Current waste technology prefers not to have halogenated additives in this feed stream as it may limit or "poison" the subsequent generation of products.

According to Apple (2014c), in 2008, when phase-out was initiated by Apple, the differences in costs were too significant from the business perspective to be the sole driving force. The main driving forces were the precautionary principle and a general personal commitment in light of the understanding that substitutes are to have less significant environmental impacts. In their regulated substance specification Apple (2014a) also mention the need "*to make sure that anyone who assembles, uses, or recycles an Apple product can do so safely*".

5.2.3.9. Reference organisations

- Reference organisations identified in Greenpeace 2014 report as companies with phase-out commitments (Table 1, pg. 38-43):

Table 5-17: Reference Organisations

Commitment Status	Company	Product groups with full phase-out accomplished	Product groups with partial phase-out accomplished (components)	Comments
Company has met commitment to phase out PVC and BFRs and has all products free from these substances	Apple	Mobile phones; PCs*; Desktop monitors and other products	-	PVC cables phased out in 2013, PVC and BFRs phased out from all other products by the end of 2008.
	Nokia	Mobile phones		PVC free since 2005, all new models BFR and PVC free since 2010;
	RIM	Blackberry phones		BFR and PVC free as of the end of 2013.
Company is still working towards completing its phase-out of PVC and BFRs, based on a credible commitment; it is showing progress by bringing products free of these substances onto the market	HP	Specific monitor models are BFR & PVC free; Specific all-in-one printer model is PVC free	Notebook products and 60% of non-mobile families are low halogen; Cables not PVC free	
	ACER	Many desktops, monitor and notebook models are PVC and BFR free; A few mobile phone models and a few monitor models PVC & BFR free	90-99% of mobile phone parts are PVC/BFR free; Cables not PVC free	
	WIPRO	80% of Wipro PCs were PVC& BFR free at the end of 2012	No information as to cables being PVC free available	
	DELL	All removable media storage devices, memory and hard drives BFR & CFR & PVC-free; Specific notebook, desktop and monitor models are PVC & BFR free	Cables not PVC free;	BFR, CFR and PVC phased out of removable media storage devices and hard drives since 2011;
	LG	79 monitor models PVC & BFR free	All laptops developed after 2013 PVC and BFR free except components such as adapter, laptop, touchpad etc.	BFR and PVC phase-out in monitors as of 2013;

Commitment Status	Company	Product groups with full phase-out accomplished	Product groups with partial phase-out accomplished (components)	Comments
			Television, refrigerator and washing machine models have PVC and BFR free parts; Cables not PVC free	
	Lenovo	Some notebooks are PVC and BFR free	Monitors are PVC and BFR free aside from PCBA and external cables; Laptop and desktop models have low halogen components; Cables not PVC free	
	Philips	More than 80% of Philips shaving and grooming products are completely PVC/BFR-free	Philips lighting products are 78% PVC free and 29% BFR free; Consumer Lifestyle product portfolio was 55% PVC free, 55% BFR free.	Committed to the phase-out of PVC and BFRs in new consumer products placed on the market after January 2011.
	Toshiba	Specific PC models which are PVC and BFR free	Many PCs and notebooks have PVC and/or BFR free components; Most TVs have BFR components; Cables not PVC free	
	Sony	Mobile phones are free from PVC and BFRs	PVC phase-out from some models of other equipment, BFR free only concerns PBBs, PBDEs & Deca BDE in other than mobile phones;	In mobile phones, PVC free since 2007, all new models BFR free;
Company's phase-out of PVC and/or BFRs is only partial and its commitment to future action is unclear, or there is insufficient progress	HCL; Samsung; Panasonic; Sharp	See Greenpeace (2014) for further detail.		

Notes: PCs include desktops, laptops and monitors.

Source: Adapted from Greenpeace (2014)

5.2.3.10. Chapter references

Apple (2014a) Apple Inc.; Apple Regulated Substances Specification, Version H, effective September 1, 2014; available at: https://www.apple.com/environment/reports/docs/apple_regulated_substances_specification_sept2014.pdf

Apple (2014b) Apple Inc.; Website: Statement on Toxins; http://www.apple.com/uk/environment/toxins/, last viewed 6.10.2014

Apple (2014c) Apple Inc.; Website: Environmental Responsibility – Questions Answered: Which Products are Covered by Apple's BFR-free and PVC-free Transition? Available at: http://www.apple.com/uk/environment/answers/, last viewed 6.10.2014

Apple (2014) Interview with Apple representative requesting anonymity, conducted 12.9.2014

BEAMA (2014) BEAMA (British Electrotechnical and Allied Manufacturers); Contribution submitted on 04.04.2014; available at: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Substance_Review/Substance_Profiles/201404040_PVC_BEAMA_Questionaire_Substances_prioritisation_BEAMA_response.pdf

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5.2.4. Disclose and set targets for supply chain GHG emissions

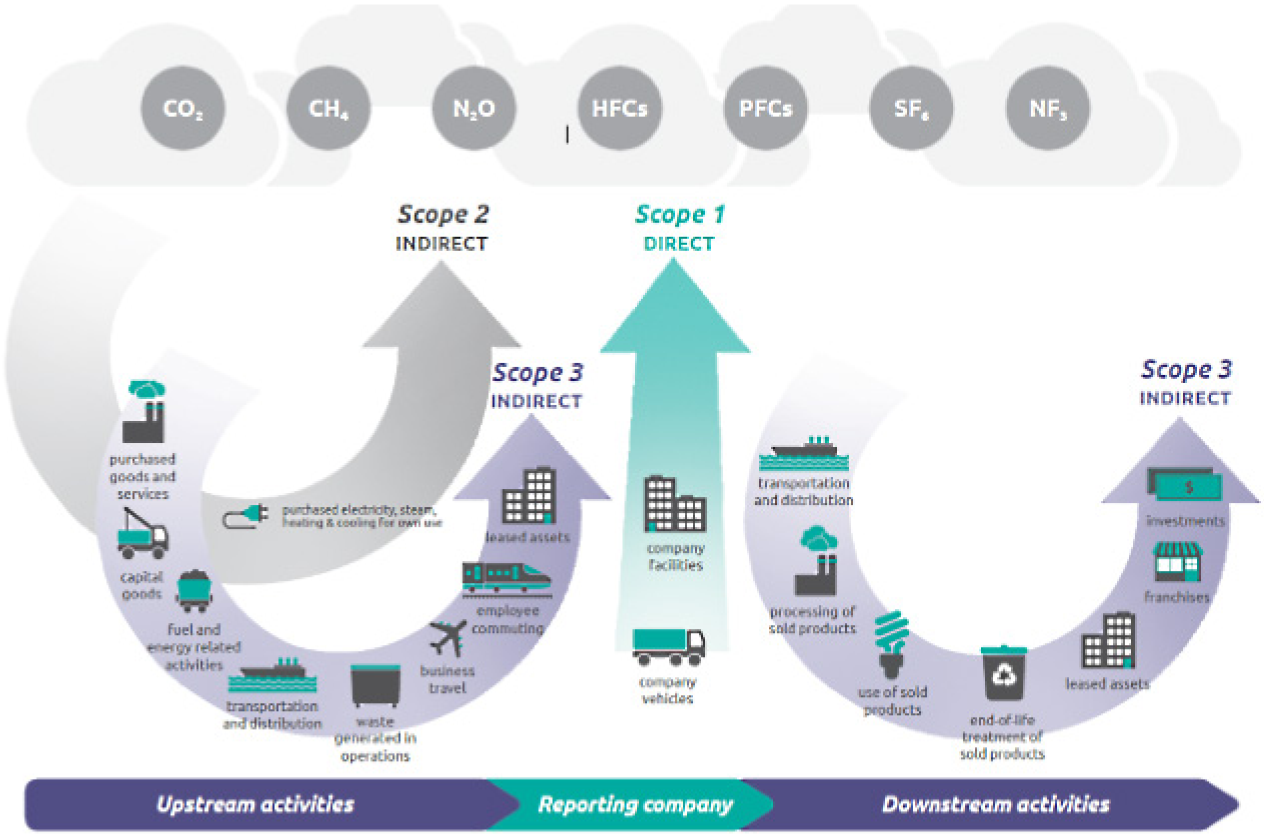
5.2.4.1. Description

EEE manufacturers are part of complex supply chain networks, made up of many different companies, all contributing in some form to the goods and services an EEE manufacturer offers. Each of these companies itself, through purchasing and processing of materials and energy, directly or indirectly causes the release of greenhouse gas (GHG) emissions to the atmosphere. Manufacturing of the final products, hence, through this supply chain network, indirectly contributes to the release of GHG emissions. This best management approach aims at reducing these indirect GHG emissions, through

- publicly disclosing significant supply chain emissions according to recognised standard(s) and
- setting and meeting (absolute and relative) targets for their reduction.

These indirect emissions are commonly referred to as “Scope 3 emissions”. Scope 1 emissions are all direct GHG emissions accruing within the vicinity of a company, i.e. GHG emissions that are released in owned or controlled facilities or vehicles (burning of fossil fuels for heat, cooling, transport, refrigerants in cooling equipment, etc.). Scope 2 emissions are indirect GHG emissions from consumption of purchased electricity, heat, cold or steam, e. g. emissions that were released elsewhere to produce the energy consumed within company boundaries. Scope 3 finally denotes all other indirect emissions from product (good or service) or material flows entering or leaving the company boundaries (refer to Figure 5-10).

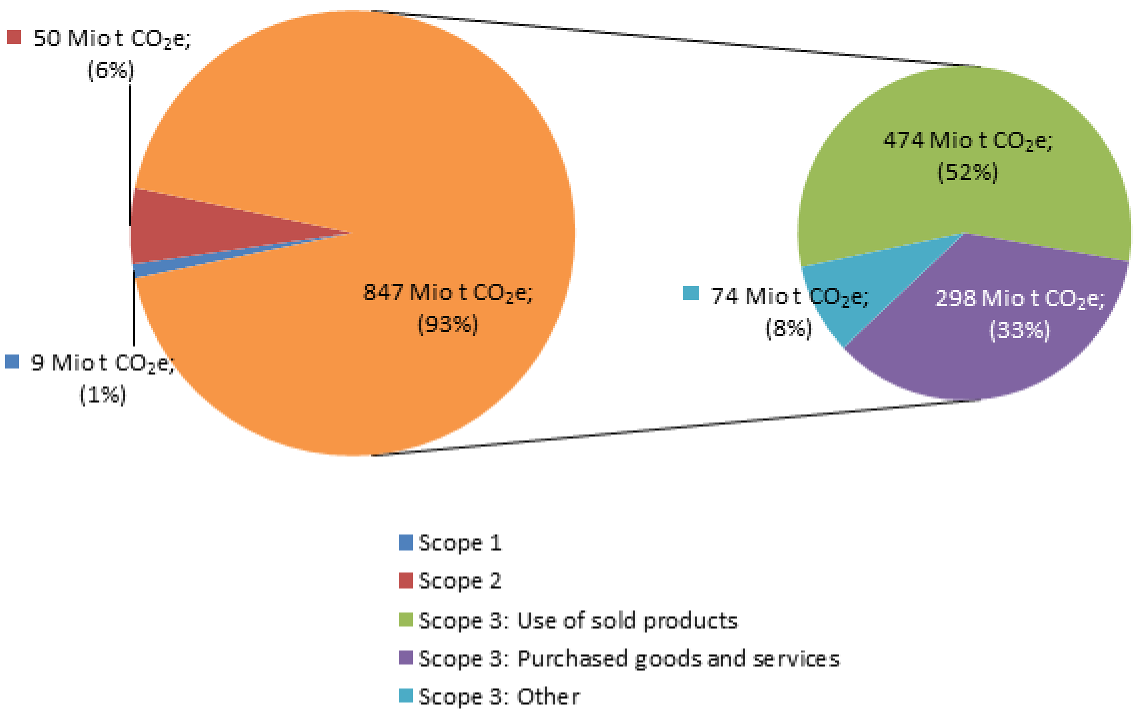
Figure 5-10: Definition of Scopes in GHG Protocol Corporate Value Chain Standard



Source: GHG Protocol (2013b); please note that GHG NF3 has been added consistent with amendment to GHG Protocol Standard (GHG Protocol 2013a)

Scope 3 emissions typically make up a major share of overall corporate GHG emissions, often exceeding Scope 1 and 2 emissions significantly. Figure 5-11 shows total GHG emissions reported by 320 ICT companies to the Carbon Disclosure Project (CDP), broken down by Scope. Scope 3 emissions are further broken down into “use of sold products”, “purchased goods and services” and “other”. Though reporting of Scope 3 emissions is still incomplete, these emissions are already today assessed at more than 90% of aggregate direct and indirect GHG emissions of ICT companies, with “use of sold products” and “purchased goods and services” providing for the major share.

Figure 5-11: Aggregate reported Scope 3 emissions to the CDP by ICT companies and comparison to Scope 1 and 2 emissions



Source: Own illustration based on CDP (2014a)

Important to note, Scope 3 emissions of one company are the Scope 1 (and 2) emissions of other companies. The sum of all Scope 1 emissions, of all organisations and other human operations, together would be equal to overall anthropogenic GHG emissions. Scope 3 emissions, in contrast, cannot be added up in the same manner as this would result in double counting of emissions. Nonetheless, measuring indirect Scope 3 GHG emissions provides an important avenue for companies to understand and influence their overall impact on climate change in collaboration with their supply chain partners.

Companies implementing the BEMP assess and disclose these emissions according to recognised standards. Through the use of recognised standards GHG emissions can be assessed comprehensively and systematically and results can be interpreted by external stakeholders and business partners. Wide acceptance of a standard also facilitates streamlining of information/ data exchange across business partners in the supply chain. Though a number of standards exist for Scope 1 and 2 GHG accounting, standards for comprehensive Scope 3 accounting remain limited. A widely applied and accepted standard is the GHG Protocol Corporate Value Chain (Scope 3) Standard.

(GHG Protocol 2011) Another comprehensive standard is the Organisation Environmental Footprint Guide published and recommended by the European Commission. (European Commission 2013a and 2013b) It similarly provides detailed requirements and guidance for assessing and reporting supply chain GHG emissions, and, as part of a comprehensive environmental assessment, also including other environmental impacts. It is, however, still undergoing a pilot test phase and therefore not yet adopted as widely.

Figure 5-10 provides an overview of the activities each of the Scopes encompasses. Indirect Scope 3 activities are broadly clustered into downstream and upstream activities. These two are basically distinguished with regard to money flows:

- Emissions from *downstream* activities are “indirect GHG emissions from sold goods and services” (GHG Protocol 2011, p. 137). They “also include emissions from products that are distributed but not sold” (ibid.).
- Emissions from *upstream* activities are “indirect GHG emissions from purchased or acquired goods and services” (ibid., p. 141).

The GHG Protocol further subdivides downstream and upstream activities into Scope 3 categories (ibid., pp. 34-37):

- Downstream categories are *downstream transportation and distribution*, *processing of sold products*, *use of sold products*, *end-of-life treatment of sold products*, *downstream leased assets* (assets leased to another company), *franchises*, and *investments*.
- Upstream categories are *purchased goods and services*, *capital goods*, *fuel- and energy-related activities* (not included in Scope 1 and 2), *upstream transportation and distribution*, *waste generated in operations*, *business travel*, *employee commuting*, and *upstream leased assets*.

Companies implementing the BEMP subsequently identify and address all applicable of these Scope 3 emission categories, ideally focussing on the most relevant first and working towards including all categories. For EEE manufacturers the category of “purchased goods and services”, i. e. particularly the manufacture of components and raw materials in the upstream supply chain, generally contributes significantly to overall (Scope 1, 2, and 3) GHG emissions, as does the “use of sold products” and are assessed as part of BEMP (see explanation and Figure 5-11 above). However, this relationship must be established individually as the specific boundaries and processes for Scope 1, 2, and 3 categories can differ significantly from company to company.

Companies implementing the BEMP account and report for “the emissions of all GHGs required by the UNFCCC/Kyoto Protocol at the time the corporate or product inventory is being compiled”. (GHG Protocol 2013a) These GHGs currently include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). As NF_3 was only recently added to the list, it is not yet routinely included in GHG inventories. However, as it is now required by the GHG Protocol Standards, this will likely change in the near future. Table 5-18 provides an overview of typical sources of these greenhouse gases related to EEE.

Table 5-18: Selected EEE-related sources of GHGs

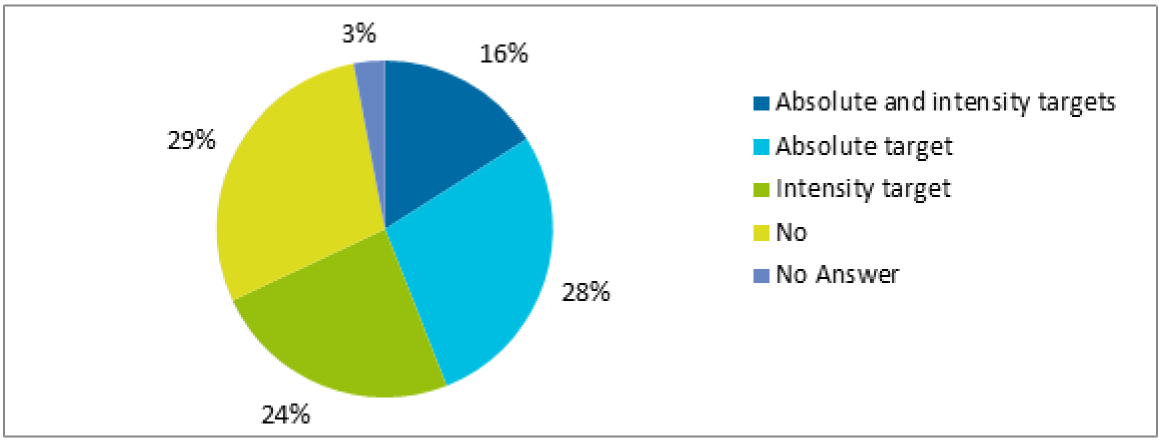
CO_2	From burning of fossil fuels for electricity, transport and other energy, burning of solid waste; from production of cement, metals (such as iron and steel) and certain chemicals
CH_4	From production and transport of coal, natural gas, and oil; from agricultural products; from landfills
N_2O	From combustion of fossil fuels and production of agricultural products
HFCs	Used as refrigerants, aerosol propellants, solvents, and fire retardants
PFCs	From aluminium production and semiconductor manufacturing
SF_6	From magnesium processing and semiconductor manufacturing; electrical transmission equipment; tracer gas for leak detection
NF_3	Plasma etchant and equipment cleaning gas in the semiconductor industry (manufacture of flat screen displays and PV panels)

Source: EPA (2014); Prather & Hsu (2008)

However, public disclosure in itself does not automatically entail lower GHG emissions and environmental impact. The sole internal implementation of GHG accounting lacks external scrutiny and accountability and thus also lacks an important incentive for continued GHG reduction efforts. Companies implementing the BEMP disclose the full Scope 3 inventory (in addition to Scope 1 and 2), highlighting which parts have undergone third-party review and where major gaps still exist. BEMP includes describing the main sources and underlying processes of the major share of identified greenhouse gas emissions.

However, disclosure alone is not best practice and, to a certain degree, is already in fact common practice among large EEE manufacturers. BEMP therefore combines comprehensive disclosure with ambitious GHG reduction targets and achievements for most significant GHG emission sources. As part of BEMP, absolute and relative targets for the reduction of overall and supply chain greenhouse gas emissions are set and met. In 2012/2013, 16% of ICT companies reporting to the CDP have absolute and relative targets in place (see Figure 5-14). Companies implementing the BEMP demonstrate progress with regard to set targets by periodically reapplying the same measurement standards, explaining the measures implemented for reducing Scope 3 GHG emissions and highlighting any changes in overall GHG inventory to methodological adaptations.

Figure 5-12: Type of emission reduction targets among 320 global ICT companies reporting to the CDP



Source: CDP (2014a)

Amount and type of energy are significant drivers of GHG emissions and other environmental impacts. Energy produced by renewable energy sources generally entails lower GHG emissions and other environmental impacts than energy from fossil fuels. Increasing the share of renewable energy in energy intensive parts of the supply chain can hence reduce overall GHG emissions and other environmental impacts. In fact, changes in the energy system are a very important element in any strategy to significantly reduce GHG emissions. However, clear unambiguous accounting standards for the recognition of renewable energy use in product and corporate GHG accounting are not established yet and implementation differs widely among companies.

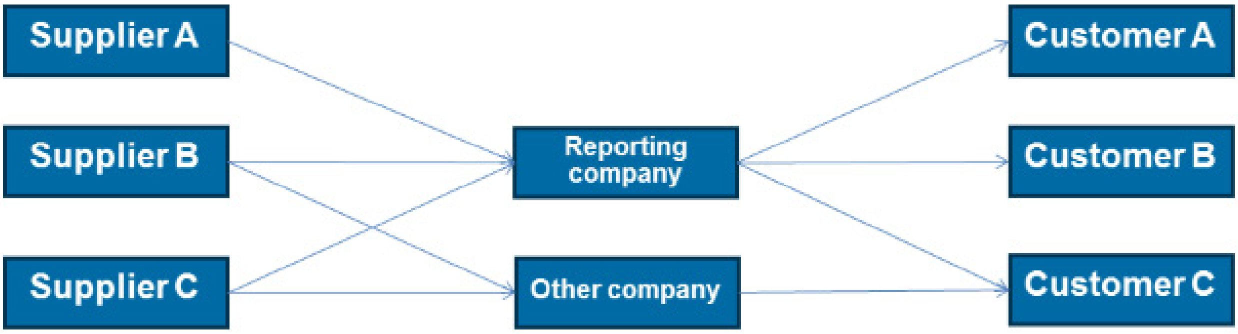
5.2.4.2. Environmental benefits

Reducing anthropogenic GHG emissions is the primary means for limiting global warming. Achieved reductions in supply chain GHG emissions contribute to overall GHG emission reductions and hence to climate change mitigation.

Actually achieved absolute emission reductions may be lower than disclosed achieved emission reductions due to a number of factors:

- Suppliers would be implementing GHG reducing measures also in absence of a specific supply chain program by the company implementing the BEMP. BEMP would merely achieve business-as-usual emissions reductions.
- Suppliers may be part of multiple manufacturers supply chains, who would each report on the progress of their supply chain GHG emissions, effectively reporting on the same achieved emission reductions (see Figure 5-13).
- Increased energy and resource efficiency and hence reduced cost may lead to increased energy or resource use due to higher overall output (rebound effect).

Figure 5-13: Suppliers being part of multiple supply chains



Source: Own illustration

But the opposite may also be true, i.e. higher achieved emission reductions than the ones reported:

- Emission reductions achieved at supplier facilities or in supplier procurement due to actions from the company implementing the BEMP may lead to reduced supply chain GHG emissions also of other companies, e. g. a more efficient production process that is used for a component shipped to multiple clients.
- Innovation and knowledge gained in emission reductions are transferred and scaled to other processes/ companies, contributing to emission reductions elsewhere.

It is in the nature of Scope 3, i.e. indirect emissions, that the full effect of emission reductions is not achieved by the reporting company alone but contingent upon other partners and customers in the supply chain.

5.2.4.3. Appropriate environmental performance indicators

The implementation and environmental benefit of the BEMP can be monitored by the following performance indicators:

- Periodically published (e.g. annual) report according to recognised standard;
- Number and extent of Scope 3 emissions/emission categories covered;
- Disclosure of absolute or relative GHG emission reduction targets in the periodically published (e.g. annual) report
- Absolute and/or relative emission reductions demonstrated based on same standard.

5.2.4.4. Cross-media effects

GHG emission reductions are achieved through a range of different measures. Possible effects on other environmental impact categories cannot be generalised and require a case-by-case consideration. Possible cross-media effects include:

- reduced fossil fuel and resource consumption usually entails reduced emissions also of other pollutants;
- increased water-cooling of data-centres can contribute to reduced energy-consumption and GHG emissions, while increasing water consumption;

- substituting refrigerants by variants with lower or no global warming potential may lead to increased energy consumption.

Specific effects on other environmental impact categories should be assessed as part of the consideration of specific measures.

5.2.4.5. Operational data

The most commonly applied and accepted standard for assessing, disclosing and managing GHG emissions associated with the supply chain of a company is the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard. (GHG Protocol 2011) Besides establishing requirements, it provides detailed guidance on the assessment and appropriate disclosure of GHG emissions in corporate value chains (commonly referred to as Scope 3 emissions). It complements the GHG Protocol Corporate Standard (GHG Protocol 2004), which does the same for direct and energy-related indirect (Scope 1 and 2) GHG emissions of organisations. Compliance is demonstrated through a "report in conformance with the GHG Protocol Corporate Standard and the GHG Protocol Scope 3 Standard" (GHG Protocol 2011, p. 6)

As explained earlier, the category "purchased goods and services" is of particular importance for EEE manufacturers. This Scope 3 category includes emissions from "extraction, production, and transportation of goods and services purchased or acquired by the reporting company in the reporting year" (GHG Protocol 2011, p. 34). Hence, all purchased goods and services are included in the GHG inventory with their "cradle-to-gate" emissions. These typically include emissions from:

- extraction of raw materials;
- agricultural activities;
- manufacturing, production, and processing;
- generation of electricity consumed by upstream activities;
- disposal/treatment of waste generated by upstream activities;
- land-use and land-use change;
- transportation of materials and products between suppliers;
- any other activities prior to acquisition by the reporting company.

Some of these emissions may be reported in a different category, e.g. upstream transportation and distribution and would then not be included in purchased goods and services.

The category "use of sold products" includes the "direct use-phase emissions of sold products over their expected lifetime" (GHG Protocol 2011, p. 36). This category includes emissions from (GHG Protocol 2011, p. 48):

- products that directly consume energy (fuels or electricity) during use;
- fuels and feedstocks (petroleum products, natural gas, coal, biofuels, and crude oil;
- greenhouse gases and products that contain or form greenhouse gases that are emitted during use.

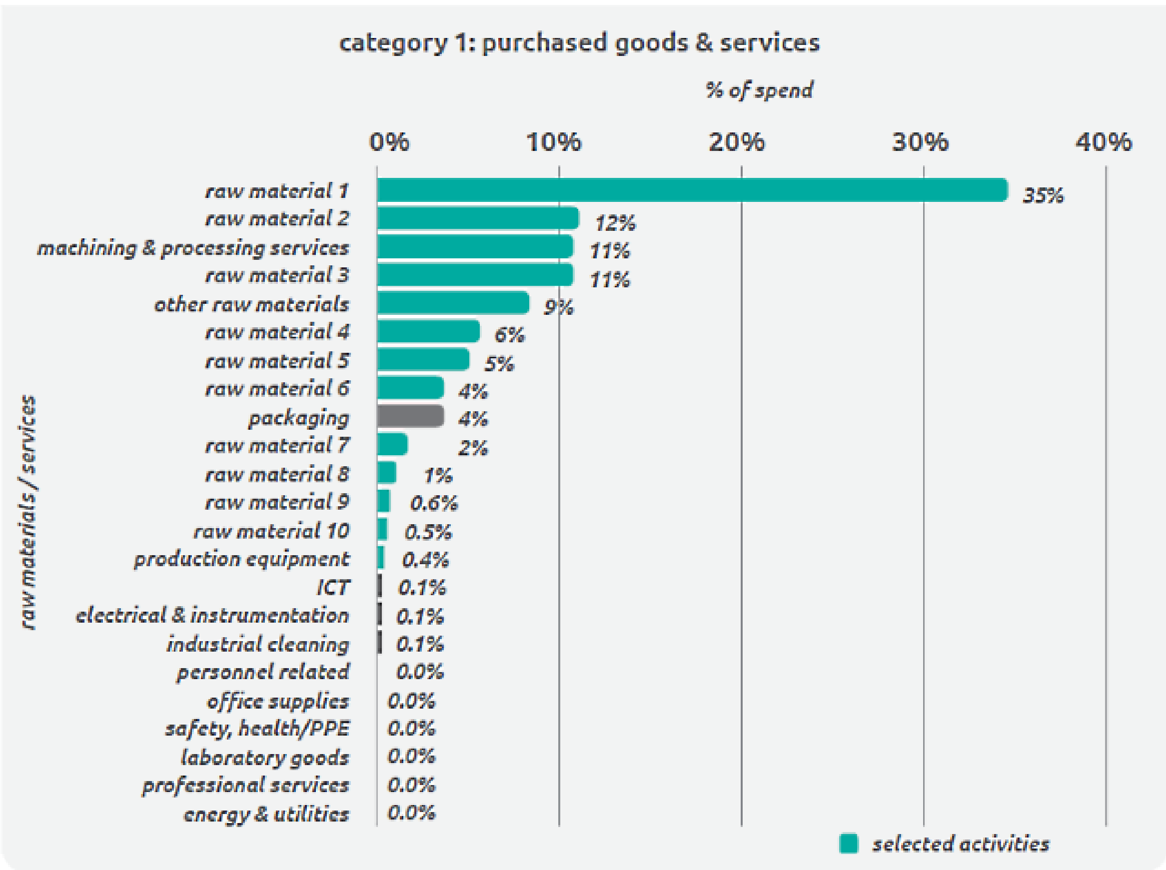
For EEE, the most important emissions driver in the use-phase of sold products will usually be electricity use.

Data for value chain GHG emissions is gained through one of two means: either based on a value chain model or scenarios for use of sold products and the application of secondary data from databases or by directly engaging suppliers and asking them for site-/process-specific ("primary") data. BEMP entails increasing the share of supplier specific data for the most relevant purchased goods and services.

To establish relevance of the different Scope 3 emission categories and particularly purchased goods or services for subsequent more detailed analysis, a screening exercise can be used. A screening is based on readily available or easily accessible data. Figure 5-14 shows the result of such as screening exercise as undertaken by AkzoNobel based on financial spend on purchased goods and services to inform subsequent more detailed analysis of most relevant (intermediate) products. In this example, focus for getting supplier and process specific data would e.g. be reasonably first placed on raw materials 1, 2, 3 and machining and processing services. It is, however, possible to build a full standard-compliant Scope 3 inventory based on secondary data only.

Relevance should be established based on expected contribution to overall GHG emissions. However, also additional criteria may be applied (see Figure 5-15). A company may for example also do a more detailed analysis of activities which it can influence more easily or that are deemed relevant by stakeholders.

Figure 5-14: Example of outcome of screening exercise



Source: GHG Protocol (2011), p. 67

Figure 5-15: Possible criteria for identifying relevant Scope 3 activities

Criteria	Description of activities
Size	They contribute significantly to the company's total anticipated scope 3 emissions
Influence	There are potential emissions reductions that could be undertaken or influenced by the company
Risk	They contribute to the company's risk exposure (e.g., climate change related risks such as financial, regulatory, supply chain, product and technology, compliance/litigation, and reputational risks)
Stakeholders	They are deemed critical by key stakeholders (e.g., customers, suppliers, investors or civil society)
Outsourcing	They are outsourced activities previously performed in-house or activities outsourced by the reporting company that are typically performed in-house by other companies in the reporting company's sector
Sector guidance	They have been identified as significant by sector-specific guidance
Spending or revenue analysis	They are areas that require a high level of spending or generate a high level of revenue (and are sometimes correlated with high GHG emissions)
Other	They meet any additional criteria developed by the company or industry sector

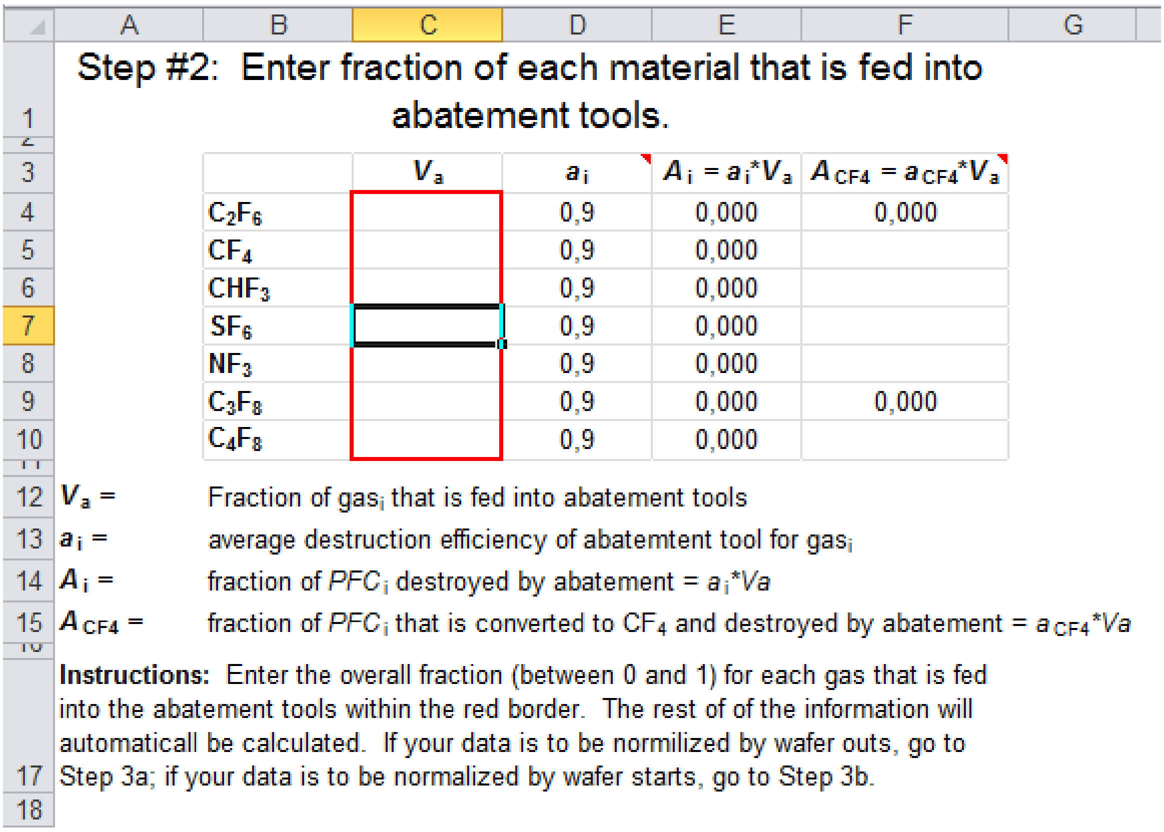
Source: GHG Protocol (2013b), p. 12

For data collection and compilation, detailed guidance is available. Besides, the general GHG Protocol Value Chain (Scope 3) Standard, the GHG Protocol Initiative additionally provides the following documents, which can guide EEE manufacturers in the implementation of the BEMP:

- WRI / WBCSD; Greenhouse Gas Protocol; Technical Guidance for Calculating Scope 3 Emissions (version 1.0): Supplement to the Corporate Value Chain (Scope 3) Accounting & Reporting Standard, 2013 (GHG Protocol 2013b) provides detailed calculation guidance for the different Scope 3 categories.
- GeSI / WBCSD / WRI / Carbon Trust; GHG Protocol Product Life Cycle Accounting and Reporting Standard: ICT Sector Guidance, January 2013 (draft) (GHG Protocol 2013c) is a supplement to the GHG Protocol Product Standard and hence not fully aligned with the GHG Protocol Value Chain Standard. It does, however, provide detailed guidance for a lot of ICT specific processes, e. g. with regard to Telecommunications Network Services, Desktop Managed Services, Cloud and Data Centre Services, Hardware, Software and may be useful in the elaboration of a full Scope 3 inventory.
- Excel-Tools for the calculation of GHG emissions associated with specific processes, e. g. for refrigeration and air-conditioning equipment or semiconductor manufacturing. Also a list of Third-party databases for secondary data is provided: http://www.ghgprotocol.org/calculation-tools

As Scope 3 emissions are (at least partly) Scope 1 emissions of other companies, specific tools for calculating Scope 1 emissions may be used in collaboration with supply chain partners. The mentioned excel tool for calculating emissions from semiconductor manufacturing, e. g., allows for the calculation of PFC emissions from the production of semiconductor wafers (see Figure 5-16).

Figure 5-16: Excel tools for the calculation of process specific GHG emissions (here: PFC emissions from semiconductor manufacturing)


Step #2: Enter fraction of each material that is fed into abatement tools.

	V_a	a_i	$A_i = a_i*V_a$	$A_{CF4} = a_{CF4}*V_a$
C_2F_6		0,9	0,000	0,000
CF_4		0,9	0,000	
CHF_3		0,9	0,000	
SF_6		0,9	0,000	
NF_3		0,9	0,000	
C_3F_8		0,9	0,000	0,000
C_4F_8		0,9	0,000	

V_a = Fraction of gas_i that is fed into abatement tools

a_i = average destruction efficiency of abatemtent tool for gas_i

A_i = fraction of PFC_i destroyed by abatement = a_i*Va

A_{CF4} = fraction of PFC_i that is converted to CF_4 and destroyed by abatement = $a_{CF4}*Va$

Instructions: Enter the overall fraction (between 0 and 1) for each gas that is fed into the abatement tools within the red border. The rest of of the information will automaticall be calculated. If your data is to be normilized by wafer outs, go to Step 3a; if your data is to be normalized by wafer starts, go to Step 3b.

Source: http://www.ghgprotocol.org/calculation-tools/semiconductors

Furthermore, specific ICT industry standards and guidance documents exist that may help companies implementing the BEMP in elaborating a Scope 3 inventory:

- The Electronic Industry Citizenship Coalition (EICC) offers its members and their suppliers an online sustainability data management system building on GHG Protocol Standard and incorporating demands from CDP and GRI reporting platforms.
- EICC has published detailed suggestions for using supplier data to estimate emissions from the purchase of HDDs, LCDs, PCBs, PCB Assembly and ICs (EICC 2014a)
- ITU L.1420: Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations (ITU 2013)
- ADEME; Assessing GHG emissions – Sectoral Guidance for the ICT sector (“Réalisation d'un bilan des émissions de gaz à effet de serre – Guide sectoriel: Technologies Numériques, Information et Communication”) (ADEME 2012)

Based on a first screening and detailed calculation of relevant Scope 3 emissions, the full Scope 3 inventory is established, providing overall Scope 1, 2, and 3 emissions as well as a breakdown of Scope 3 emissions by category.

Sharp has over the course of several years implemented a comprehensive Scope 3 assessment, disclosure and management plan. It currently (2013) reports on 10 out of 15 Scope 3 categories (see Table 5-19 and Table 5-20). Scope 1 and 2 emissions together contribute 1.3 million tons CO_2e to overall GHG inventory, while Scope 3 contributes more than 31 million tons CO_2e based

on Scope 3 categories assessed so far. Sharp also provides explanations on underlying sources of these emissions.

Table 5-19: Reported overall Scope 1, 2, 3 emissions for Fiscal Year 2013

Scope	Emissions (thousand tons CO_2)	Notes
Scope 1 (direct GHG emissions from business activities)	361	Emissions from combustion of gas, heavy oil, etc.
Scope 2 (indirect GHG emissions from energy usage in business activities)	950	Emissions from the use of electricity
Scope 3 (indirect GHG emissions from areas outside the scope of business activities)	31,252	Calculated for 10 categories such as Procurement, Shipping & Distribution, Product Usage, and Employee Commuting & Business Trips

Source: Sharp (2014), p. 48

Table 5-20: Detailed reported Scope 3 emissions for Fiscal Year 2013

Classification	Category	Emissions (thousand tons CO_2)	Notes
Upstream	Purchased goods and services	4,090	CO_2 emissions from the manufacture of materials procured for main products*8 that the Sharp Group sold in the relevant year
	Fuel- and energy-related activities not included in scope 1 or 2	110	CO_2 emissions from transmission losses of electricity purchased by the Sharp Group
	Upstream transportation and distribution	50	CO_2 emissions from transportation and distribution of materials procured by the Sharp Group
Sharp	Business travel	20	CO_2 emissions from business travel by all employees of Sharp Corporation
	Employee commuting	20	CO_2 emissions from commuting by all employees of Sharp Corporation
	Leased assets	—	Included in scope 1 and 2 CO_2 emissions
Downstream	Processing of sold products	410	CO_2 emissions from processing at destination of Sharp Group products
	Downstream transportation and distribution	250	CO_2 emissions from transportation and distribution of products manufactured by the Sharp Group
	Use of sold products	26,300	CO_2 emissions*9 in the relevant year from the use of main products*8 that the Sharp Group sold in the relevant year
	End-of-life treatment of sold products	2	CO_2 emissions from recycling 4 types of appliances*10 that Sharp Corporation sold in Japan
Total		31,252	(Indirect GHG emissions from areas outside the scope of business activities)

*8 LCD TVs, air conditioners, refrigerators, washing machines, air purifiers, microwave ovens, LED lights, Blu-ray Disc recorders, facsimiles, mobile phones, LCD monitors, MFPs, solar cells (13 product types)

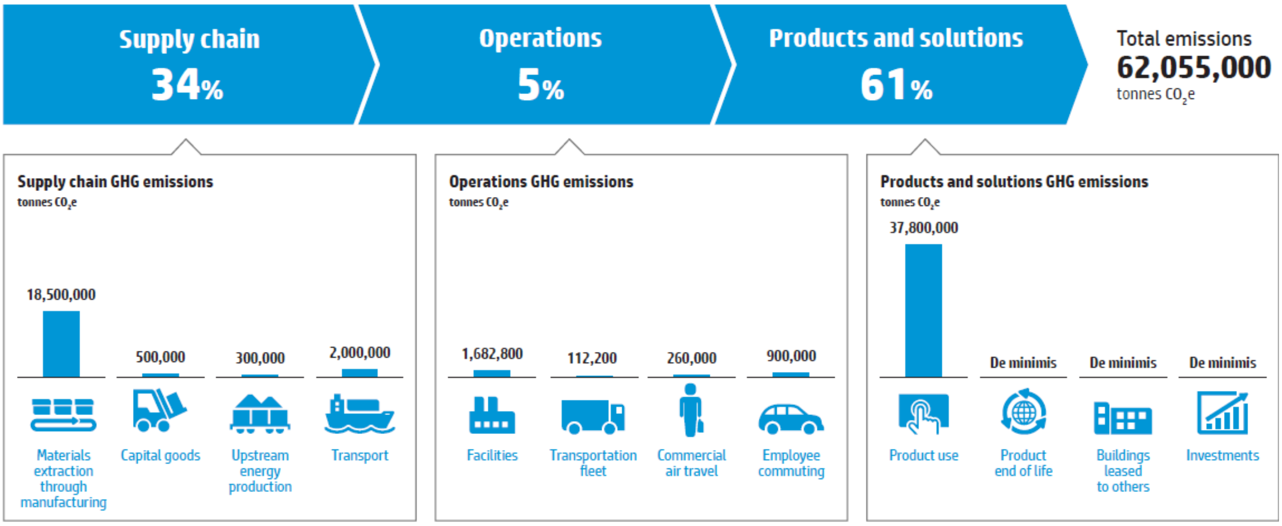
*9 The amount of CO_2 emissions from the use of sold products does not include avoided emissions from the use of solar cells.

*10 LCD TVs, air conditioners, refrigerators, washing machines

Source: Sharp (2014), p. 48

HP is also pursuing Scope 3 assessment and disclosure. Results for Fiscal Year 2013 are depicted in Figure 5-17. Again, purchased goods and services, denoted "Materials extraction through manufacturing" and product use make up major share of overall GHG emissions.

Figure 5-17: HP Fiscal Year 2013 GHG inventory

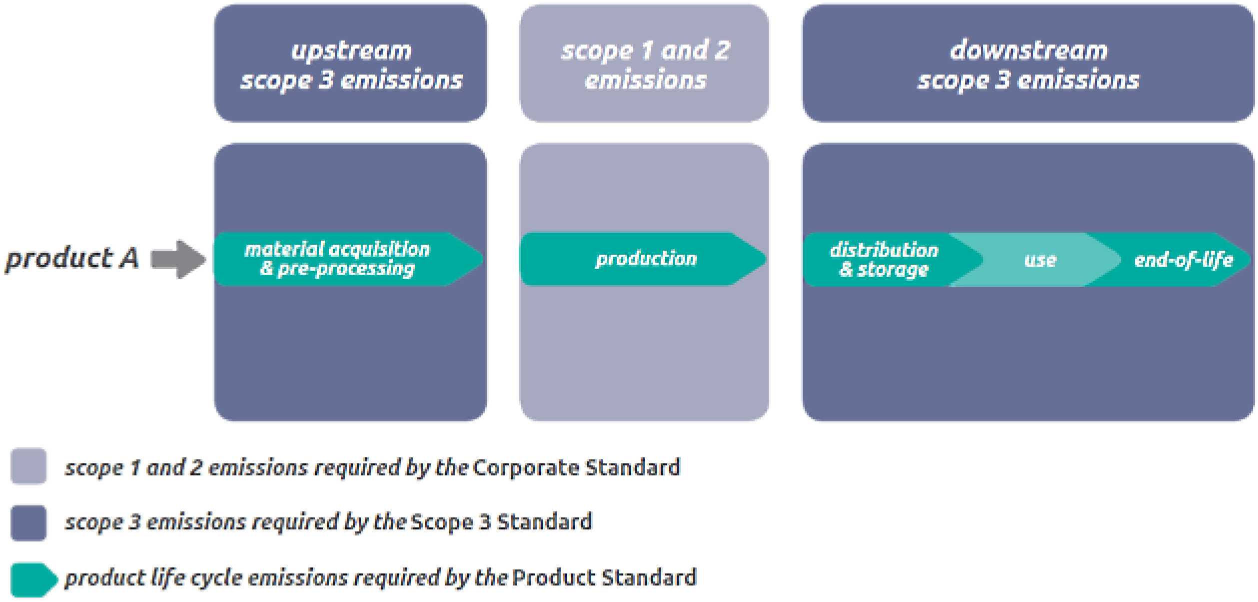


Source: HP (2014)

Companies implementing the BEMP may want to establish relation to product specific carbon/ environmental footprint or LCA assessments. This is possible and reasonable, particularly for the most relevant purchased and sold products. Figure 5-18 illustrates this relationship between a product assessment and overall Scope 3 assessment. Through a detailed assessment of "Product A" in the illustration, an implementing company can derive specific emission factors for the cradle-to-gate emissions of this purchased product before it enters the company boundaries. Similarly a specific emission factor can be applied to assess downstream emissions associated with this particular product. Theoretically it is possible to undertake such detailed assessments for all (intermediate and final) goods and services entering and leaving the company boundaries and adding their emissions up to compile an overall Scope 3 inventory. In practice this will usually only be feasible for the major products a company manufactures.

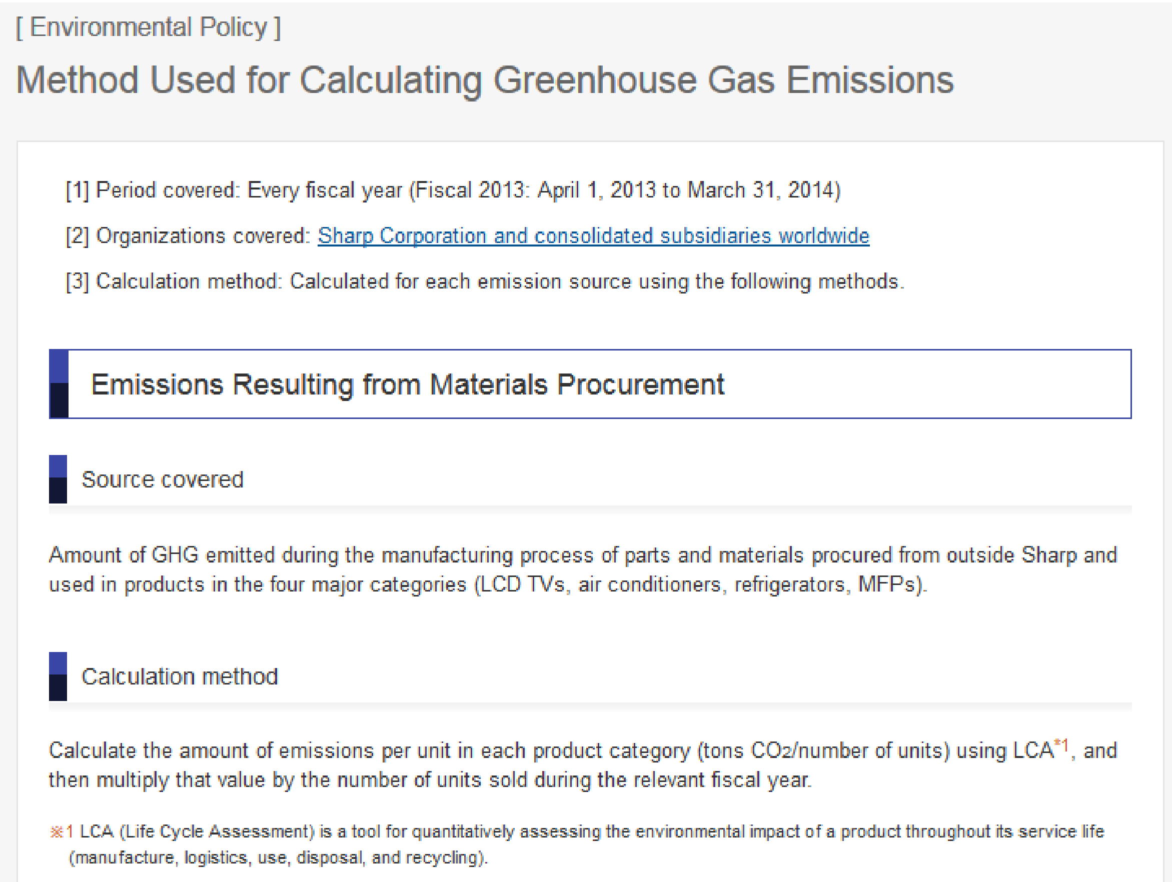
This approach is used by Sharp to calculate emissions from "materials procurement", i.e. purchase of goods and services by subdividing its product range into products for which specific LCA results are available. These unit emission factors are then multiplied by the number of units purchased. The method is established in its Environmental Policy (see Figure 5-18).

Figure 5-18: Relationship between GHG Protocol Product and Value Chain Standards



Source: GHG Protocol (2011), p. 8

Figure 5-19: Sharp: Calculation method for materials procurement as established in its environmental policy



[Environmental Policy]

Method Used for Calculating Greenhouse Gas Emissions

[1] Period covered: Every fiscal year (Fiscal 2013: April 1, 2013 to March 31, 2014)

[2] Organizations covered: Sharp Corporation and consolidated subsidiaries worldwide

[3] Calculation method: Calculated for each emission source using the following methods.

Emissions Resulting from Materials Procurement

Source covered

Amount of GHG emitted during the manufacturing process of parts and materials procured from outside Sharp and used in products in the four major categories (LCD TVs, air conditioners, refrigerators, MFPs).

Calculation method

Calculate the amount of emissions per unit in each product category (tons CO_2/number of units) using LCA[*1], and then multiply that value by the number of units sold during the relevant fiscal year.

※1 LCA (Life Cycle Assessment) is a tool for quantitatively assessing the environmental impact of a product throughout its service life (manufacture, logistics, use, disposal, and recycling).

Source: http://sharp-world.com/corporate/eco/report/ssr/vision/env_policy/method_emissions/

Another company using a comprehensive Scope 3 assessment is Cisco. The company has previously worked on establishing and meeting GHG emission reduction goals for its own operations and the Scope 3 category "Business air travel". These goals have been formulated on an absolute basis (see Figure 5-20).

Figure 5-20: Cisco GHG emission reduction KPIs and results achieved

Key Performance Indicators (KPIs; Base Year, if Applicable, and Last 5 Years Reported)

Performance Summary	FY07 Baseline Year[1]	FY10	FY11	FY12	FY13	FY14	Comments
Total contractual GHG emissions: Scope 1 and 2, metric tonne CO_2e.	436,489	376,141	416,927	251,672	312,525	305,656	Values from 2012 CSR Report have been updated.
Percent progress against reduction goal. Goal: Reduce total, Cisco, Scope 1 and 2, GHG emissions worldwide by 40% absolute by FY17 (FY07 baseline).	base year	-14%	-4%	-42%	-28%	-30%	Cisco's new corporate GHG reduction goal was announced in February 2013.
Total Scope 3 air-travel GHG emissions, metric tonne CO_2e.	199,104	96,442	114,707	125,605	139,530	157,868	All emissions recalculated using the United Kingdom's Department for Environment, Food and Rural Affairs (DEFRA) 2014 emissions factors (Ricardo-AEA/Carbon Smart); radiative forcing not included.
Percent progress against reduction goal. Goal: Reduce total, Cisco, business-air-travel, Scope 3 emissions worldwide by 40% absolute by FY17 (FY07 baseline).	base year	-51%	-42%	-37%	-30%	-21%[2]	FY12 was goal year for first, 5-year goal of -25%.
Product return, metric tonne	n/a	8,580	11,595	13,324	12,539	12,180	
Returned material sent to landfill	n/a	0.33%	0.89%	0.43%	0.33%	0.30%	Landfilled material consists only of nonelectronic waste materials, such as broken pallets, wet cardboard, and shrink wrap, accompanying Cisco products returned by customers for recycling.

1. Our annual CSR reports include data for the past five fiscal years and, for GHG/energy, our goal base year.
2. If air travel from the approximately 5,000-employee NDS acquisition is excluded, FY14 value is -25%.

Source: Cisco (2014), p. F4

As manufacturing is completely outsourced, Scope 3 emissions are of particular importance for Cisco. (Full Scope 3 emissions are disclosed to the CDP.) Consequently, Cisco is implementing specific goals and measures to reduce its Scope 3 GHG emissions. Out of 600 suppliers Cisco has identified 130 suppliers, which together account for more than 80% of supply chain expenditure and which it targets in its “sustainability supply chain program”. This group is adjusted slightly to focus on “key” suppliers, which are assessed through “business performance scorecards”. From Cisco’s 2013 CSR report:

> *We use a business scorecard to monitor key suppliers’ performance on a range of criteria, such as technology, cost, quality, responsiveness, and collaboration. Sustainability represents between 3 and 8 percent of the total score (depending on supplier type), and suppliers’ performance on sustainability metrics is reviewed at least once per year, and as often as quarterly, as part of regular business reviews. Suppliers must maintain strong scores to earn and retain their status as key suppliers, and those that perform particularly well often gain more business from Cisco. (Cisco 2013)*

GHG emissions in the supply chain are addressed through specific targets, moving from disclosure gradually to performance. To account for the diversity in its supply chain, Cisco differentiates between manufacturing partners, logistics providers, and component manufacturers. Manufacturing partners and logistic providers are smaller in number and more closely connected to Cisco, making their involvement in sustainability programs more straightforward. They are almost all identified as “key” suppliers. Component manufacturers are much more diverse, often smaller, with Cisco not always being the main customer. Nonetheless, some component manufacturers are also identified as “key” suppliers.

Cisco is then using a tiered approach to address GHG emissions. It is asking and encouraging its key suppliers to assess, disclose and subsequently set GHG reduction targets. Implementation is then closely monitored for each supplier, e. g. if Scope 1 and 2 emissions have been assessed and GHG emission reduction targets set (see Table 5-21). Key suppliers are requested to report to the CDP as part of the CDP Supply Chain Program.

> *Energy consumption and greenhouse gas emissions are to be tracked and documented, at the facility and/or corporate level. Participants are to look for cost effective methods to improve energy efficiency and to minimize their energy consumption and greenhouse gas emissions.*

Table 5-21: Cisco sustainability scorecard results for “key” suppliers

Table 1. Scorecard Sustainability Survey Results			
Key suppliers publishing a CSR Report	**FY12**	**FY13**	**FY14**
Manufacturing partners	86%	86%	100%
Logistics providers	57%	100%	100%
Component suppliers	38%	52%	52%
Key suppliers reporting to CDP			
Manufacturing partners	88%	100%	100%
Logistics providers	56%	100%	100%
Component suppliers	46%	74%	86%
Key suppliers that have set a GHG emissions-reduction target			
Manufacturing partners	Not tracked	71%	100%
Logistics providers	Not tracked	67%	62%
Component suppliers	Not tracked	41%	56%
Key manufacturing partners and logistics providers providing GHG emissions data related to Cisco products	100%	100%	100%

Source: Cisco (2014), p. C8

Targets for manufacturers and logistics providers are more ambitious than for component manufacturers, due to different levels of maturity of sustainability programs and complexity of implementation. For component suppliers focus is placed on reporting of emissions while manufacturing partners and logistics providers are encouraged to set targets and disclose these via CDP. Cisco states “we believe that public disclosure is a more effective tool to help suppliers make the changes required to meet these targets”. (Cisco 2013) Manufacturing partners and logistics providers are additionally requested to report Cisco’s share of GHG emissions to Cisco.

Cisco also works with the Electronic Industry Citizenship Coalition (EICC) to harmonize and streamline data requests to suppliers together with its peers. Within the EICC the industry has, e.g., established a Code of Conduct for suppliers. On energy and GHG emissions it states (EICC 2014b): “*Energy consumption and greenhouse gas emissions are to be tracked and documented, at the facility and/or corporate level. Participants are to look for cost-effective methods to improve energy efficiency and to minimize their energy consumption and greenhouse gas emissions*”.

These measures are supported by extensive training on sustainability of its own managers that deal with suppliers in business operations and of managers at suppliers. Specific targets are set for the share of managers trained on sustainability.

5.2.4.6. Applicability

This BEMP, in principle, is applicable to all organisations. Sector specific guidance is applicable.

Synergies with other BEMPs can be established, in particular establishment of an LCA programme. Information gained from detailed environmental assessment of important products can inform the elaboration of a comprehensive GHG inventory and, vice versa, a comprehensive GHG inventory can ensure focussing detailed assessment and improvement efforts on the most important products.

Specific measures to reduce Scope 3 emissions are often the same as for Scope 1 and 2 emissions, except that they are not implemented in the company itself but at partner companies in the supply chain. Hence, the BEMPs on manufacturing of EEE can be applied (see section 4, Manufacturing of EEE).

5.2.4.7. Economics

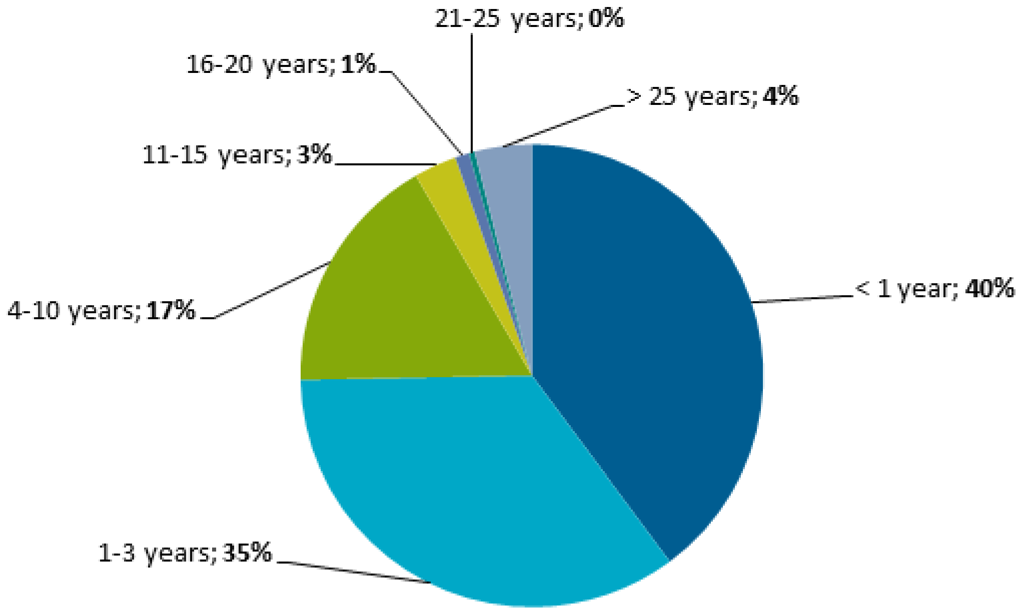
Two major cost components can be clearly distinguished:

5. Costs for elaborating a Scope 3 GHG inventory, reporting, setting reduction targets and
6. Costs for specific measures for the reduction of GHG emissions

However, both components can also provide benefits to the implementing company. Recognition for advanced reporting can raise the company profile with customers, investors and other stakeholders, securing or generating revenue for the reporting company.

Also, GHG emission reductions are often achieved by reducing unnecessary amounts of energy or materials. As these are direct cost-factors for companies, their reduction entail reduced costs, which, over time, amortise initial investment costs and, hence, reduce overall costs to the company. Often, implementation will be dependent upon achievable payback times. In an analysis of all ICT companies reporting to the CDP, it was found that three fourth of implemented reduction activities achieve payback times within 3 years but that also reduction activities requiring longer payback times are implemented (CDP 2014a; see Figure 5-21). Investments with longer payback times may, in fact, also make business sense. Of all Global 500 companies reporting to the CDP and analysed in their 2013 report “77% of companies with at least one investment with a payback time of three years or more state their climate strategy gives them a competitive advantage. Of the companies which do not have long-term investments in emissions reductions, only 54% report a strategic advantage from their response to climate change.” (CDP 2013). However, it is not evident from the data if a direct causal relationship can be implied. Also, with regard to supply chain GHG emissions, some of these benefits typically do not accrue at the level of the reporting company but with other business partners in the supply chain.

Figure 5-21: Proportion of emission reduction investments by payback time among ICT companies reporting to the CDP



Source: CDP (2014a)

In a pilot testing exercise of ICT sector carbon footprint methodologies for the European Commission, participating companies were asked about "workability" and costs of the (one-off) implementation of organisational carbon footprinting. Out of 7 participating companies that provided an answer (European Commission 2013c),

- four reported out-of-pocket costs between 200k and 500k Euro per year, one company reported no out-of-pocket costs, two companies considered this information confidential;
- four companies estimated 1 to 5 full-time equivalents (though it is not clear from the report over what time period), one company reported 7.5 full-time equivalents; additionally four companies reported 10-30 non-full-time people involved in the study;
- full implementation time was estimated at 1 months to 3 years.

However, this pilot study partly involved the testing of several methodologies at once by some companies.

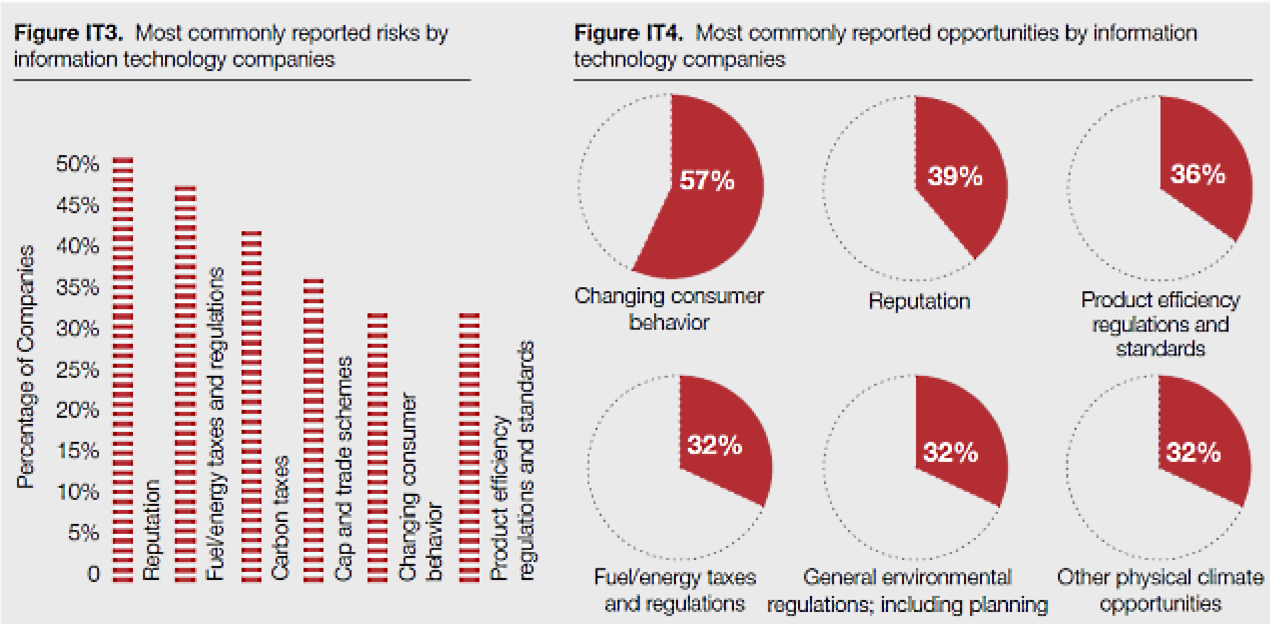
5.2.4.8. Driving force for implementation

Supply chain GHG disclosure and management is attributed to a number of different driving forces: (GHG Protocol, pp. 12)

- Ambition to address possible loss/gain of reputation (reputation is repeatedly stated by companies as a major risk and opportunity with regard to climate change; see Figure 5-22)
- Aim to better understand risks and opportunities associated with GHG emissions
- Demand for disclosure by customers and/or business partners (see for example Figure 5-23 on rising response rate of supplier to GHG disclosure based on increasing number of customers asking for disclosure)

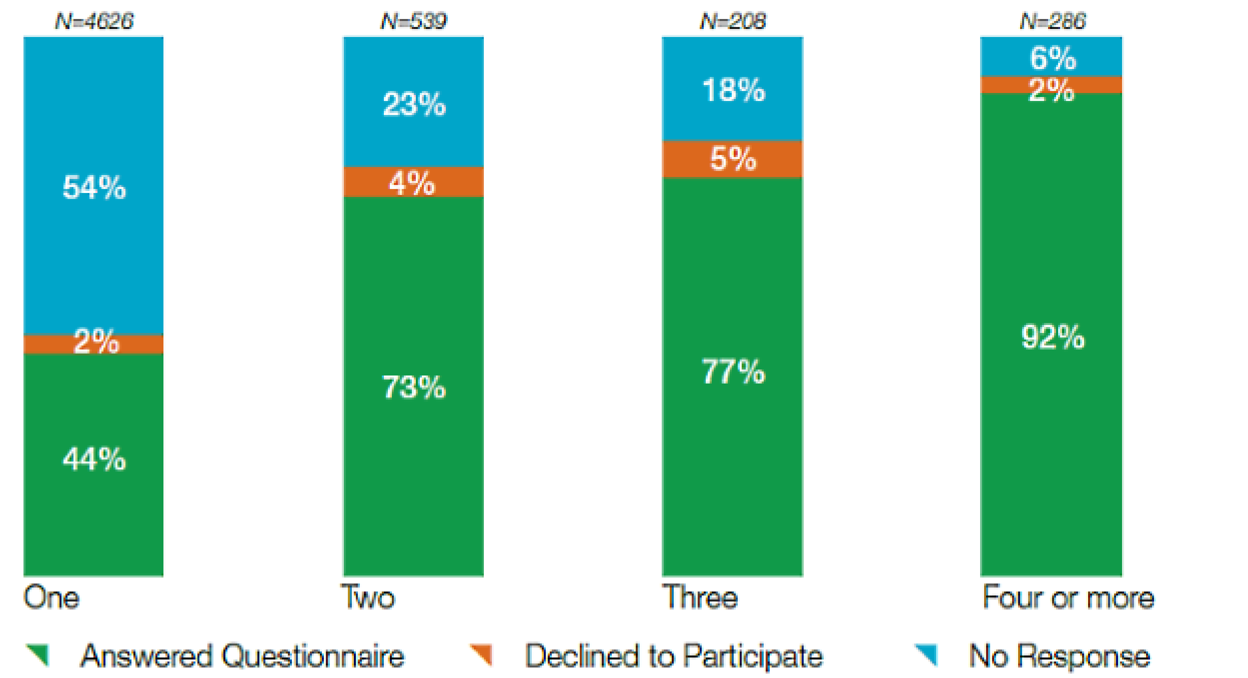
Presumably, also possible future regulation is a driving force for the elaboration of comprehensive GHG inventories.

Figure 5-22: Risks and opportunities from climate change as reported by information technology companies to the CDP Global 500



Source: CDP (2014a)

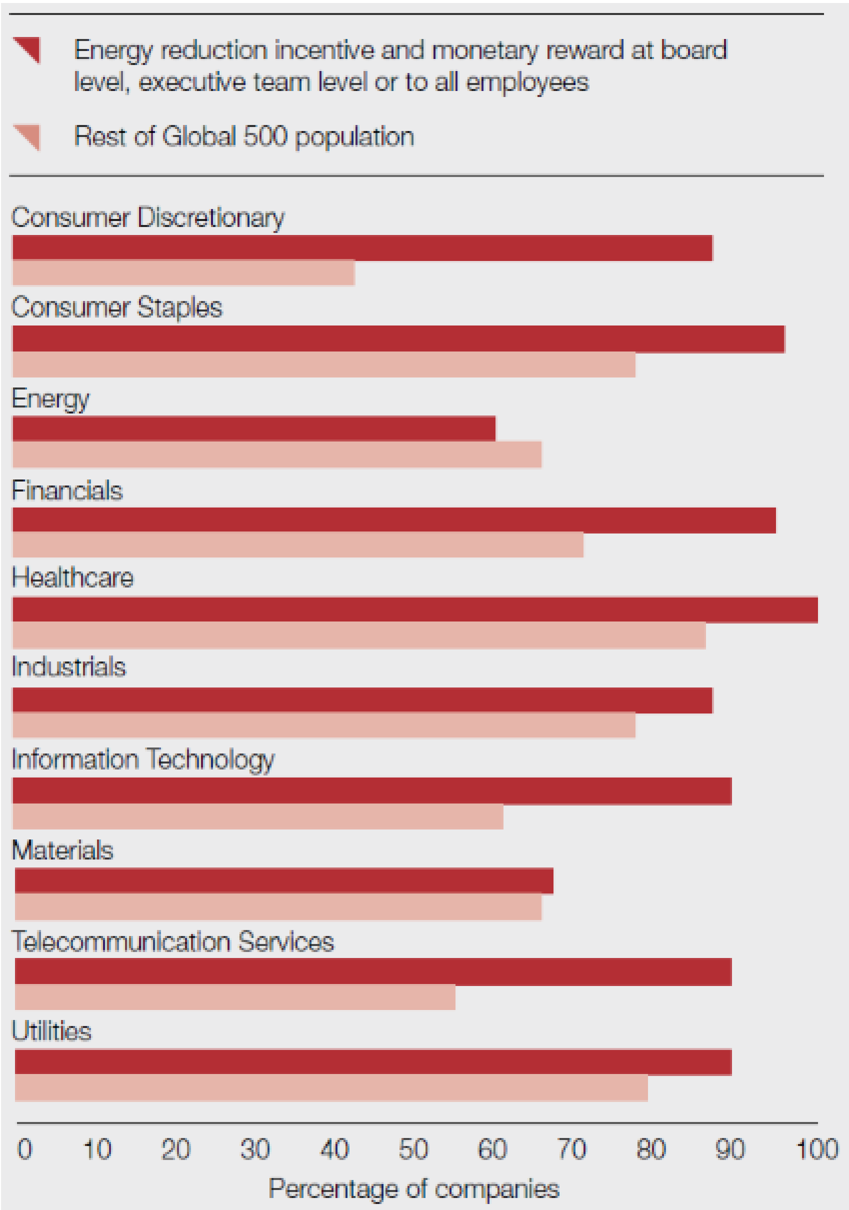
Figure 5-23: Response rate of suppliers based on number of customer requests received



Source: CDP (2014c)

Companies establishing monetary incentives for employees, especially at board and higher management levels are significantly more likely to achieve reductions in absolute GHG emissions. This is demonstrated by CDP analysis on 381 companies reporting to the CDP out of the "Global 500", the largest companies by market capitalization in the FTSE global Equity Index Series: 90% of Information Technology and Telecommunication Service companies having such incentives in place reported emission reductions, while less than 70% of companies in these sectors without such incentives reported absolute emission reductions (see Figure 5-24).

Figure 5-24: Share of companies with and without monetary incentives and reported absolute GHG emission reductions



Source: CDP (2013)

5.2.4.9. Reference organisations

- Cisco: Discloses most Scope 3 categories to the CDP, elaborate supply chain management approach in place
- HP (Hewlett-Packard): Discloses most Scope°3 categories to the CDP
- Sharp: Discloses most Scope°3 categories to the CDP

5.2.4.10. Chapter references

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5.2.5. Conducting Life Cycle Assessment (LCA)

5.2.5.1. Description

For a company that wants to become a green business in accordance with the provisions of EMAS, it is of utmost importance to systematically analyse, evaluate, and improve the environmental performance of its activities. This applies not only to the impacts of company-owned facilities. From a life cycle perspective, the impacts from activities outside the factory gates are also relevant. The environmental performance of a company is often determined by impacts due to processes throughout the supply chain or after the point of sale. The EEE-industry is therefore increasingly motivated to implement Life Cycle Assessment (LCA). This method makes the idea of life cycle thinking operational in a business management context (UNEP 2009). The methodological framework of LCA is specified by the international standards ISO 14040 and ISO 14044 (ISO 2006a; ISO 2006b). In addition, the ILCD handbook provides detailed guidance for the appropriate undertaking of ISO-conform LCAs (ILCD 2010). Sectorial standards facilitate the implementation of LCA for the specific needs of the respective sectors, as they provide a robust framework to increase the transparency of LCA results. The international standard ECMA-341 specifies the life cycle thinking approach for the ICT and CE industry[124] (ECMA 2008). The standard can be regarded a reference for environmentally conscious product design and development. It offers a range of eco-design rules and guidelines specifically for ICT/CE-manufacturers. Within the telecommunication sector, the ETSI standard TS 103 199 provides technical specifications on LCA methods for ICT networks and services equipment (ETSI 2011). The aforementioned standards are compliant to the 14040 series of international ISO standards on LCA. Worth mentioning in this regard is the initiative of the European Commission, notably DG Environment, which together with the Joint Research Centre (JRC IES) and other European Commission services has been working towards the development of a harmonised methodology for the calculation of the Product Environmental Footprint (PEF) as well as Organisational Environmental Footprint (OEF)[125]. By using the life cycle approach, it is possible to compare the environmental impacts of products with alternative design solutions thereof (Horne et al. 2009). LCA offers an analytical framework that is also known as “cradle-to-grave” analysis. Its scope encompasses the materials and energy inputs as well as the emissions along the whole value chain of products (JRC 2012). It takes into account the complete consumption of resources and energy as well as emissions that occur during the production of raw materials (the cradle), the manufacturing processes, transports, the use phase and the end-of-life phase (the grave) of products. Advanced life cycle ideas go even further and consider a closed-loop value chain (“cradle-to-cradle”). This refers to the vision of a circular economy that appeals particularly to EEE manufacturers that find their supply with critical raw materials increasingly constrained. Philips[126], for instance, has been using LCA with great success for eco-design improvements of TV-sets, household appliances, lighting products, and healthcare equipment[127]. A truncated variant of LCA, the so-called “cradle-to-gate” analysis, takes only the production and manufacturing processes into account. The ’gate’ refers to the system boundary of a manufacturer. This variant is often used in the context of EMS to determine environmental aspects of a production site.

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[124] ICT (Information and Communication Technologies), CE (Consumer Electronics)

[125] http://ec.europa.eu/environment/eussd/smgp/dev_pef.htm

[126] http://www.philips.com/about/sustainability/ourenvironmentalapproach/greeninnovation/circulareconomy.page

[127] http://ec.europa.eu/enlargement/taiex/dyn/create_speech.jsp?speechID=19779&key=9aa1f2c85a2d27c1bdb61f68d50d3329

There is no mandatory requirement for businesses to conduct LCA. Nevertheless, many companies evaluate their environmental performance on a discretionary basis. Some companies run LCA programmes as a part of environmental management and audit schemes, such as the European EMAS directive (EU 2009) or the international standard ISO 14001. While these EMS schemes do not prescribe the implementation of LCA, it helps in identifying the relevant aspects that need to be tackled first. LCA assists in making an organization's environmental targets measurable.

The LCA method is applicable as a decision support instrument in the context of the following decision situations (ILCD 2010):

- Meso/macro-level decision support: strategic planning,
- Micro-level decision support: design and planning of products, facilities, and processes,
- Accounting: monitoring the environmental performance of companies or sectors.

In regard to strategic decisions, LCA can be used complementary to statutory planning procedures, such as Environmental Impact Assessment (EIA). The system approach of LCA allows a comparison of process alternatives or abatement choices in regard to their "indirect effects" (Tuker 2000). Indirect environmental impacts usually occur outside the boundaries of a company's own facilities. Therefore, the use of LCA broadens the scope of EIA, providing that environmental improvements of production processes do not go at the expense of increased environmental burdens beyond a site-specific system boundary (Guinée 2002).

Decision support at the micro-level represents the most relevant application area of life cycle assessment in industry. It is also used in the context of environmental management, cleaner production, green procurement, and in the product design process (Cooper & Fava 2006; Kloepffer 2008). LCA makes it possible to systematically analyse the inputs and outputs of production processes and the environmental impacts thereof. Assessing the whole life cycle helps to avoid short-sighted environmental management decisions[128].

Many users of LCA state that the assessment does not only reveal environmental improvement potentials but also unleashes economic benefits due to optimization of production technologies, logistics, and procurement. For example, the saving of energy and consumables in EEE manufacturing does not only reduce waste and emissions but also contributes significantly to saving costs and fines.

In eco-design, the application of LCA provides intelligence for environmentally conscious selection of materials, manufacturing technologies, energy saving measures etc. It is thus possible to create more competitive products through a higher eco-value and lower environmentally liability. It is important to note that the implementation of LCA does not automatically improve the environmental performance of a company and their products. It serves as a knowledge support tool that can enhance environmental intelligence and trigger actions for improvement. "*The conclusion from an LCA could point to the aspect of a product that is responsible for generating the most significant environmental impacts. Consequently, the manufacturer and product designer are able to identify that aspect quickly, and then focus on it to seek ways of improving the product*" (ETBPP 2000).

[128] For instance, eliminating an energy-intensive production process by procuring pre-manufactured materials would create little environmental advantage. The environmental impacts of energy consumption would only be transferred geographically along the supply chain to countries with lower environmental standards.

Another application area of LCA in businesses refers to environmental reporting and green marketing. LCA offers a standardised and transparent method to substantiate marketing claims regarding the environmental product performance in form of CSR[129] reports, eco-labels, and Environmental Product Declarations (EPD).

Accounting LCAs are used in the framework of corporate environmental management schemes (EMS), such as EMAS and ISO 14001. These standardised environmental management procedures do not require LCA per se, but its implementation "*can assist the identification and minimization of the environmental effects of a company's operations*" (ETBPP 2000). Enterprises often conduct cradle-to-gate LCAs to identify the relevant environmental aspects of their own operations. Iterated implementation of LCA helps monitoring the success of measures aiming at continuous improvement of a company's environmental performance. In this context, LCA serves as a controlling instrument that makes continuous environmental improvements[130] measurable.

In summary, LCA can be used to analyse specific details regarding the environmental impacts of a company, but more important is the adoption of Life Cycle Thinking (LCT) in the first place. LCT provides the general life cycle perspective on environmental performance – this is a qualitative approach with no need for quantitative analysis. Thinking about the whole life cycle of products can be a huge source of inspiration towards new innovative solutions, which are not only beneficial for the environment but also for the business success of a company.

5.2.5.2. Environmental benefits

LCA is usually a part of the environmental management process. Companies can use LCA to better understand the environmental aspects of their products and the value creation process. It provides a number of relevant insights in environmental aspects and helps prioritising them in order to allocate resources for environmental improvements. Conducting LCA brings about indirect competitive advantages too: it is a means to demonstrate seriousness regarding corporate environmental policies and enhances green brand reputation. It also helps to identify and maintain green competitive advantage or to find the own position on the market (Andreä 2014). Front-runners on the market may use LCA to determine the difference in eco-performance of their products to the competitors' ones. LCA can also serve as a monitoring and control tool in the context of sustainable product design (Klaffke et al. 2000). In this respect, the life-cycle perspective helps avoid shifting environmental problems from one stage in the product related value chain to another one. It can also contribute to analysing and evaluating trade-offs between the environmental implycations of different design alternatives. Making conscious decisions of environmental relevance in how to deal with such trade-offs (e.g. one material versus another, saving product weight by using critical materials) is a major advantage of using LCA as a decision support tool.

Frontrunners in LCA application use the tool not only for a single purpose but rather in support of strategic decisions in the environmentally conscious management of a company. Huawei, for instance, considers LCA as an essential tool to advance in its aspiration towards progressing in a circular economy (Andrae 2014). Philips is to be mentioned as a frontrunner in implementing the principles of circular economy, which are a strong incentive for using LCA in support of eco-design. LCA facilitates the environmentally conscious product development and supports environmental management by more comprehensive insights in environmental aspects of a company and its products (Apple 2014). LCA helps to focus on the mitigation of most relevant environmental

[129] Corporate Social Responsibility

[130] The continuous improvement of an organisation's environmental performance constitutes the central proposition of both environmental management schemes, EMAS and ISO14001.

impacts and avoids misallocation of resources. To this end, the use of LCA can directly benefit the environmental performance of a company.

In the context of the EEE industry, LCA can be used to:

- Identify ‘significant environmental aspects’ and understand their nature (direct or indirect ones),
- formulate objectives and setting targets for the improvement of a company’s environmental performance,
- identify the important environmental impacts of products and support environmentally conscious design / re-design,
- monitor indicators of environmental performance and control progress towards their continuous improvement,
- substantiate the environmental reporting and stakeholder communication of a company.

The implementation of LCA does not per se lead to improvements in a company’s environmental performance. Rather, the implementation of LCA is instrumental for environmentally conscious decision making as it provides new insights and substantiated intelligence. It is therefore not useful to measure a company’s environmental performance by counting the number or ratio of LCAs conducted in a certain management process.

5.2.5.3. Appropriate environmental performance indicators

LCA can be used for monitoring and controlling of the environmental performance. The choice of appropriate indicators depends on the objectives behind the environmental policy of an organisation. Many EEE companies use mid-point indicators such as ‘Global Warming Potential’ (GWP) or aggregated scores such as “Product Carbon Footprint” (PCF) as a proxy for the most relevant environmental pressures. These indicators represent the environmental impacts that result from the generation of electrical power, which is consumed by EEE products (Apple 2014; Ruminy 2014).

The robustness and transparency of LCA results depends on both, the use of a standard conform LCA methodology and the use of high-quality input data sets. Both aspects are crucial indicators for the quality of any LCA project. However, the required quality of results depends on a company’s motivation for applying an LCA in the first place. Robustness and transparency are often not considered a primary concern if internal decision making (e.g. environmental management or eco-design) is the primary purpose. In these cases, an iterative LCA approach (that is, starting with a rough estimate of data and simplified methodology) is just the right choice. Conversely, the requirements on robustness and transparency are much higher, if public communication and marketing via environmental product claims is the purpose of conducting an LCA. In the latter case, the LCA must cohere to the provisions of the international ISO 14044 standard, which (among others) requires a critical review by external LCA experts. Apple, for instance, has published product environmental reports for each major product on its website[131].

[131] http://www.apple.com/environment/reports

5.2.5.4. Cross-media effects

Cross-media effects might arise as a result of the choice of a LCA practitioner in terms of the scope, system boundaries, cut-off criteria, allocation rules and other methodological considerations. For instance, the climate change indicator (or GWP) is the most common impact category amongst product-oriented methodologies. Many methodologies that cover other impact categories set specific focus on this indicator, e.g. ETSI TS 103 199 requires that GWP is mandatory, while other categories are optional. For ISO 14040/14044, the impact categories to analyse depend on the goal and scope definition. For many products, GHG emissions are not the most significant environmental pressure, therefore neglecting other environmental impacts might lead to biased results.

Another source of variation in the LCA results is related to the selection of data types. For instance, PAS 2050 and GHG Protocol standards require primary data for processes under the control of the organization carrying out the study. PAS 2050 additionally requires primary data from suppliers if the processes under the organizations control account for less than 10% of the upstream emissions. Thereby, it should be ensured that at least 10% of the cradle-to-gate emissions are based on primary data. The IEC TR 62725 encourages communicating with direct suppliers on possible supply-chain cooperation for primary data. When using secondary data, important differences in the overall results can result from the different data sets used for upstream processes (e.g. data for precious metals and high-purity materials). The use of these data sets is not always transparent in the published results. Public data sets for upstream processes (e.g. raw material acquisition) and some additional modules (e.g. transport and electricity) would help to improve the transparency and overall comparability. In this regard, the JRC provides a specific hierarchy for LCI databases to be used for generic emission data. This hierarchy puts commonly used commercial/property databases such as EcoInvent or the databases from EIME/Gabi at a relatively low level (after public databases). According to the JRC PEF Guide, specific data shall be obtained for all foreground processes (i.e. core processes in the product life cycle for which direct access to information is available) and for background processes (i.e. those processes in the product life cycle for which no direct access to information is possible), where appropriate. However, in case generic data is more representative or appropriate than specific data (to be justified and reported) for foreground processes, generic data shall be also used for the foreground processes. Generic data should be used only for processes in the background system, unless (generic data) are more representative or appropriate than specific data for foreground processes, in which case generic data shall also be used for processes in the foreground system (Prakash et al. 2014).

Thus, robustness and reliability of LCA depends to a large extent of methodological choices and selection of data types as well as data bases.

5.2.5.5. Operational data

Approaches of easy LCA implementation

For a company, the definition of objectives and goals is the most important starting point before a decision on whether to apply an LCA or not is made. Companies need to sort out what they want to learn from it and what purpose they need the results for (e.g. eco-design, compliance management etc.) This influences the kind of LCA to conduct (and the costs of it) (Andrae 2014).

There are numerous approaches and tools that help companies in overcoming the aforementioned difficulties of conducting a full-scale LCA. Practitioners can take advantage of simplified LCA screening tools and ready-made databases that mitigate the difficulties of full-scale LCAs. Below, these tools are portrayed in more detail.

Free and commercial LCA software,

Life cycle inventory databases: repositories for ready-made data of materials and processes,

Fast-track LCA methods that allow streamlined impact assessments of products.

Free LCA-software tools

These LCA tools are freely available online and promise easy applicability for practitioners.

Ccalc V3.3 [132]	Carbon Footprinting tool for users in various industry sectors
Ecolizer 2.0 [133]	An LCA-based booklet tool for designers to estimate environmental impacts
EIOLCA [134]	Economic input–output LCA using macro-economic data of the EEE sector
eVerdEE [135]	Tool developed by the EcoSMEs project (2004), Guidelines for EEE industry
LCA-to-go [136]	EEE sector-specific online tool developed by the LCA-to-go project (2014)
Life cycle analyses tool [137]	Simple generic LCA tool with an intuitive user interface
LiMaS [138]	LCA web-suite developed for companies in the sector of energy-related products (ErP) and electrical-electronic products (EEE)
OpenLCA [139]	Full-scale open source LCA software developed by GreenDelta

Proprietary LCA-software tools

The three market-leading tools are suited for full-scale LCAs:

- Gabi [140] proprietary full-scale LCA software provided by PE international: product and process chain analysis.
- SimaPro [141] proprietary full-scale LCA software provided by PRé Consultants: based on a hierarchical product tree concept.
- Umberto [142] proprietary full-scale LCA software provided by ifu Hamburg GmbH: based on the material-flow analysis concept.

Life cycle inventory (LCI) databases

Access to primary data about the product life cycle is often a point of concern. Companies should be able to request information from their suppliers, e.g. bill of materials (BOM) or aggregated LCA-based indicators (KEPIs). These data can, besides LCA, also be useful for other purposes, such as product development. Often, the data are available from technical datasheets and need to be converted into LCA input variables. Companies should therefore, before they start with supplier

132 http://www.ccalc.org.uk
133 http://www.ecodesignlink.be/en/tools/ecolizer-1
134 http://www.eiolca.net
135 http://www.ecosmes.net/everdee/login2?idlanguage=null
136 http://www.lca2go.eu
137 http://design-4-sustainability.com/life_cycle_analyses
138 http://www.limas-eup.eu
139 http://www.openlca.org http://greendelta.com
140 http://www.gabi-software.com/index
141 http://www.pre-sustainability.com/simapro
142 http://www.umberto.de/en

inquiries, undertake a literature screening for generic data that are readily available. Of course, companies need to put some efforts into data collection and questioning the key suppliers if possible. Templates for supplier questionnaires are an adequate approach to keep the efforts within reasonable limits.

Depending of the goals of the LCA, one can accept some gaps in life cycle inventory data.

Ideally, LCA calculations should take reference to primary LCI data (information retrieved from sources within a company and from its suppliers). However, access to primary data is often difficult or unviable. As a surrogate, primary data gaps can be filled with secondary data from LCI databases. Such data sets contain generic information on numerous industry-relevant semi-finished materials and background processes. Secondary data can be used in an LCA, if the data descript-tion corresponds more or less to the situation in reality (e.g. an alloy purchased from a supplier).

- European reference Life Cycle Database (ELCD)[143]: contains reviewed LCI data for a range of materials, energy carriers, transport, and waste management processes.
- Idemat database[144]: Free datasets in form of excel files that contain generic component inventories of more than 6000 substances and components. For each item, three indicators are shown: Eco-costs, product carbon footprint (PCF), cumulative energy demand (CED).
- ProBas[145]: Free German LCI database that contains 37 LCI data of semiconductor processes.
- GABI database (proprietary LCI database): contains 211 LCI data sets of electronics processes and components (coil, diodes, ICs, PWBs, solder pastes, capacitors, transistors, LED SMDs, resistors, ring core coils, FR4 substrates, thermistors and others).
- Eco-Invent (V3)[146]: proprietary, reviewed LCI database provided by the Swiss Eco-Invent association.

Streamlined LCA methods

LCA software is used to master the complex arithmetic of any LCA calculation. The complexity stems mainly from the enormous amount of inventory flow data that has to be computed, if all environmentally relevant inputs and outputs (inventory model) are to be considered in a cradle-to-grave analysis. The interpretation of results from such a complex LCA calculation is often not easy and requires expert knowledge. Streamlined LCA methods offer simplified solutions for LCA practitioners. Streamlining means short-cutting some of the highly data-intensive calculation steps by using heuristics or pre-calculated proxy data (fast track approach).

The LCA-to-go tool

The LCA-to-go approach uses sector-specific heuristics based on knowledge from previously conducted LCAs on electronics and photovoltaics products. Built upon an 80/20 paradigm, the LCA-to-go concept reduces the methodological complexity of LCA and yields results that are not fully accurate but nevertheless 80% right. This requires the user to invest only 20% of the efforts that are typically needed to create a full-scale LCA. The results of this simplified LCA-approach can already point at the most relevant environmental aspects with moderate accuracy. In practice, SME can make environmentally conscious decisions with an approximate comprehension of key-

[143] http://eplca.jrc.ec.europa.eu/ELCD3 (available as zip package)
[144] www.ecocostvalue.com (open the link "data" and download the xls file)
[145] www.probas.umweltbundesamt.de
[146] http://www.ecoinvent.ch

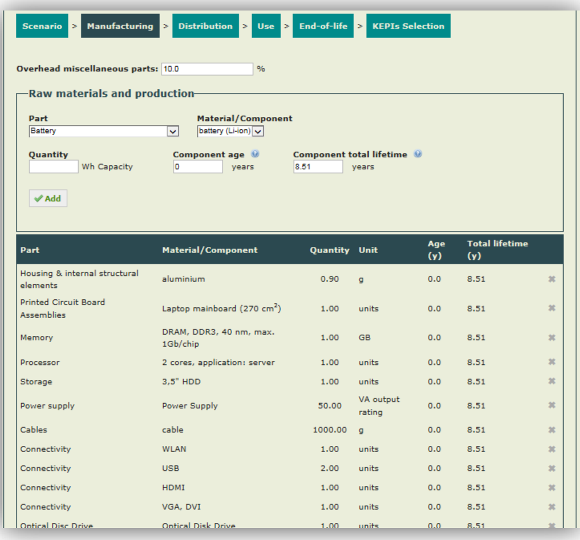
aspects instead of exact knowledge in all details. This is enough intelligence for internal decision making to trigger actions towards environmental improvements.

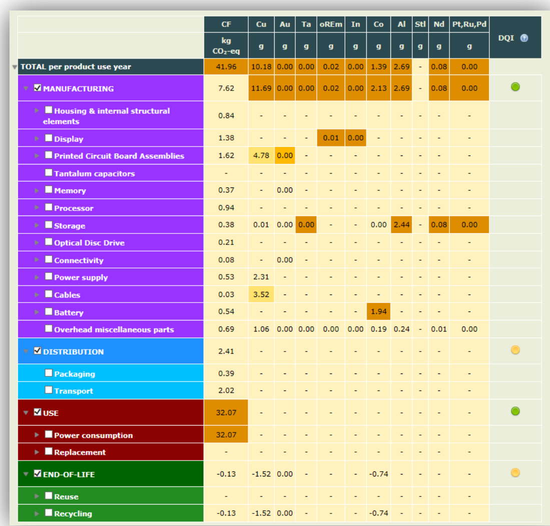
The LCA-to-go tool is an open source LCA web-suite catering to the specific needs of companies in six different industry sectors. Tailored web-suites for the electronics industry and the photo-voltaics (PV)-sector are freely available upon registration. The LCA-to-go tool is built upon a needs-driven environmental assessment approach that pays foremost attention to the needs of SMEs. The LCA-to-go approach makes LCA more feasible in business practice and offers sufficient decision support in product design and supply chain management (LCA-to-go 2013).

The respective web-suites for the electronics and PV sectors are designed differently. Users are to enter sector-specific input data, such as technical parameters of products, which are often provided by suppliers of components and materials. This information is typically available to skilled persons such as products designers or project planners. The input data are to be inserted in a straight-forward designed user-interface and computed on the basis of scientifically verified calculation rules. The results are displayed on a result page and can also be graphically visualised (Figure 5-25).

A number of electronics equipment and component manufacturers have participated in the LCA-to-go mentoring programme. These SMEs report on their experiences with the application of the LCA-to-go tool on the project's website[147]. The tool helped them to evaluate eco-design ideas and select the most promising options for further developments. It also served to resolve trade-offs in environmental performance aspects that emerged in the course of eco-design projects regarding their products. Mr. Krzaczek of Semicon, a polish PCB manufacturer said: "*The tool is very easy to use and it will help us to estimate the carbon footprint of our products if will be such an enquiry from clients.*" (LCA to go 2014).

Figure 5-25: Screenshots of the LCA-to-go web-suite for the electronics sector





Left side: data input page **right side: results page**

Source: www.lca2go.eu

[147] http://www.lca2go.eu/sectors,electronic.en.html

Eco-costs – *a fast-track LCA method*

Vogtländer et al. (2001) conceived the eco-costs method as a 'fast-track' approach to LCA. The prevention-oriented eco-costs concept takes into account the monetary value of the environmental burden of products. The Eco-costs method generates a single indicator that is easily comprehensible for product developers and business decision makers, since the results are expressed in Euro. The 'fast-track' LCA approach is designed to be used in the specific decision context situation of the product design process (Vogtländer et al. 2009).

The eco-costs concept is an LCA-based indicator for the cumulated environmental burden throughout a product's life cycle "from cradle to cradle". Eco-costs embody a single indicator concept that interprets the LCA results from a prevention-oriented economic perspective. The method is grounded on the concept of "marginal prevention costs" and is fully compatible with the provisions of ISO 14040 and ISO 14044. Eco-costs are calculated on the base of LCA results in the impact categories global warming, acidification, eutrophication, summer smog, fine dust, eco-toxicity, and resource depletion (natural resources and energy).

eco-costs total = eco-costs emissions + eco-costs energy + eco-costs materials depletion

Since the abatement of these environmental impacts entails economic costs, it would be wise to prevent such impacts before they occur. In this sense, the eco-costs represent virtual abatement costs that would occur if the environmental burden of a product were to be limited to a sustainable level. That means, pollution and materials depletion should be brought in line with the earth's estimated carrying capacity before any damage to the environment takes place. This can be done, for instance, by investing in cleaner production technologies or by a system of integrated management solutions. However, the required prevention measures are currently not yet fully integrated in the life cycle costs of the product value chain (the current Costs). Eco-costs are thus the polluter's "neglected obligations" to prevent environmental impacts. They must not be confused with "external costs" (which are costs incurred after environmental damage has occurred). Such costs are considered externalities, as the business calculation of product life cycle costs usually neglects them. The character of prevention measures is that the costs of prevention will counterbalance the damage costs of environmental pollution (e.g. costs related to human health problems). Hence, the overall effect of all prevention measures on our society is that it results in a better environment at virtually no extra costs, since costs and savings will level out (Vogtländer et al. 2001; 2002).

Eco-costs are easily understandable and intuitively comprehensible by non-LCA experts as they express a standardized monetary value (€). Eco-costs allow for a fast-track analysis of the environmental performance of a product in respect to its consumption of materials and energy as well as emissions throughout the life cycle of the product.

Carbon footprinting

A streamlined LCA may focus on one environmental impact category instead of a full set of different ones. The concentration on a single environmental impact category reduces the methodological complexity. Results of the streamlined LCA are less accurate (it is possible to miss out relevant impacts). On the other hand, the results are also less ambiguous and therefore easier to interpret and communicate. The most relevant impact category is the carbon footprint, i.e. the total amount of greenhouse gas emissions of a company or a product.

The product carbon footprint encompasses the direct and indirect emissions of greenhouse gasses that can be associated to the whole life cycle of a product. It is often used in the EEE industry to benchmark products.

5.2.5.6. Applicability

Most of the large electronic OEMs conduct in-house LCAs to analyse the environmental burden of selected products. They usually employ skilled staff under the umbrella of environmental management teams. This necessitates a longer period of capacity building and full commitment of the top management. HP, for instance, has conducted and published LCAs on printing equipment and processes in order to understand which components and materials result in the most significant life cycle environmental impacts, and to calculate product carbon footprints[148]. HP uses LCA results as an element of decision support metrics for product developers to compare design and technology alternatives and chose the environmentally best performing option. Apple employs a team of LCA experts who investigate the environmental impacts concurrent to the product development. LCA is carried out once that design features are specified and prototypes of new products become available (Apple 2014). Other companies contract independent consultants to conduct LCAs on a case-to-case basis. External sub-contractors may have a higher proficiency in using LCA tools and databases and they might approach the assessment with an unbiased view at routines and habits in a company. The latter aspect can lead to fresh insights and unveil surprising improvement potentials for environmental, but also process- or management-related aspects. On the other hand, external consultants may facilitate in the communication process between employees and suppliers.

Small and medium sized enterprises (SME) have less internal resources to conduct LCA. Only 10% of the SMEs in the electronic sector have already conducted LCAs although most of them have positive attitudes towards environmental protection. About 40% of European electronics SMEs are familiar with environmental management schemes (ISO 14001 or EMAS). Reasons for not using LCA are a shortfall of available time during the product development process and the paucity of resources (e.g. skilled workforce). They also point to the lack of data about the complete life cycle of their products (Pamminger & Schischke 2011).

The methodological complexity of LCA is often considered as a barrier for application in businesses, especially SMEs. Interested practitioners often face difficulties to master the methodological concept of full-scale LCA appropriately, such as scope, functional unit, system boundary, and allocation. This is particular difficult for manufacturers of EEE products since they are created in multi-staged value chains. Moreover, collecting primary environmental data is often difficult for a company. The implementation of full-scale LCA necessitates collecting data from various sources, such as production and procurement, but also suppliers (e.g. components) and providers (e.g. energy). The emissions generated by manufacturing facilities are taken into account as well as those occurring in the supply chain, during transportation, use, and recycling phases of products. The compilation of this data is the most time-consuming part of a full-scale LCA project, because environmentally relevant information from in-house processes and suppliers is usually not readily available.

Against this background, there is a trend among large EEE companies to rely on LCA-based heuristics in decision-making, i.e. on condensed wisdom originating from results of numerous LCAs conducted previously (Rüdenauer et al. 2004; Andreä 2014; Swanstrom 2014). The heuristic approach works well for manufacturers of electrical appliances and household goods because such products are seldom subject to radical technology changes. The most important LCA-based heuristics for eco-design of EEE products are:

- Lower the power consumption of the product during its use phase,

[148] http://www.hp.com/hpinfo/globalcitizenship/09gcreport/enviro/design/lifecycle.html

- Phase out hazardous substances and components.
- Extend the service life of products (exception: if a new technology becomes available that helps to significantly reducing power consumption).

5.2.5.7. Economics

The costs of LCA depend on the objectives of the company that want to conduct an environmental analysis. In economic terms, the direct costs can be separated into the following aspects:

- costs of workforce (skilled staff is necessary to collect primary life cycle data and to undertake the data analysis and interpretation of results),
- costs of software licences (licence costs of € 5,000 to € 10,000 for full versions of commercial LCA software, free open source software is available as well. See section 5.2.5.5)
- costs of secondary data sets (licence costs of € 2.000 to € 3.000 for commercial LCI databases) (usually included in commercial LCA software).
- costs of external consultants (if any) and external reviewers (if any).

There are large ranges in each cost factor, depending on the quality requirements of LCA which, in turn, are subject to management decisions regarding purpose and intended use of the results. Moreover, the complexity of the analysed product, system, or process determines the costs.

At the upper end of the range, a robust and high-quality (fully ISO 14040 conform) LCA project for an average product may consume between 30 and 40 full working days for skilled LCA experts. Some large companies, such as Apple, Huawei, and Philips etc. employ internal LCA experts whereas other companies work with independent consultants that are specialized in the task and have access to LCA software and commercial life cycle inventory data sets. As a rough estimate, the price range of specialized LCA consultants ranges between € 13.000 (for a rough scoping study) and € 60.000 (for a comprehensive) LCA project.

On the other hand, LCA does not necessarily have to be a costly undertaking for businesses. Free LCA tools and databases are available online (see “Free LCA-software tools” in section 5.2.5.5). Simplified methods, such as the LCA-to-go concept, make it possible to get started with LCA without large investments in training of workforce, staff costs and licences. At any rate, many companies that have used LCA, stated that – in any way - a positive return on investment for LCA implementation was recorded.

A quantification of direct economic benefits in terms of revenue is, however, not feasible. Benefits are created rather indirectly, for instance in form of management intelligence, avoided bad investments, and improved stakeholder communication. In particular market-leading companies add a lot of credibility to their brand value if they base the reporting of environmental performance indicators on LCA results.

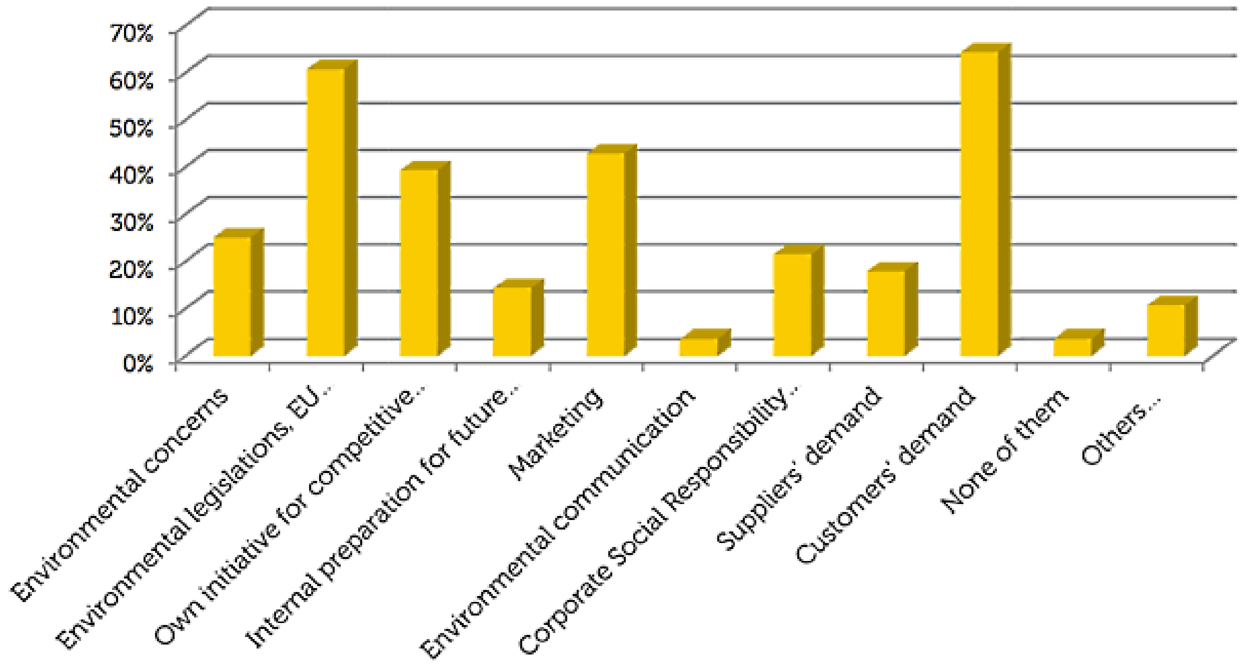
5.2.5.8. Driving force for implementation

What motivates small and medium sized enterprises (SMEs) of the European electronics industry to implement LCA has been investigated by the LCA-to-go project[149]. Findings suggest that environmental regulations and governmental policies are the strongest driver for firms to analyse

[149] www.lca2go.eu. The LCA-to-go project, 2011–2014, was financed under the European Union's Seventh Framework Programme.

their environmental aspects. Large EEE-manufacturers are under growing scrutiny by environmental authorities and stakeholders. The use of life-cycle approaches is perceived as one element of corporate responses to their environmental producer responsibility. Marketing is a further reason. LCA is widely accepted as the best available method to substantiate green product claims. Component suppliers more and more frequently receive requests from their business-to-business customers to provide environmental factsheets, so-called Environmental Product Declarations (EPDs). End-consumers of EEE-products are increasingly interested in environmental information as well. The publication of selected LCA-based environmental performance can help to make continuous improvements visible and boost the brand reputation. Substantiated LCA results can also serve as a strong argument in defence against stakeholder scrutiny (Andreä 2014).

Figure 5-26: Drivers for environmental assessment (SMEs of the electronics sector)



Source: Pamminger & Schischke (2011, p.59)

5.2.5.9. Reference organisations

The following case studies were derived from questionnaire-based phone interviews with representatives of the respective companies. The interviewees were selected with view to their job position and experiences (i.e. environmental manager, LCA expert).

<u>ABB</u>

From the beginning, the implementation of LCA was promoted by ABB's environmental management system and the persons responsible for its implementation. LCA is considered a valuable tool for organisational learning and professional training of engineers and technical staff in the company. It is seen as an organisational learning exercise that helps to better understand the environmental implications of operations and products. Thereby it is deemed instrumental for the facilitation of incorporated knowledge and awareness about environmental aspects rather than a tool for day-to-day usage. Nowadays, LCA is carried out by experienced staff if there is a demand, and the results are taken into the general body of organisational knowledge (e.g. check-lists that are used by staff members in daily business). Training of product developers and process

engineers with LCA heuristics is considered particularly important. In this context, the application of quick-LCA tools is very appropriate to help people understand the environmental hot-spots. Simplified LCA methods reduce the complexity and facilitate learning even if the results are not 100% accurate (Swanstrom 2014).

Apple

Apple uses LCA for internal decision making in the context of environmentally conscious product design and allocation of resources for this purpose. An important objective of applying LCA is the support of eco-design. LCA yields more comprehensive insights and data of environmental aspects, and provides information on the environmental relevance of materials and products. It also allows better monitoring and documentation of achieved improvements in environmental performance of products. LCA is a useful tool for benchmarking the Product Carbon Footprint of different products in the company's portfolio. At the bottom-line, the cost benefit ratio of LCA implementation has been positive. On its website[131], Apple publishes product environmental reports that explain the key environmental aspects for each product. The reports, covering the major series of Apple products, present LCA-based figures that underwent a critical review by independent external reviewers (Apple 2014).

Bosch und Siemens Hausgeräte GmbH (BSH)

BSH has a long-standing experience with LCA since the 1990s when the first pilot LCA projects were conducted. The motivation to conduct LCA is explained by the environmental policy of the company: the production of household appliances with a good environmental performance. It enables BSH to monitor and control the progress in environmental performance and benchmarking of their own product generations. LCA helps to make an objective evaluation of environmental targets. It can also be used to simulate the success of technical measures to improve the eco-performance. In the segment of household appliances it is not useful to repeat the LCA for each new product generations, because the major impacts will stay the same. Ninety percent of impacts occur during the product use phase due to energy consumption. Therefore, BSH relies on heuristics that draw experiences from many LCAs conducted in the past. If LCA is conducted nowadays, then it is done ex-post to the new product development process to check whether the chosen technologies or designs are in line with the companies' environmental improvement targets. Making reference to their long application history, LCA-practitioners at BSH summarise their experiences as follows: "Use LCA as a learning exercise and don't make a science out of it, rather start with simplified LCA tools to identify the hot-spots" (Ruminy 2014).

Huawei

The driving force for LCA implementation at Huawei is the company's environmental policy. This is to respond to customers' requests (network operators) and to meet regulatory requirements. Compliance to existing regulations and standards is as important as acting in advance of expected compliance schemes in future. Huawei aims at proactive compliance to coming EU regulations and policies, such as the EU Commission's PEFCR programme. Huawei's goal is to conduct LCAs for 10 types of products per year. However, LCA is only a tool among others – what matters is the goal of environmental improvement: making the shift from a linear towards a circular economy (Andrae 2014b).

Royal Philips N.V.

In the past, Philips – Consumer Lifestyle has used LCA extensively to measure the environmental impacts of products in "Green Focal Areas" (energy efficiency, packaging, hazardous substances, weight, recycling and disposal, and lifetime reliability). At present, Philips CL is moving beyond LCA by extracting the knowledge from previous LCA projects in form of heuristics. This approach

involves the use of Key Environmental Performance Indicators (KPIs), specifying sales targets for Green Products on every product category (Presently, 30% of a certain product category needs to meet Philips internal Green Product requirements). The KPIs encompass a set of self-imposed requirements for Green Products, which are defined by the central CL sustainability team, and based on discussions with the respective innovation teams. The use of KPIs makes it more tangible for the innovation teams to integrate environmental performance targets into innovation projects for Green Products. Philips CL aims at leadership in at least one Green Focal Area compared to industry standards, which is defined by a sector-specific peer group. The target is to surpass the environmental performance of best-in-class products or standards by at least 25%. Philips CL implements product-specific eco-design requirements in advance of regulation and complies with internationally recognized eco-performance labels (de Olde 2014).

In regard to a more environmental benign mode of manufacturing, Philips CL cooperates with EcoChain LC[150] to expedite the implementation of life cycle assessments. EcoChain has developed a simplified LCA methodology[151], which offers a cost-efficient way of conducting environmental assessments in support of process management and strategic choices, such as investment decisions. The EcoChain tool is now tested in a pilot project at Philips' production site Drachten (NL). Thus far, the pilot has mapped the factory processes with input, process & outputs. The tool determines the environmental impacts for each part of the manufacturing chain. The primary environmental data from manufacturing operations are fed into the "sustainability reporting and validation tool" and used to calculate the impact per individual product.

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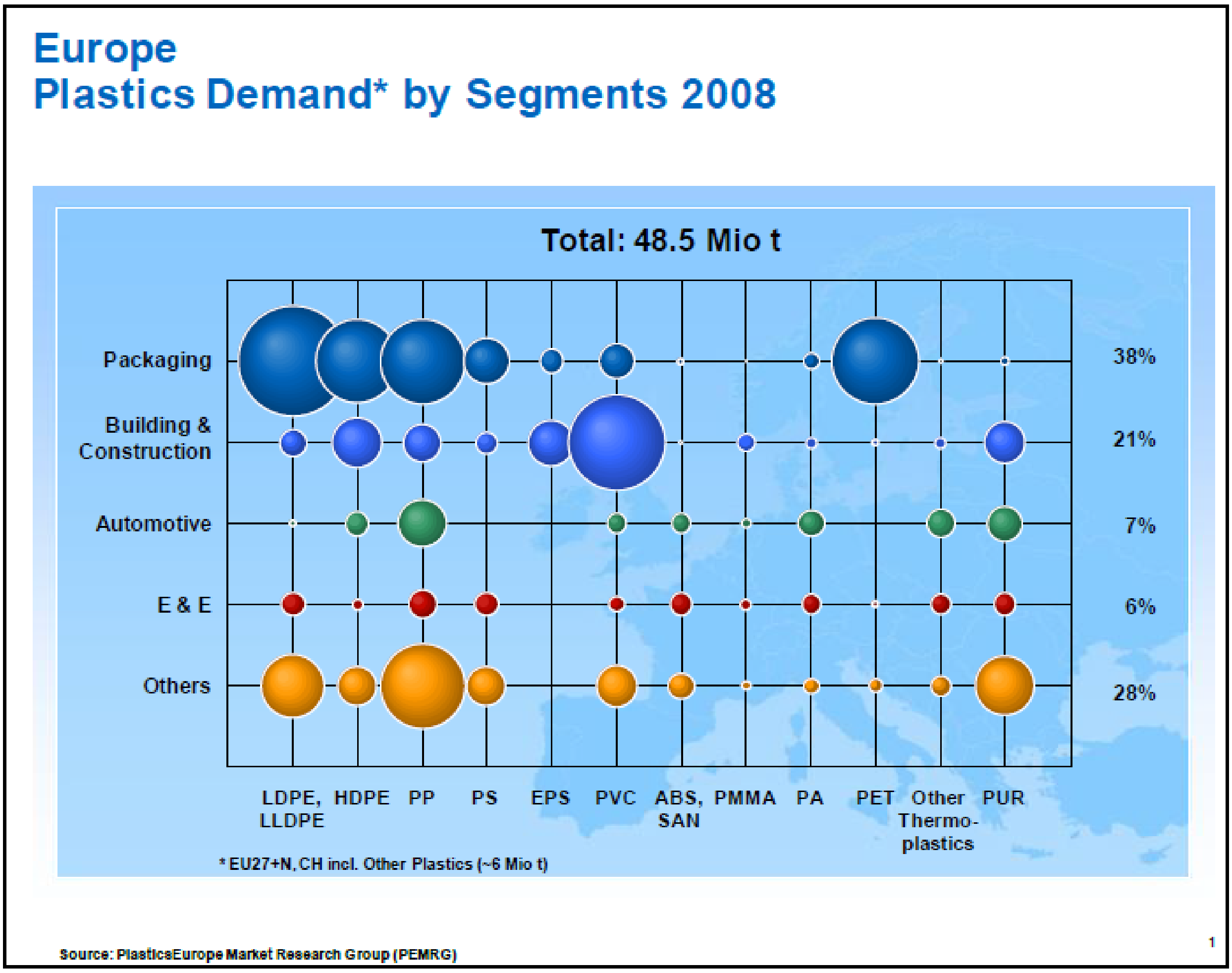
5.2.6. Increasing the content of recycled plastics in EEE – Case study of closed-loop recycling process for polyethylene terephthalate (PET) and polypropylene (PP) plastics in inkjet printing cartridges

5.2.6.1. Description

According to Plastic Europe, 245 million tonnes of plastic was produced worldwide in 2008 (EuPC 2009). Out of that, 48.5 million tonnes was processed in Europe. The following figure shows the consumption of plastics in various branches and according to plastic types in Western Europe. The total consumption of the EEE was about 7% (approx. 3 million tonnes). It shows that EEE does not play a significant role for all the plastic types. Important plastic types in EEE are PS, ABS, PMMA and PA (Sander & Wirth 2012).

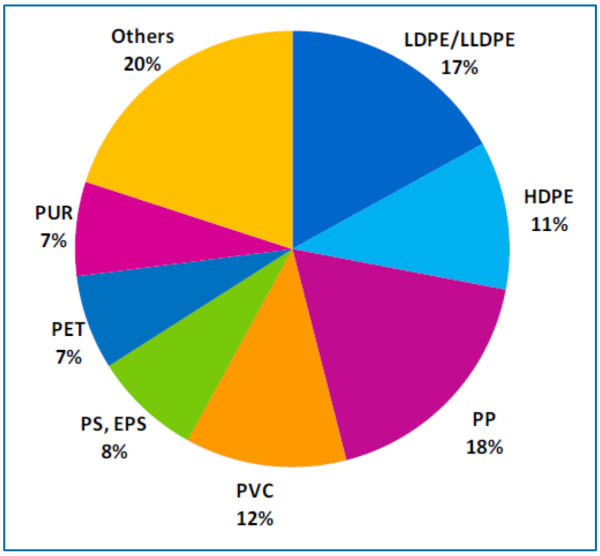
Figure 5-27: Consumption of plastic according to various branches and plastic types



Source: Dr. Baunemann, PlasticEurope Germany, personal communication

The following figure shows plastic conversion industry demand by category of plastic in EU-27, Norway and Switzerland. PE accounts for 28%, including low density LDPE, linear low density LLDPE and high density HDPE. The share of PET is low in Europe (7%) compared with the world level (Mudgal et al. 2011).

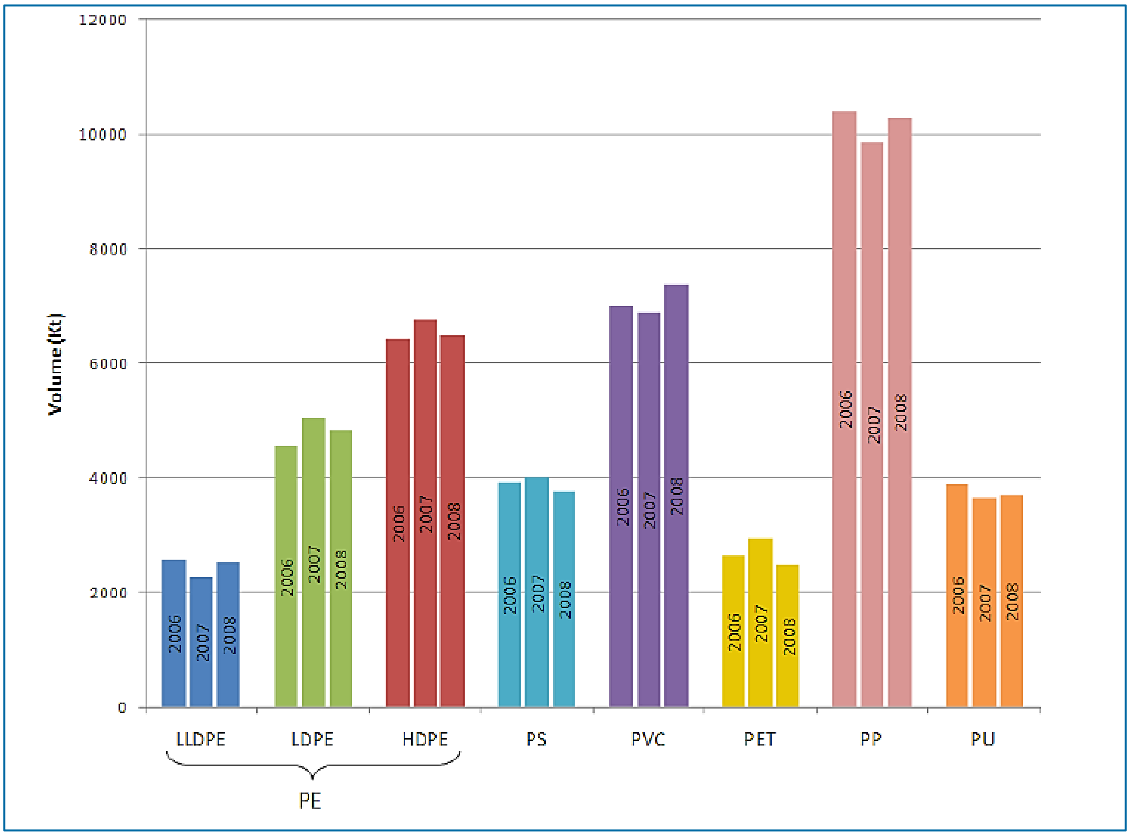
Figure 5-28: Plastics converters demand in EU-27, Norway and Switzerland by plastic polymer type, 2008



Source: PEMRG & PlasticsEurope (2009)

The following figure shows the volume of sales for different types of primary plastics (kt) in EU-27 between 2006 and 2008 (Mudgal et al. 2011).

Figure 5-29: Volume of sales in EU-27 for different types of primary plastics, 2006-2008 (kt)



Source: Mudgal et al. (2011), adapted from Eurostat PRODCOM database, NACE 2.0, category 20.16.

According to Mudgal et al. (2011), the principal polymers used in EEE are PP, PS and ABS, the latter being increasingly used. The following figure presents the polymer composition of some EEE.

Table 5-22: Typical applications of primary polymers in EEE

Application	Type of plastic
Components inside washing machines and dishwashers, casings of small household appliances (coffee makers, irons, etc.) Internal electronic components	PP
Components inside refrigerators (liner, shelving) Housings of small household appliances, data processing and consumer electronics	PS (HIPS)
Housings and casing of phones, small household appliances, microwave ovens, flat screens and certain monitors Enclosures and internal parts of ICT equipment	ABS
Housings of consumer electronics (TVs) and computer monitors and some small household appliances (e.g. hairdryers) Components of TV, computers, printers and copiers	PPO (blend HIPS/PPE)
Housings of ICT equipment and household appliances Lighting	PC
Housings of ICT equipment and certain small household appliances (e.g. kettles, shavers)	PC/ABS
Electrical motor components, circuits, sensors, transformers, lighting Casing and components of certain small household appliances (e.g. toasters, irons). Handle, grips, frames for ovens and grills Panel component of LCD displays	PET (PBT)
Insulation of refrigerators and dishwashers	PU (foam)
Lamps, lighting, small displays (e.g. mobile phones)	PMMA
Lighting equipment, small household appliances Switches, relays, transformer parts, connectors, gear, motor basis, etc.	PA
Gears, pinions	POM
Cable coating, cable ducts, plugs, refrigerator door seals, casings	PVC
Cable insulation and sheathing	PE
Housing, handles and soles of domestic irons, handles and buttons of grills and pressure cookers	UP polymers
Printed circuit boards	EP polymers

Source: Mudgal et al. (2011)

The following figure describes the composition by polymer of the main Waste Electrical and Electronic Equipment (WEEE) items collected. According to Mudgal et al. (2011), the complexity of WEEE items is illustrated by the fact the all items contain at least three different types of polymers. Small household appliances can contain as many as six different plastic types.

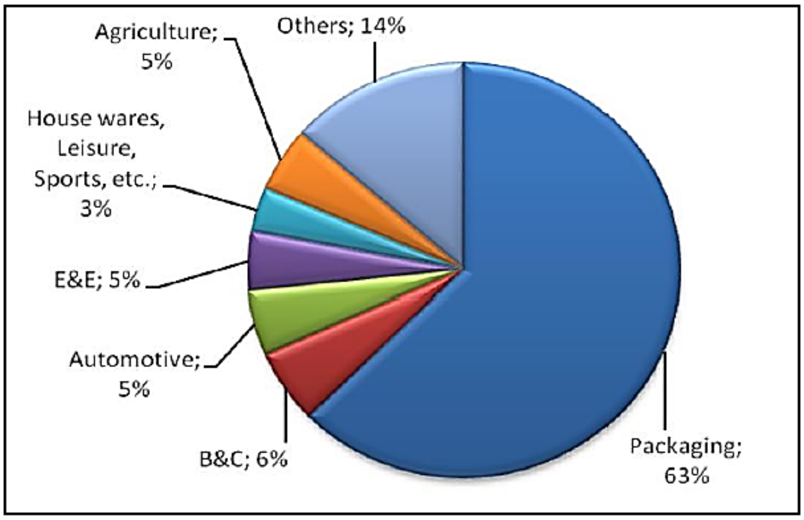
Table 5-23: Main polymers used in the manufacture of the most common WEEE items collected

WEEE item	Polymer composition
Printers/faxes	PS (80%), HIPS (10%), SAN (5%), ABS, PP
Telecoms	ABS (80%), PC/ABS (13%), HIPS, POM
TVs	PPE/PS (63%), PC/ABS (32%), PET (5%)
Toys	ABS (70%), HIPS (10%), PP (10%), PA (5%), PVC (5%)
Monitors	PC/ABS (90%), ABS (5%), HIPS (5%)
Computer	ABS (50%), PC/ABS (35%), HIPS (15%)
Small household appliances	PP (43%), PA (19%), ABS-SAN (17%), PC (10%), PBT, POM
Refrigeration	PS&EPS (31%), ABS (26%), PU (22%), UP (9%), PVC (6%),
Dishwashers	PP (69%), PS (8%), ABS (7%), PVC (5%)

Source: Mudgal et al. (2011), taken from JRC IPTS (2007) Assessment of the Environmental Advantages and Disadvantages of polymer recovery processes

The total quantity of plastics from post-consumer waste was found to be about 24.9 million tonnes in 2008 (EuPC, 2009). Out of that, about 51% were recovered (5.3 million tonnes, i.e. 21% were recycled and 7.5 million tonnes, i.e. 34% were used for energy recovery). According to EuPR (2010), 5% (i.e. about 1.3 million tonnes) of the post-consumer plastic waste emerges from EEE applications. A detailed illustration of the waste occurrence according to various fields of application is shown in the following figure (Sander & Wirth 2012).

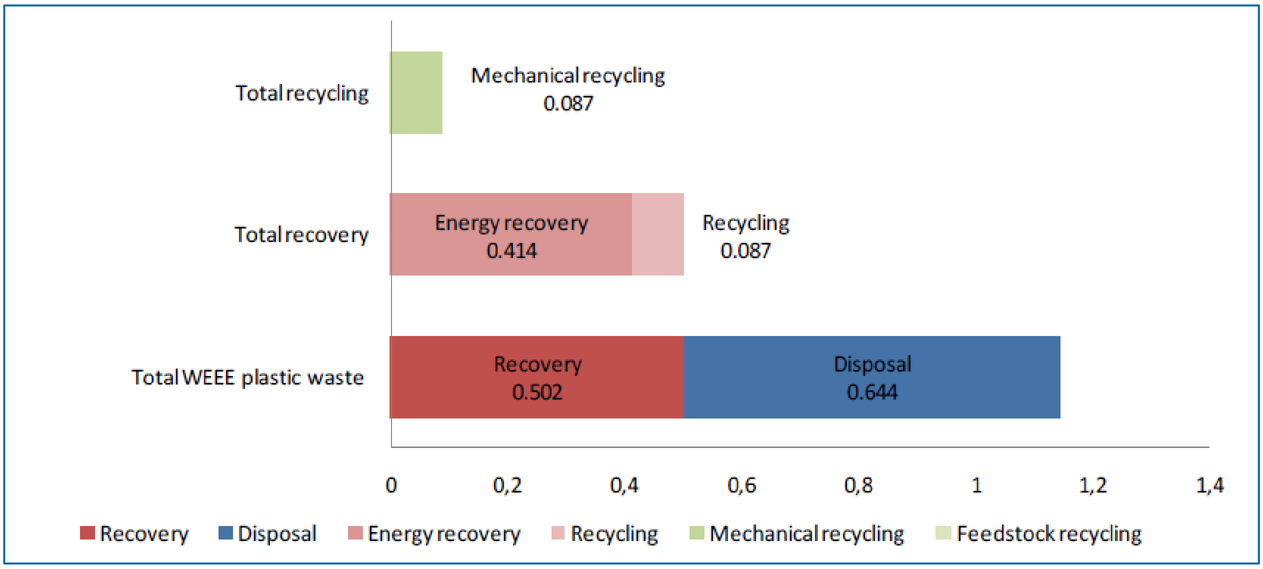
Figure 5-30: Post-consumer plastic waste for different applications



Source: EuPR (2010)

According to Mudgal et al. (2011), 1.1 million tonnes of WEEE was generated in EU-27, Norway and Switzerland in 2008. Of this total amount, 0.6 Mt (55.2%) was disposed of and 0.5 Mt (43.8%) was recovered. Mechanical recycling accounted for 0.09 Mt of the recovered fraction (7.6% of total), and energy recovery amounted to 0.4 Mt (36.2%).

Figure 5-31: Treatment of total plastic waste from WEEE in EU-27, Norway and Switzerland, 2008 (Mt)



Source: Mudgal et al. (2011) with data from PlasticsEurope, EuPC, EuPR, EPRO and Consultic (2009) "The Compelling Facts about Plastics – An analysis of European plastics production, demand and recovery for 2008"

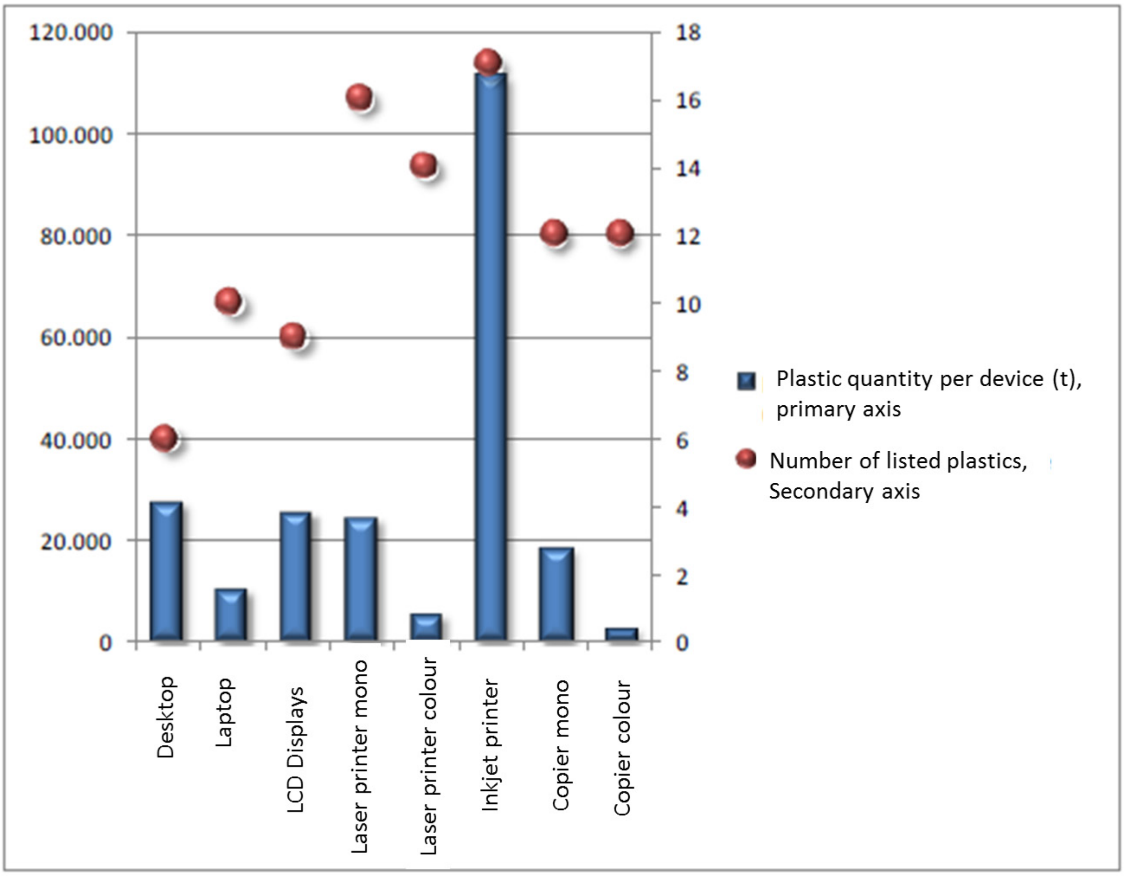
According to PlasticsEurope, mechanically recycled plastics coming from EEE represent less than 2% of the total amount of mechanical recycling[152]; the origin of this material is mainly large domestic appliances (e.g. refrigerators). Plastics-rich WEEE streams (>95% plastics by weight) can be achieved by manual dismantling (but at a high cost), or through a multistep mechanical separation. However, economic pressures on shredder operators may lead them to optimize towards metal recovery, which results in waste plastic that is not suitable either for mechanical recycling or feedstock recycling (Mudgal et al. 2011).

According to Mudgal et al. (2011), the average recycling rate across the EU is 7.6% (all mechanical recycling) with a recovery rate of plastic waste in WEEE of 43.8%. Despite the low global recycling rate, some countries (Norway, Germany, Austria) manage recycling rates over 80% for this waste source.

However, there is very little information available with respect to the use of recycled plastics in various EEE applications. Sander & Wirth (2012) estimated the potential of waste from plastic components of computers and printers on the basis of the data from EuP preparatory studies – Personal Computers (desktops and laptops) and Computer Monitors (Lot 3) und Imaging Equipment (Lot 4). As the next figure shows, the major share of plastic waste in applications analysed by Sander & Wirth (2012) comes from the inkjet printers (49%). Desktop PCs, displays and monochrome laser printers contribute each with about 11% to the total volume of waste plastics in the selected product groups.

[152] APME (2001): Plastics – Insight into consumption and recovery in Western Europe 2000

Figure 5-32: Potential of plastic waste in selected applications



Source: Sander & Wirth (2012)

Various type I eco-labels, such as the Blue Angel, Nordic Swan, EcoMark, EPEAT and the TCO Label "TCO Certified Edge Displays" put various degrees of requirement for the use of recycled plastics in an EEE product. The following table shows the EPEAT criteria for the material selection of imaging equipment.

Table 5-24: EPEAT criteria for the use of post-consumer plastic

Materials selection	
Required	Declaration of postconsumer recycled plastic content
Required	Minimum content of postconsumer recycled plastic
Optional	Minimum 5% to 10% content of postconsumer recycled plastic
Optional	Minimum 25% content of postconsumer recycled plastic
Required	Declaration of biobased plastic materials content
Optional	Minimum content of biobased plastic material
Required	Declaration of product weight

Source: www.epeat.net; accessed: 15.12.2014

The TCO Certified Edge Displays 2.0 requires that a product shall contain a minimum of 85% recycled plastic by weight of the total weight of plastic parts in the product. The requirements are valid for all plastic parts except panels, electronic components, cables, connectors, PWBs, insulating mylar sheets and labels. These exclusions are due to a general lack of available alternative materials for use in these components in IT products. This also means that the weight of these items is not included when calculating the total weight of the plastic in the product in this requirement (TCO Development, 2014).

While the use of recycled plastic remains an important issue in the manufacture of EEE, the following BEMP takes the example of using recycled polyethylene terephthalate (PET) and polypropylene (PP) plastics in inkjet printing cartridges in a closed-loop recycling process. It is to be mentioned that the inkjet printing cartridges are taken only as an example and this practice is applicable to a broad category of EEE. While the recycling of inkjet printing cartridges can be considered as a BEMP within the category of establishing and implementing an efficient collection and recycling process in order to generate sufficient input to manufacture recycled cartridges, it is important to know that the largest potential for reducing a printer's environmental footprint lies in saving the natural resources (oil, aluminum, timber) by not having to produce a new toner of inkjet cartridge, but remanufacturing it for its (multiple) re-use. Various LCA studies have concluded that regarding toner cartridges, remanufacturing reduces the environmental impact by 45-60% on average as compared to producing a new cartridge (ETIRA 2014). Thus, the main strategy from the eco-design's point of view should be to use a cartridge design which will allow cartridges to be re-used.

It is estimated that 300-500 million ink cartridges and 10-20 million toner cartridges are annually sold in the EU-27. It is further estimated that in total volume per year, 40-70% of these cartridges end up in landfills and/or incinerators (Kougoulis et al. 2013).

Various plastic polymers are used in the manufacture of inkjet printing cartridges and laser toners, to form the different components of these products. For example, Hewlett-Packard uses polyethylene terephthalate (PET) and polypropylene (PP) in the manufacture of their inkjet printing cartridges (HP 2014a), which account for as much as 70% of the product (based on empty weight) (HP 2014c).[153] Both Lexmark and Canon manufacture laser toner cartridges among others with high-impact polystyrene (HIPS) (Lexmark 2014a; Canon 2014a).

Though some polymers can be recycled more easily than others, a major obstacle to recycling of plastics is associated with the ability of separating products constructed from mixed plastics into separate plastic streams. For example, according to PP production and recycling figures provided by the American Chemistry Council, PP is one of the least recycled post-consumer plastics, at a rate below 1% for post-consumer plastics. This is mainly due to the difficulties of decontamination and removing odour and taint. Because of the short life-span of PP made packaging, the majority of these thermoplastics end up in landfills as waste. The US Environmental Protection Agency states that approximately 20% of solid waste produced comprises some form of plastics which include PP. Products made of PP degrade slowly in landfills and take approximately 20-30 years to completely decompose (LeBlanc 2014).

To allow for easier recycling of plastics used in ink cartridges, different plastics need to be separable from each other as well as from other materials. Plastics need to be separated from

[153] Further communication with HP clarifies that the company uses both materials across a variety of cartridge types, and that the 70% weight contribution is typical +/- 10%. In general, non-HP printing supplies are said to have similar form factors and are likely to have similar plastic weight percentages. (Ord 2014b)

other materials, such as metals used in the cartridge head, as well as from one another. To this end, some manufacturers have changed product design, for example Canon has standardized the main plastic parts in its toner cartridges in order to facilitate recycling. As a rule, the plastics Canon uses in cartridge parts are made of the same colour and type in order to make them easy to sort. As the purity of materials is important in the recycling of plastics, Canon replaced labels and stickers with engravings, to prevent adhesives and other foreign materials from affecting the quality of recycled materials (Canon 2014b).

Once plastics can be separated and recycled, they can be reused in the manufacture of new products. However, here too, attentive product design as well as working with the supply chain and consumers can allow recycled content to be used in the manufacture of new cartridges, as opposed to down-cycling, in cases where the recycled plastic stream has a loss of quality. The use of recycled PET (rPET) and recycled PP (rPP) as well as of other recycled plastic polymers provides a solution for such wastes, while also decreasing the amount of resources required when manufacturing with virgin plastics. However, the use of recycled content has proven challenging, especially when the complete phase-out of virgin materials is aspired to, as plastics for manufacture need to have certain properties to ensure the same reliability in comparison with products manufactured from virgin materials or from a mix of virgin and recycled plastics.

Though various cartridge manufacturers have been striving towards a complete phase-out of virgin plastics, such practices have a number of obstacles. A shift to recycled content would require that a loss of reliability does not occur over time, once virgin plastics are phased out of manufacture. In the case of HP's closed-loop-recycling practice of printing ink cartridges, according to information from the PET compounder, recovered plastic exhibited no loss of performance in a test of processing material through seven cycles, and it is further assumed that it can undergo infinite cycles of use (Four Elements 2010). However, another obstacle is the ability of collected cartridges to provide manufacturers with sufficient amounts of recycled content to allow a full shift away from virgin materials. One of the keys to overcoming such hurdles requires enhancing consumers' willingness to take part in collection schemes. Thus, involving various actors in the supply chain is essential, both for the success of collection schemes as well as in the processing of used cartridges into post-consumer recycled plastic that can be used in the manufacture of new cartridges.

Implementation of closed-loop plastic recycling processes in the manufacture of ink cartridges allows manufacturers to influence their supply chain, both where consumers (collection of used cartridges) and recyclers (influencing recycling processes to be compatible with plastic property requirements for products) are concerned.

Though this document focuses on the closed-loop recycling of plastics in the manufacture of ink cartridges, it is also implemented by some companies in laser toner cartridges, and should be considered for both ink and laser toner cartridges.

5.2.6.2. Environmental benefits

The use of recycled plastic polymers in the manufacture of new ink cartridges decreases the demand for virgin materials – in this case crude oil.

For example, in 2010, Four Elements Consulting performed an environmental Life Cycle Assessment (LCA) to quantify and highlight the environmental benefits of using rPET in HP's ink cartridges. Since rPET is a direct replacement to virgin PET, the production processes of these substances were compared with each other. Production of rPET incorporates the HP Planet Partners take-back program, transportation logistics, and the various processes that the cartridges undergo in order to manufacture "cartridge-ready rPET" (rPET which can be used in the manufacture of new cartridges). This study was updated in April 2014, based on the latest data

and statistics relevant for the comparison of the manufacture of both virgin and recycled cartridge-ready PET. The Four Elements 2014 study covered the use of the cartridges collected through HP's Planet Partners programs in North America (NA), Europe and the Middle East and Africa. The LCA quantified the advantage, on average, of producing ink cartridges with recycled plastic recovered via the Planet Partners program, and other sources, from 2005 through 2013 worldwide, as well as the environmental performance of the program as structured in 2013.[154] The study has modelled and compared the environmental impacts of producing 1 kg[155] recycled PET or virgin PET and the impact of recycled PET as a percentage of the impact of virgin PET (Four Elements 2014).

Results of the LCA study show that the replacement of virgin PET with rPET in HP cartridges has a clear advantage for eight of the twelve compared impact categories. The results, summarised in Table 5-25 and in Table 5-26 below, indicate that for most of the categories, rPET performs better than virgin PET or is at least comparable to the former in terms of performance. rPET has impacts below 75% of the impacts of virgin PET for six of the impact categories, including water depletion, freshwater eutrophication, fossil fuel depletion, total energy, climate change, and human toxicity. The only category where rPET performed significantly worse was freshwater eco-toxicity (approximately 3.7 times worse than virgin PET in the cumulative model and 3 times worse in the 2013 model). It is assumed that this is linked to the management of waste ink and waste polyurethane (PUR) through the incinerator. Four Elements indicated that the data used to model incineration at the recycling facilities were based on LCA data sets on solvent and PUR incineration, which may or may not be representative of the incinerators used by the Planet Partners recyclers. Thus, these eco-toxicity results might be different if data from the HP Planet Partners incinerators were used instead (Four Elements 2014).

The recycling of 1 kg of PET results in an equivalent use of around 55% less fossil fuel. The 2014 Four Elements LCA showed that virgin PET production requires extraction of fossil fuels as raw materials. Since recycled PET reclaims used PET, extraction of additional fossil fuels is avoided. In addition, the manufacturing process for virgin PET requires more fossil fuel energy than rPET production. The study estimated that recycled PET produced through the closed-loop recycling practice required the use of ~0.70 kg of oil equivalents, whereas the manufacture of virgin PET was estimated to require 1.51 kg oil equivalents (Four Elements 2014).

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[154] The details of the Planet Partners program vary by region and have been enhanced over time to continually improve the program's efficiency and thus further lower the environmental impact. (Four Elements 2010)

[155] The Functional Unit used in the study: The function of the study system is production of PET and rPET for HP ink cartridge lids and bodies. The function of the study does not include injection moulding into bodies but does include delivery of the materials to injection moulding plants. The unit to which all results are normalized and reported is 1 kg, which can subsequently be converted into the use of these resins in any number of cartridges defined by HP. Impacts were calculated to look at 1 kg of PET and rPET for both the cumulative (2005-2013) and current (2013) systems. The "savings" in impacts potentially generated due to the use of rPET is the net difference between the PET and the rPET. (Four Elements 2014)

Table 5-25: Overall results of comparison of cumulative model (2005-2013) rPET average vs. virgin PET

Impact category	Unit	RPET (Cumul Model)	Virgin PET	RPET as % of Virgin	Use of recycled plastics vs. virgin plastic
Climate change	kg CO2 eq	2.04	3.06	67%	33% less
Ozone depletion	kg CFC-11 eq	1.1 E-07	1.1 E-07	102%	2% more
Terrestrial acidification	kg SO2 eq	0.01	0.01	88%	12% less
Freshwater eutrophication	kg P eq	2.7 E-04	7.5 E-04	36%	64% less
Human toxicity	kg 1,4-DB eq	0.31	0.44	72%	28% less
Photochemical oxidant formation	kg NMVOC	0.01	0.01	101%	1% more
Particulate matter formation	kg PM10 eq	4.5 E-03	5.5 E-03	82%	18% less
Terrestrial ecotoxicity	kg 1,4-DB eq	2.1 E-04	2.0 E-04	104%	4% more
Freshwater ecotoxicity	kg 1,4-DB eq	2.3 E-03	6.3 E-04	372%	272% more
Water depletion	m3	1.45	5.76	25%	75% less
Fossil depletion	kg oil eq	0.70	1.51	46%	54% less
Cumulative energy demand	MJ	33.91	72.27	47%	53% less

Source: Four Elements (2014), p. 5

Table 5-26: Overall results of comparison of 2013 rPET vs. virgin PET

Impact category	Unit	RPET (2013 Model)	Virgin PET	RPET as % of Virgin	Use of recycled plastics vs. virgin plastic
Climate change	kg CO2 eq	2.06	3.06	67%	33% less
Ozone depletion	kg CFC-11 eq	1.2 E-07	1.1 E-07	106%	6% more
Terrestrial acidification	kg SO2 eq	0.01	0.01	93%	7% less
Freshwater eutrophication	kg P eq	2.5 E-04	7.5 E-04	33%	67% less
Human toxicity	kg 1,4-DB eq	0.32	0.44	72%	28% less
Photochemical oxidant formation	kg NMVOC	0.01	0.01	102%	2% more
Particulate matter formation	kg PM10 eq	4.7 E-03	5.5 E-03	85%	15% less
Terrestrial ecotoxicity	kg 1,4-DB eq	2.0 E-04	2.0 E-04	96%	4% less
Freshwater ecotoxicity	kg 1,4-DB eq	1.9 E-03	6.3 E-04	302%	202% more
Water depletion	m3	1.38	5.76	24%	76% less
Fossil depletion	kg oil eq	0.69	1.51	46%	54% less
Cumulative energy demand	MJ	33.80	72.27	47%	53% less

Source: Four Elements (2014), p. 5

Since 2005, HP has used more than 35,000 metric tons of recycled plastic and manufactured more than 1.8 billion inkjet printing cartridges from this quantity. These quantities are mainly a result of the PET closed-loop recycled practice, as implementation of the PP closed-loop process recycling began in 2013. Now that HP is operating not one, but two closed-loop recycling processes (PET

and PP), the company forecasts using more than 8,000 metric tons of recycled plastics per year (HP 2014a).[156]

Manufacturers, who have cartridge collection programs for ink cartridges or laser toners, also explain such schemes to allow reducing the carbon footprint of cartridges. For example, in LCA studies conducted for Lexmark by an independent firm it was shown that by sending a used toner cartridge back to recycling in the program, as opposed to discarding it in a landfill, a cartridge's overall carbon footprint is reduced by up to 50% (Lexmark 2014b).

As most ink cartridges use PET and/or PP,[157] this BEMP could be applied by all manufacturers who have a take-back program for their cartridges in place, assuming that various plastic streams can be separated in the recycling process efficiently (see section 5.2.6.6 for detail).

5.2.6.3. Appropriate environmental performance indicators

The performance should be monitored by a number of indicators:

- **Per product:**
  - **Percent of recycled content** – Enabled recycled content per cartridge in terms of the amount of recycled plastic polymers (PET, PP, HIPS, etc.) from the total amount of plastic polymers used per cartridge (%). For example, HP achieves between 30% and 70% recycled content (most of which is post-consumer recycled content between 29% and 67)[158] in various cartridge models, depending on the cartridge model[159]. The average amount of recycled plastic content per cartridge is currently between 45-50%, expected to be above 50% by February 2015 (ORD 2014d). Lexmark achieves an average post-consumer plastic content of 10% across all toner cartridges at present, aspiring to increase the postconsumer plastic content of toner cartridges to 25% by 2016.[160] Where different polymers are used in the manufacture of a specific cartridge, manufacturers should also provide data for the amount of recycled content specific to each type of polymer in use (i.e., rPET from total PET used, etc.).
  - **Closed-loop post-consumer recycled content** – In cases where an external plastic waste stream (such as PET bottles or PP clothe hangers) is used to ensure that sufficient recycled content is available for full replacement of virgin material, the amount of closed-loop recycled content from the total amount of plastic polymers used per cartridge could also be quantified.
- **Per manufacturer**:
  - **Collection scheme efficiency** - Percentage of cartridges recycled from total cartridges sold per manufacturer.
  - **Percent of cartridges manufactured with recycled content** from total amount of cartridges sold by manufacturer. The percentage of recycled content that can be achieved is to be specified in relation to this performance indicator, to clarify to what degree collection schemes

[156] HP (2014a): Hewlett-Packard (HP) Submission to the Circular Economy Success Award – Final.

[157] According to HP, PET is understood to be more common for printhead cartridges and PP is more common for ink container type cartridges, where the printing head is part of the device itself and not integrated into the cartridge. (Ord 2014b)

[158] For more detailed data for Western Europe on page 6: http://www.hp.com/hpinfo/globalcitizenship/environment/productdata/recycledcontentink.pdf?jumpid=reg_R1002_USEN

[159] According to Ord (2014e), the lower figures regard older models which have less of an impact on the average in light of their lower volumes.

[160] For further information see http://csr.lexmark.com/materials.html

(raw material) and manufacture (design) have allowed achieving the target of virgin material phase out. As mentioned above, it is understood that Lexmark uses a minimum amount of post-consumer plastic content across all toner cartridges.[161] 75% of HPs inkjet cartridges are manufactured with recycled content (Ord 2014e).

- **For recycler**:
  - % mass of cartridges recycled into materials suitable for reuse (plastics suitable for similar applications; metals; etc.) – currently approx. 76% at PDR162, HP's EU recycling site (PDR 2014b)
  - % mass of cartridges recycled thermally – (currently approx. 22% at PDR (PDR 2014b)[163]

5.2.6.4. Cross-media effects

The use of recycled polymer plastics requires the utilisation of various resources for the collection and processing of recycled content (water, energy, etc.) as well as creating various emissions (greenhouse gases, ozone depleting gases, etc.). However, the comparison of the closed-loop manufacture of recycled materials with the alternative use of virgin materials has shown that from an environmental perspective, these practices can be beneficial. The success of such practices depends on various factors, such as the logistics of collection and processing of cartridges. The amount of collected content that can be recovered from old cartridges and used to reduce the need for virgin materials and other resources is also important.

In the case of HP's closed-loop recycling scheme, as detailed in Table 5-26 above, for rPET, this practice results in benefits in the comparison of 12 different environmental indicators. The Four Elements LCA (2010) notes that in one sensitivity analysis, the result for one of the 12 categories evaluated was sensitive. With greater consumer distances travelled to recycle cartridges,[164] the human toxicity result was better for virgin PET than recycled PET. For the other categories evaluated, with increased distances travelled by consumers, results for recycled PET were still better than for virgin PET.

The results of the Four Elements (2014) study link the performance of rPET in terms of freshwater eco-toxicity with the management of waste ink and polyurethane (PUR) through the incinerator. Thus, future application of this technique by other enterprises should evaluate possible eco-toxicity impacts based on these management practices to ensure that possible impacts are avoided or at least manageable.

In HP's EU cartridge recycling facility (PDR), the only inputs to the process aside from used cartridges are electricity, water and an anti-foaming agent. The recycling process causes no emissions to air, and waste water amounts are negligible, due to the closed-looped recycling of process water. The outputs of the process include various plastics (PP, PET – both recycled back

[161] For further information see http://csr.lexmark.com/materials.html

[162] PDR has been the European partner of HP for the recycling of inkjet printer cartridges since 2002. Together with HP and the Bavarian Institute for Applied Environmental Research (BIfA), PDR developed a special recycling technology for inkjet printer cartridges, optimized it and built the adequate recycling facility in Thurnau. (PDR 2014a)

[163] According to PDR, the 22% break-down is comprised of a mixed fraction of cartridge materials (8%) which cannot feasibly be recycled; ink concentrate (12%); and ink distillate (water -2%). In general the above figures (recycled into materials vs recycled thermally) accounts for 98% of the inputs but is based on the Q3/2014 performance. (PDR 2014b)

[164] Understood to mean a longer average distance travelled by consumers to deliver cartridges to location of collection point, in comparison with the average distance used in the initial model of the analysis.

to cartridge manufacture); other plastics (PPO, HDPE, PSU, PUR); steal; noble metals and ink concentrate (PDR 2014a).

Additives may be necessary in the compounding of various plastic polymers such as rPP and rPET resins, to bring the recycled material to the level of virgin performance properties. Factors determining the choice of substances to be used as additives should include possible hazardous properties, to avoid negative cross-media effects in terms of toxicity.

The additives that HP uses are common plastic constituents and should meet any requirement applicable to virgin resin. In HP’s practice, the additives are impact modifiers (rubber) and polymer chain extenders which are commonly used with PET and PP, for both virgin and recycled materials. The materials meet all the relevant provisions of HP’s General Specification for the Environment. For instance, the additives meet HP’s requirements restricting polycyclic aromatic hydrocarbons (PAHs) in plastics (Ord 2014b).

5.2.6.5. Operational data

The practice of the closed-loop recycling of plastic polymers, such as PET and PP, in ink cartridges begins with the collection of materials from the consumer. After collection, cartridges are processed into recycled plastics and then transported to facilities where new cartridges are to be manufactured. From the supply chain perspective, this process involves a number of actors and mechanisms. Figure 5-33 provides an example of the various supply chain stages in the manufacturing of recycled PET for ink cartridges in the closed-loop mechanism of HP. Further information as to such stages in the closed-loop recycling is detailed below.

According to Hewlett-Packard (HP), it recovers plastics from its own customer-returned inkjet printing cartridges (through its Planet Partners Program[165] initiated in 1991) and combines this with post-consumer waste plastics from external sources (HP 2014a). HP ink and LaserJet cartridges returned through HP Planet Partners go through a multi-phase "closed-loop" recycling process. The recycled plastic from empty cartridges is used to create new Original HP cartridges. The company partners with shipping companies to collect and return printing supplies. Once the supplies have been returned, HP works with advanced recycling organizations to recover and recycle materials from empty or used HP printing supplies.

In 2005, HP developed a closed-loop recycling process for polyethylene terephthalate (PET) used in their inkjet cartridges. Until 2010, some of the HP cartridges manufactured with recycled content still contained a small percentage of virgin PET. However, this process has been improved to allow the complete phase-out of virgin PET plastics in new inkjet cartridges manufactured by the company since 2010 (Four Elements 2010).

Additionally, in 2013, HP started the incorporation of a similar process for the closed-loop recycling of polypropylene (PP). The new process is now (2014) fully incorporated concerning the use of recycled PP materials used in the manufacture of HP’s inkjet printing cartridges. This has been achieved through the development of a recycled PP resin ‘recipe’ capable of replacing virgin PP resin. The new process was launched in October 2013 and after a short period it was observed that the process enabled HP inkjet printing cartridges to enter multiple lifecycles in respect of the use of PP.

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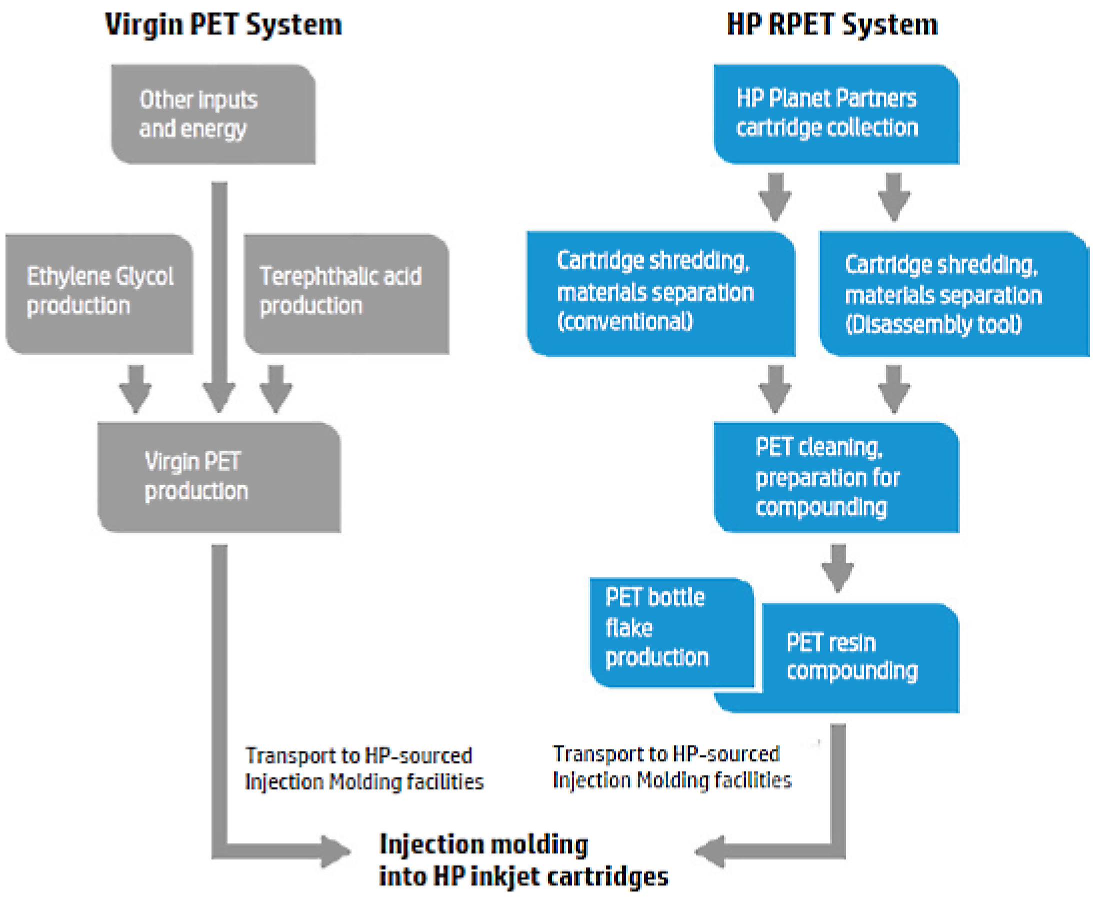
[165] HP Planet Partners is HP's return and recycling program for computer equipment and printing supplies. It is available in more than 50 countries and territories worldwide. For more information also see http://h30248.www3.hp.com/recycle/supplies/overview-hpe.asp?__cc=us&__la=en

Recent communication with HP has clarified that this was observed in part in light of the colour change of cartridge. New data shows that just nine months after implementing the rPP program, some cartridges are likely heading into their 4th or 5th lifecycle. In parallel, with rPET, where the program has been applied for almost ten years – plastic from these supplies might have already been through ten or more cycles (Ord 2014b).

Through this practice, 566 million cartridges, 498 tonnes of PP clothes hangers and 2.5 billion post-consumer plastic bottles (PET) have been kept out of landfills[166] (HP 2014d).

Closed-loop recycling processes for polyethylene terephthalate (PET) and polypropylene (PP) will significantly reduce the use of virgin resins. Furthermore, recycled PET and PP resin 'recipe's' also provide solutions for the use of other post-consumer waste plastics, sourced from unrelated industries.

Figure 5-33: Comparison of extraction and manufacture of virgin PET, and collection and manufacture of rPET, destined for use in injection moulding of inkjet cartridges



In both cases, the process ends with delivery of plastic to injection moulding manufacturing facilities. Once the virgin PET / rPET reach the injection moulding facilities, further manufacture phases are identical for each plastic.

Source: Four Elements (2014), p. 7

[166] Source refers to landfilling as the alternative treatment at end-of-life, however, depending on the country where WEEE is collected, this practice may also provide an alternative to incineration or to other collection and treatment methods practiced where take-back systems are not in place for specific products or components.

The production of HP's rPET (in the 2013 program) starts with consumer returns at retail drop-off centres and through the web program. The collection of cartridges from consumers is facilitated through a number of alternatives (Four Elements 2014). In 2013, HP's take-back program for inkjet cartridges is said to have covered 88% of its market, providing consumers various opportunities to return used products (HP 2014d).

The main input of the European cartridge recycling facility (PDR) is cartridges from all over Europe, as well as occasional cartridge shipments from the Asian facility. Cartridges are collected as follows (PDR 2014a):

- business consumers – collection in boxes sent to PDR;
- private consumers:
  - Authorized retail recycling locations, in which case boxes of cartridges are sent to PDR;
  - Collection through pre-paid envelopes – these are sent to a central address (usually in the country), collected and then sent together to PDR. In this case, though the collective shipment saves shipping costs, the cartridges that arrive at PDR are still enclosed within an envelope, which needs to be discarded through the sorting stage.

The vast majority of cartridge returns are collected by authorized retail recycling locations, whereas the web-based program has dwindled to a small percentage of cartridge returns (Four Elements 2014).

Once cartridges arrive at the EU recycling facility, they are removed from boxes and envelopes and sorted by hand. Cartridges are sorted according to cartridge model type which is related to the main plastic polymer content, as different plastics will require different knives for shredding and will thus be recycled separately. Black and colour cartridges of the same type are collected and later sent to recycling, once the amount collected is sufficient for 1-2 recycling shifts. In the sorting phase, non-HP cartridges are removed so as not to create a risk of contamination. The quantity of this fraction is far below 1% (PDR 2014a).

In the recycling process, boxes of cartridges of the same type are emptied into a first container from which they are fed to the process. After the shredding of the cartridges with special knives, separation between plastics is established through a sink float separator combined with a removal by suction. By means of the sink float separator, the cartridges are mixed with water in order to remove ink residues from the ink containers. An anti-foaming agent is used in this process as an additive. The ink is separated along with the waste water and sent to an evaporator, resulting in water (recycled to process) and concentrated ink. This ink consists of a mixture of inks of various colours and cannot be reused in the manufacture of further cartridges in light of the risk of quality performance (the mixture can vary in colour, though - in general - it appears to be of a black tone). Predominantly, this ink is recycled thermally.[167] Metals go through an additional magnetic separation phase to separate between steel and noble metals (PDR 2014a).

[167] At least in part this recycled fraction is sent back to HP who uses it in the manufacture of black ink pens, where the body of the pen is also manufactured from plastic recyclate (PDR 2014).

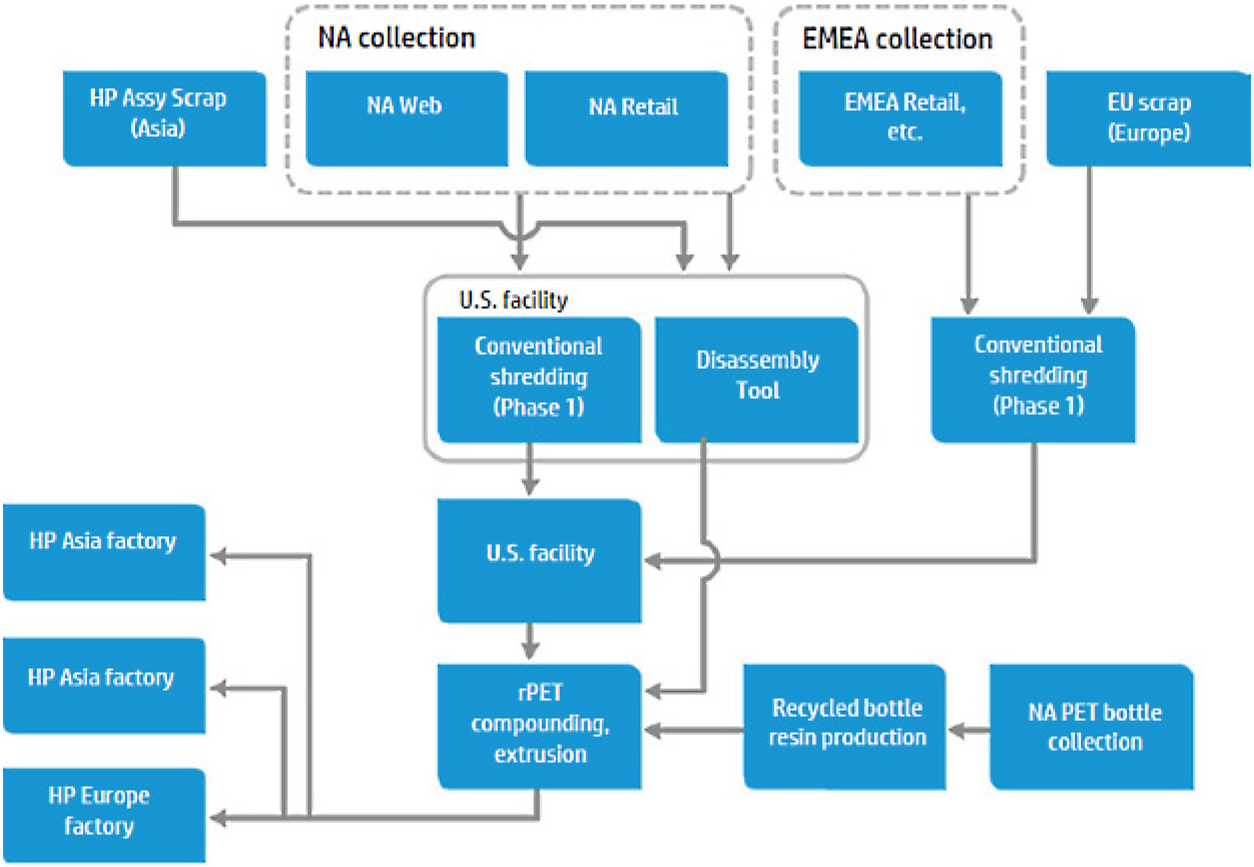
Figure 5-34: Cartridge processing facility at PDR

Notes: On the left, boxes of sorted cartridges wait to be processed. In the centre, an employee overlooks the feeding of a new cartridge batch into the installation.

Source: Appears courtesy of PDR Recycling GmbH + Co KG and HP, 2014

The cartridges collected in North America (NA) are sent for conventional shredding, material separation, reclamation, and cleaning, or to a Disassembly Tool. The conventionally-shredded PET is sent for further processing and compounding into rPET resin. The PET from the Disassembly Tool, which includes Asia Pacific manufacture scrap, is sent directly to further processing and compounding into rPET resin. The cartridges collected from the Middle East and Africa (EMEA) are sent for conventional shredding, material separation and reclamation and cleaning, then the finished RPET resin material is sent to HP-sourced injection moulding facilities located very near HP manufacturing facilities in Asia-Pacific and Europe. For further details see illustration in Figure 5-35 below (Four Elements 2014).

Figure 5-35: Illustration of 2013 RPET program



Source: Four elements (2014), p. 9

In the case of PET, post-consumer external content is retrieved from recycled bottles, whereas for PP, the current source for additional post-consumer material is waste clothing hangers from the retail fashion industry. These materials go into the manufacture of recycled PET and PP (see Figure 5-36 below), which is then sent to facilities where new cartridges are manufactured (Four Elements 2010).

To retain the reliability of materials without using virgin PET or PP, additives and modifiers are added to the recycled materials in the manufacture of rPET and rPP (Ord 2014a).

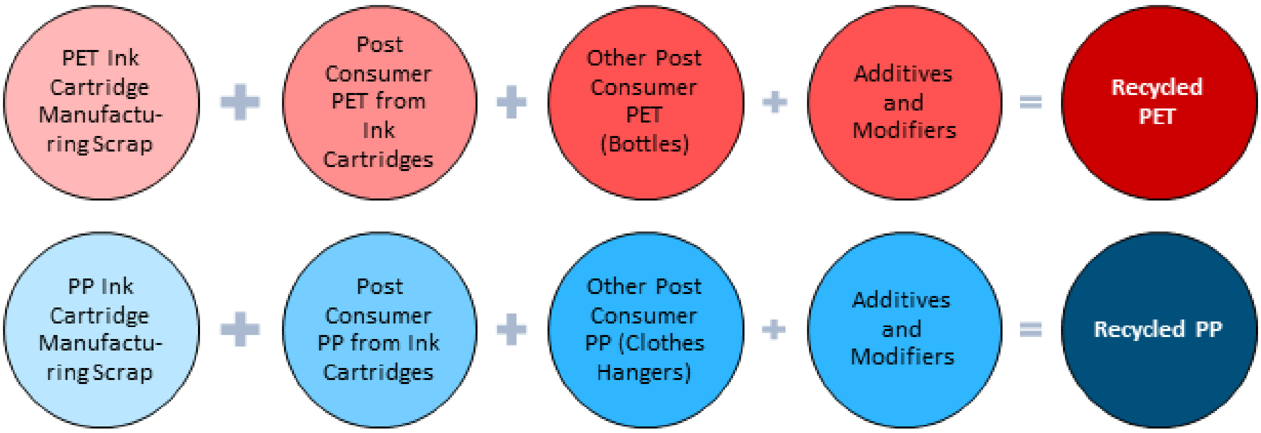
The Four Elements LCA (2010) states that Lavergne, the manufacturer of the compounded recycled PET, explained that the additives are "virgin", petroleum-based chemicals that bring the properties of the recycled PET to virgin PET performance level. It was further elaborated that recovered plastic can undergo infinite cycles without loss of performance as demonstrated in a Lavergne test processing material through seven cycles with no loss of performance.

It should be noted that HP developed a technology which disassembles, shreds, and separates cartridges, and cleans the scrap to create PET[168] ready for blending and compounding into rPET with Recycled Bottle Resin and additives. This Disassembly Tool is located at Lavergne and started operation during 2010. The all-in-one tool performs the PET preparation functions pre-

[168] This PET is described as contaminant-free, it is assumed that this means the degree of purity of the PET and not the low content of contaminants in terms of hazardous substances.

viously performed by several companies, thereby reducing shipping. Previously, de-packaging, separation, shredding and cleaning was performed by one operator, after which a second operator removed contaminants and separated material into various outputs, including shredded PET later shipped to Lavergne, the third operator. The new technology recovers more PET and reduces the overall energy and water use as compared to the previous multi-facility process. The Four Elements study (2010) also explains that this automated disassembly practice has been coupled with redesign of cartridges, to facilitate such dismantling into various materials. The shift from shredding to the disassembly practice has allowed lowering the costs of this practice, as materials are separated more easily, increasing the value of materials for smelters and recyclers of non-plastic content (Ord 2014a). According to HP, the earlier practice of shredding resulted in a supply of plastic that was so contaminated that only around 60% could be recovered, whereas the disassembly technology enables a recovery rate above 90% (Ord 2014b).[169]

Figure 5-36: Plastic constituents in manufacture with recycled plastics

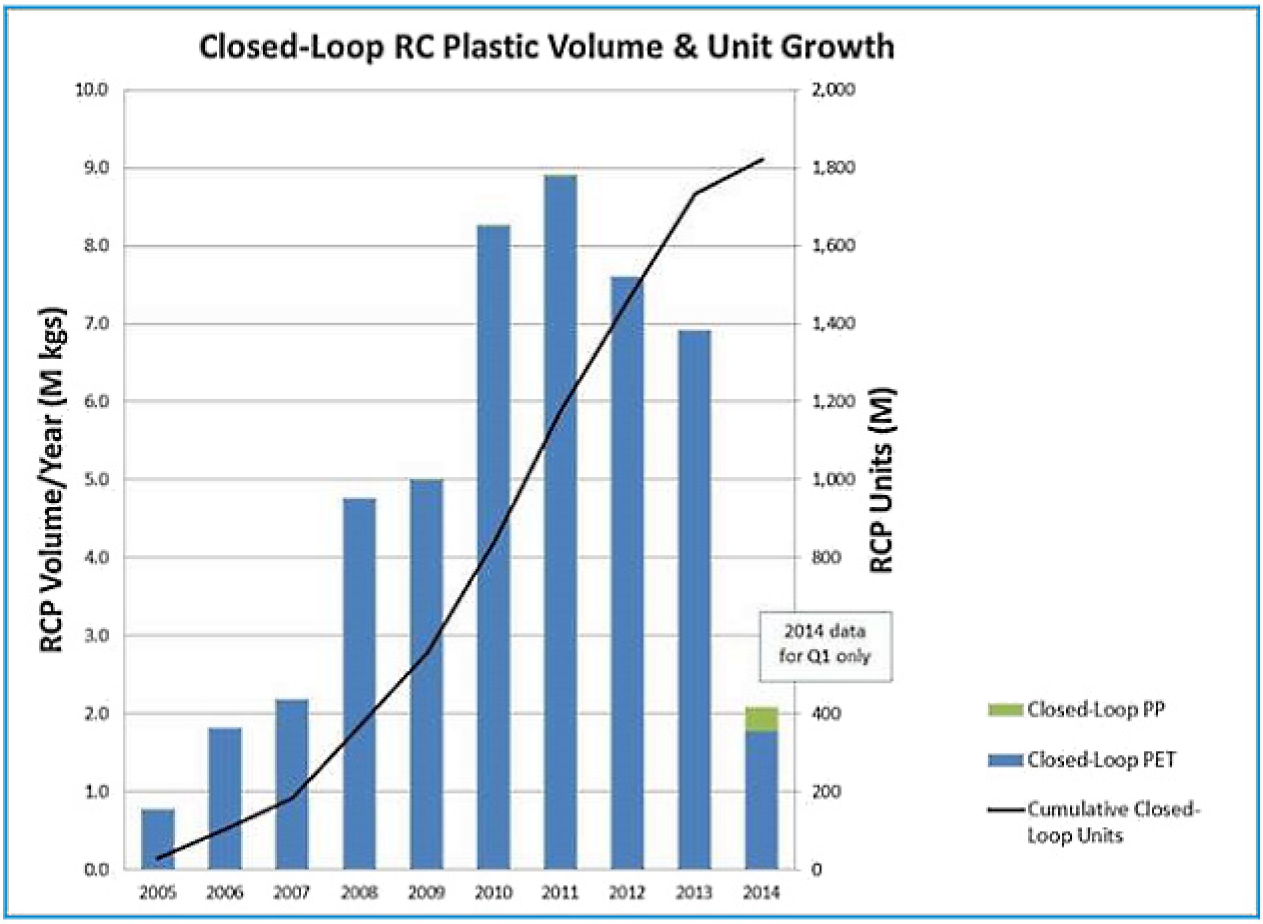


Source: Own illustration

Figure 5-37 charts the recycled content plastic volume (million kgs) used per year since the development of HP's initial polyethylene terephthalate (PET) closed-loop process, in 2005, for the manufacture of its ink printing cartridges. The 2014 data only relates to financial quarter 1 (start-October to end-January), and shows use of both PET and polypropylene (PP). The Z-axis shows the cumulative number of closed-loop inkjet printing cartridges produced since 2005 to end-January 2014 (HP 2014e).

[169] In this regard, it should be noted that the EU recycling operator achieves similar recycling rates of PP, as the disassembling tool is only applicable to PET. Furthermore, since only around 20% of the NA cartridges are recycled with the disassembly tool, here, too, the PET recycling rates of PDR are more or less comparable with those of other facilities. (ORD 2014c)

Figure 5-37: Closed-loop recycled content plastic (RCP) volume & unit growth



Source: HP (2014e)

In 2013, 70.9% of the materials collected through HP's cartridge take-back program were recycled, 27.6% were used for energy recovery, 1.5% was incinerated and 0% was landfilled. Both the rPET and the rPP initiatives have enabled more than 75% of new inkjet cartridges and 24% of laser jet toner cartridges to be manufactured by HP containing recycled plastic. At the end of January 2014, HP has manufactured more than 2 billion new ink and toner cartridges, using more than 62,000 tonnes of recycled content material (HP 2014d).

Lexmark has implemented a closed-loop toner cartridge recycling practice. This allows reclaiming a feed stream of high-impact polystyrene plastic. After returning this material to near-new quality, the plastic is used to manufacture new toner cartridges. Lexmark uses reclaimed plastic with a 10% average post-consumer plastic content across all toner cartridges, aspiring to increase the post-consumer plastic content of toner cartridges to 25% by 2016.[170]

Canon, who also practices closed-loop recycling for laser toner cartridges, states that "each element of every returned toner cartridge is reused – be it as a component in a new toner cartridge, as a base material in other industries, or as a substitute for fossil fuels. No part of the toner cartridge makes its way to landfill."

[170] For further information see: http://csr.lexmark.com/materials.html

5.2.6.6. Applicability

The practice is suitable for using recycled plastic in EEE in general. SHARP[171], for example, utilize recycled plastic in the tubs of all top-loading washer/dryers and fully automatic washing machine models as well as in SHARP's high-energy-efficiency flagship refrigerator models (SHARP 2012). It is thus understood that the closed-loop recycling of plastics could become a relevant practice for other products, assuming that the collection of end-of-life products could be facilitated at a rate sufficient to supply manufacture.

In another study, WRAP (2010) (Waste & Resources Action Programme) demonstrated that using recycled WEEE-derived plastics in high-performance electrical products could be a viable technical and economic option. Thereby, WRAP worked together with two global electronic companies, Bowers & Wilkins and Meridian, to trial recycled plastics in following products, in place of the virgin plastics used at present for the components:

- 800 series hi-fi loudspeakers by Bowers & Wilkins (B&W); and
- F80 hi-fi by Meridian, co-branded with Ferrari.

The recycled plastics used in this trial came from post-consumer TV casings and games consoles. The project trialled components in three recycled WEEE plastics from stable UK sources:

- High Impact Polystyrene (HIPS) sourced from TV casings;
- High Impact Polystyrene (HIPS) from a mixture of WEEE and other products; and
- PCABS; a blend of Polycarbonate (PC) and Acrylonitrile Butadiene Styrene (ABS) sourced from games consoles

WRAP (2010) concluded that overall the recycled materials performed to an equivalent standard to the virgin material in almost all the selected applications. Indeed, in some cases the recycled plastics performed to a higher standard than the virgin material currently used. Both grades of recycled HIPS moulded more easily than virgin HIPS for the chosen applications. All components trialled moulded successfully in HIPS, except the Meridian connector panel which needs further modification to match colour and gloss level. The use of PCABS, however, proved more problematic, highlighting the need for mould designs to be considered to accommodate recycled material as well as virgin at the outset. A cost saving of 13% per tonne could be achieved using recycled High Impact Polystyrene (HIPS) in the Bowers & Wilkins loudspeaker grills. Furthermore, a saving of 72% CO_2e per tonne could be achieved using recycled HIPS in place of virgin material (equal to 947 kg CO_2 compared to 3,400 kg CO_2). Also, a saving of 50% CO_2e could be achieved in producing the Bowers & Wilkins speaker grills with recycled HIPS (WRAP, 2010).

HP is using plastic bottles and clothing hangers (respectively) to supplement the supply of these two plastics, however, other sources of post-consumer plastics may be relevant for other manufacturers, depending on the plastic polymers in use and the properties needed in their manufacture.

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[171] Sharp and Kansai Recycling Systems Co. Ltd. jointly developed a closed-loop plastic material recycling technology that repeatedly recovers plastic from used consumer electronics and reuses it in parts of new consumer electronics for the Japanese market. This technology has been in practical use since fiscal 2001. By combining of a high-efficiency metal removal line, high-purity PP (polypropylene) separation and recovery technology, and other property improvement/quality control technologies, Sharp has been able to recover recyclable plastic, as well as to find applications for its use, such as in the exterior panels of home appliances and as flame-retardant materials. Because recycled plastic can be reused numerous times, the practice has been adopted for use in washing machines, refrigerators, and other similar home appliances sold within Japan which are subject to the Home Appliance Recycling Law. See further detail under http://www.sharp.co.jp/corporate/eco/report/backnumber/pdf/esr2012e.pdf

HP mentions three aspects which have had a beneficial influence on the applicability of the closed-loop recycling of PET and PP in the manufacturing of cartridges (Ord 2014b):

- The use of alternative post-consumer plastic streams is important to ensure a steady supply of recycled PET and PP.
- HP further explains that creating long-term relationships with recyclers (i.e. suppliers) has enabled the recycling of plastics with a technically demanding mechanism, while also having a positive impact on the quality, quantity and costs of recycled plastics.

Continuous communication between HP and each cartridge recycling facility (three in total), as well as between the facilities themselves, enables the efficiency of the cartridge recycling process to be increased even further. This regards both the improvements in the recycling process itself, as well as the fine-tuning in the design of new cartridges to enhance their recyclability (PDR 2014a).

It should be further clarified that, in some cases, additional plastics are used in the manufacture of cartridges, in quantities for which it would not be economic to recycle them back into the process of cartridge manufacture (i.e. in cases where multiple plastics are used in the manufacture of a specific cartridge model). Thus, to some degree, limitation in some types of cartridges of recycled content use may depend on the proportion of other plastics. HP takes this into consideration in the design of new cartridges which is increasingly moving away from the use of multiple plastics and towards the use of a single plastic (PET/PP) (PDR 2014a).

rPET and rPP have also been applied by HP in the manufacture of new LaserJet toner cartridges.[172] Furthermore, PET and PP are used in the manufacture of other parts used in EEE, where the application of closed-loop recycling of plastics may also prove beneficial. In this respect, the recycling process used in the EU for HP cartridges is applicable to products manufactured from plastics and metals, where possible liquid contaminations such as ink may also be an issue of relevance. An initial condition concerning the applicability to other input material (other than ink cartridges) is that such material feeds (products) are small enough to enter the processing machine (currently limited at about 25 x 25 x 25 cm). Larger products would need to be cut into smaller pieces, or the machine would need to be adjusted to the size of such products (PDR 2014a).

The program practiced by HP demonstrates how a manufacturer can successfully blend two different incoming streams of used plastic to ensure a steady supply: one stream being a close-loop source and the other stream being upcycled bottles and hangers. This stops leakage and cascaded recycling that Circular Economy seeks to minimize.

Information published by Canon and Lexmark, concerning the closed-loop recycling of HIPS enabled through laser toner collection programs, also shows that ease of disassembly and separation between the materials in use in such cartridges is important for raising the efficiency of such schemes. In this regard, Canon explains that "*the first stage in the process of recycling returned toner cartridges is to sort them by model. Since Canon has many product models, sorting by hand is a time-consuming process. In 2010, however, Canon Ecology Industry was able to introduce an automated sorting system. The new system contributes to more efficient operations at the* [recycling] *plant*" (Canon 2014a).

[172] From available information it is understood that other manufacturers may use recycled content in the manufacture of their cartridges (such as Cannon and Lexmark, see section 5.2.6.9), however, it is unclear if these processes allow the elimination or significant reduction (above 50%) of the use of virgin plastics.

5.2.6.7. Economics

The costs for closed-loop recycling of plastics for ink cartridge manufacture include costs of the collection mechanism, costs for sorting and handling collected items and costs for manufacturing recycled material that can be used in production.

According to HP (Ord 2014c), factors that determine the economic efficiency of the practice include:

- collection costs;
- recycling costs (cost of capital, inputs, and labour);
- recovery rate of recycling process;
- cartridge-recycled material content; and
- commodity prices;

HP explains that the cost of the recycled resins depends on the processing effort required. Depending on the complexity of the recycled product and the process itself, the recovered plastic can cost more or less the same as virgin resin (the price of which also varies over time due to demand and the price of feedstock). In general, the price of rPET and rPP is competitive with the price of virgin material. rPET and rPP may be a bit more expensive on average, but their prices are also more stable in light of the changes in demand affecting the prices of virgin plastics (Ord 2014b).

According to HP, with the exception of collection costs, the recycling processing costs (such as those performed at HP's EU facility, PDR), can largely be offset through the recovery and re-use of the plastics and precious metals resulting from the process. Thus, improving collection processes/the collection cost model is a key factor influencing economic feasibility. Others factors of influence include increasing virgin plastic prices, continuous improvement of recycling process efficiencies and continued progress on product design for recycling (Ord 2014d).

As the collection of ink cartridges containing electrical components by manufacturers is mandatory in the EU[173] (European Commission 2014), costs of the collection mechanism are understood to be compliance costs which have already incurred in part in the past and, which shall incur in the future. These costs, a result of the collection and recycling rates required in EU legislation, are understood to be less affected by the type of recycling applied to collected cartridges and to the use of recycled resins resulting from such operations. Thus, recycling and reuse of these materials in a closed-loop recycling program for the manufacture of a specific product, could allow offsetting of some of these costs, through reduced expenses for virgin materials.

[173] Though there has been some discussion on the applicability of EU EEE legislation (including the WEEE Directive), it is understood that cartridges which include both the ink container as well as the printing head are currently in the scope of both Directives. In this regard, the WEEE FAQ document updated periodically by the European Commission clarifies that: "*A printer cartridge falls within the scope of the Directive if it meets the definition of EEE given in Article 3(1)(a) and does not fall under the exclusions of Article 2 of the Directive. The decisive criterion is the fulfilment of the definition of EEE. Thus, printer cartridges which contain electrical parts and are dependent on electric currents or electromagnetic fields in order to function properly fall within the scope of the Directive. Printer cartridges which merely consist of ink and a container, without electrical parts, do not fall within the scope of the Directive.*" (European Commission 2014)

5.2.6.8. Driving force for implementation

As explained in section 5.2.6.7, it is understood that collection and recycling costs are a result of compliance with legislation, thus expected to incur regardless of how materials are recycled and reused. Thus, where these materials (in this case PET and PP plastics) can be reused through a closed-loop recycling mechanism; this would allow decreasing the demand for virgin plastics in production of new items, and thus for reducing expenses on virgin plastics. This reduction of expenses could offset some of the costs relevant for compliance with legislation concerning collection and compliance with WEEE legislation.

On 17 December 2013, the European Commission approved ecological criteria for the award of the EU Ecolabel for imaging equipment. Criteria listed in Annex I of this document which are of relevance for ink cartridges include the following (European Commission 2013):

- Criterion 10: Design for recycling and/or reuse of toner and/or ink cartridges;
- Criterion 11: Toner and/or ink cartridge take-back requirement. Specific requirements include that “the applicant shall offer to users a take-back system for the return, in person or by shipment, of toner and/or ink modules and toner and/or ink containers supplied or recommended by the applicant for use in the product, in order to channel such modules and containers to reuse and/or material recycling with preference given to reuse. This also applies to residual toner containers”.

The background report concerning the development of criteria for this product category provides some further detail concerning Criterion 10, addressing the area of reuse and recycling of cartridges: “In the framework requirements set by the EU Ecolabel Regulation 66/2010, one of the issues addressed is the potential to reduce environmental impacts due to durability and reusability of products to which this criterion is related. The aim of this criterion is to facilitate reuse and recycling of materials (thus reducing in this way the amount of new resources which have to be used if the end-of-life materials are not recovered) and to promote the products which are designed that way. Reuse and material recycling strategies on ink and toner cartridges contribute to resource conservation and to waste reduction” (Kougoulis et al. 2013).

Although eco-label requirements at present do not specify minimum thresholds for the use of recycled content in the manufacture of new cartridges, it is possible that such requirements could be included in the future.

In this sense, for some manufacturers, a further motivation for applying this BEMP in the future could be its potential to increase the recycled content of products as a means of complying with Eco-label requirements. Assuming the practice of this BEMP could enable the certification of a larger range of products, this would be beneficial both in terms of public relations and in terms of increasing competitiveness in tenders where green procurement guidelines are implemented.

HP have also mentioned that one of the main reasons, from as early as 1991, has been the general shift towards design for the environment and design for recycling (Kaminski 2014). This is also why prototypes of new cartridges are sent to the cartridge recycler to check recycling efficiencies and identify aspects that can be changed in design before mass-production (PDR 2014a).

Furthermore, enterprises who are motivated to reduce the environmental impacts of their manufacturing activities and who are attempting to develop their manufacturing processes in the direction of the circular economy, shall also find the possibilities of a closed-loop recycling mechanism for PET and PP plastics interesting.

5.2.6.9. Reference organisations

Reference organisations are:

- Hewlett-Packard (HP) - see details in the previous chapters;
- Canon – this company has also developed programs for collection and recycling of both ink and toner cartridges, though applicability in the EU may be limited in light of unclear availability of return points.[174]
- Lexmark – closed-loop laser toner cartridge recycling practice.[175]

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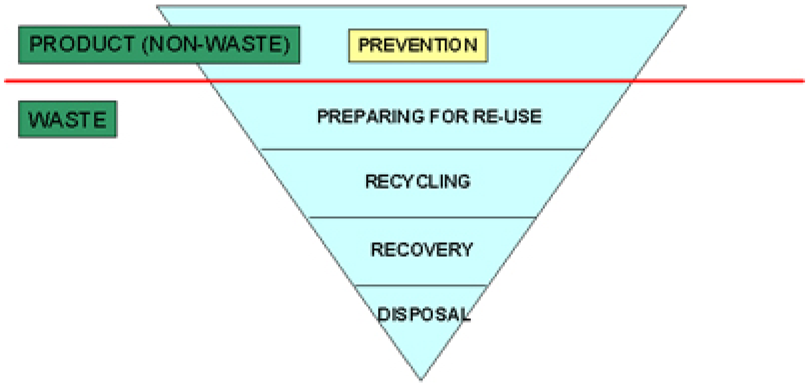
6. Recycling of waste from EEE

6.1. Scope

The scope of this chapter encompasses all activities which might assist in implementing the 5-step EU waste hierarchy as laid out in the Waste Framework Directive (2008/98/EC) (see Figure 6-1). The chapter therefore also addresses management practices in the field of waste prevention and re-use, and is not solely limited to recycling practices.

Figure 6-1: The EU Waste Hierarchy



Source: European Commission: Information on the Waste Framework Directive. Internet: http://ec.europa.eu/environment/waste/framework/ (retrieved: 31.10.2014).

Furthermore, the scope of this chapter is limited to activities that are typically carried out by companies that are classified as 'producers' in accordance with the EU WEEE-Directive (2012/19/EU), or by companies which are active in the recycling of waste electrical and electronic equipment (WEEE). Processes such as metal smelting and refining that might also be part of the WEEE-recycling chain are considered to be out of scope.

In specific, the BEMP *End-of-life removability of rechargeable batteries* (see section 6.2.1) describes a product-design option that facilitates recycling activities at the end-of-life. Although the focus of this BEMP is on the very beginning of the product life-cycle, it is still grouped in this chapter as the aim of this BEMP is to improve recycling via an appropriate design-for-recycling. The importance of this BEMP stems from the increasing market penetration of battery powered electronic devices and the significant consumption of raw materials for rechargeable batteries.

The following two BEMPs on *Integrated Product Service Offerings* (*IPSO)* and *high quality refurbishment* describe practices helping to prevent waste by refurbishing and re-use. While the BEMP on *Integrated Product Service Offerings* (section 6.3.1) describes a business model that offers economic advantages for hardware take-back, repair, refurbishing and sound recycling, the BEMP on *high quality refurbishment* (section 6.3.2) describes a type of refurbishment that holds the potential of significantly improving the quality and acceptance of second-hand EEE-products. Both BEMPs are applicable for a quite large variety of EEE-product segments so that its implementation holds large improvement potentials.

In contrast, the BEMPs on *non-destructive extraction of circuit boards* (section 6.3.3) and on *Innovative sorting solutions for black plastics from waste electrical and electronic equipment* (section 6.3.4) address improvement potentials within the recycling process for WEEE itself. They

have been chosen because they both offer significant environmental improvement potential, and are in principle applicable for a large range of waste electrical and electronic equipment (WEEE): While valuable and accessible printed circuit boards are mostly present in desktop PCs, spin-offs might also be realised for other types of WEEE. The BEMP on innovative plastic sorting is relevant for all types of WEEE as plastic is used in virtually every electrical and electronic product on the market. The overall trend to black plastic types in EEE, as well as new EU recycling-targets, render this BEMP additional importance.

The following table summarizes the developed best environmental management practices for recycling of waste from EEE and provides an overview of the addressed environmental pressures.

Table 6-1: Overview of the Developed BEMPs for Recycling of Waste from EEE and the Addressed Environmental Pressures

No.	Title of BEMPs	Environmental pressures addressed						
		Resource efficiency	Water	Waste	Emis-sions to air	Energy & climate change	Bio-diversity	Hazar-dous sub-stances
	END-OF LIFE							
17	End-of-life removability of rechargeable batteries	X		X				X
18	Integrated Product Service Offerings	X		X		X		
19	High quality refurbishment of used products	X		X		X		
20	Non-destructive extraction of circuit boards	X		X	X	X		X
21	Innovative sorting solutions for black plastics from WEEE	X		X				

Source: Own table

6.2. Description of best environmental management practice concerning the design for recycling

6.2.1. End-of-life removability of rechargeable batteries

6.2.1.1. Description

Rechargeable batteries (Li-Ion and NiMH) contain many critical and valuable materials such as cobalt, lithium and rare earth elements[176]. Data for the material compositions of typical Li-Ion and NiMH-batteries is displayed in Table 6-2. While there is a broad range of battery sub-types, cobalt-based Li-Ion batteries are most commonly used for consumer applications. This is mostly due to its outstanding properties in terms of capacity and power (Weyhe 2013).

Table 6-2: Material composition of commonly used Li-Ion and NiMH batteries (data refer to percent by weight)

Material	Cobalt-based Li-Ion batteries	NiMH batteries (prismatic cells)
Nickel	no data	38-40%
Iron & steel	22%	6-9%
Cobalt	18%	2-3%
Rare Earth Elements (La, Ce, Nd, Pr, Sm)	-	7-8%
Lithium	3%	-

Source: Own table according to data from Mählitz 2014, Kaindl et al. (2014)

Nevertheless, these materials can only be recycled if the batteries are fed into facilities specifically designed for battery recycling (e.g. Umicore Battery Recycling in Belgium or Accurec in Germany). Therefore, batteries need to be extracted from end-of-life devices such as portable electronics prior to end-processing. In this process step, it is important that the batteries are not damaged or broken as this can lead to short-cuts, overheating and fire. Thus, pre-processors have to extract the batteries in the first detoxification step, mostly applying manual labour. Nevertheless, portable electronic devices are increasingly designed in a way that makes battery removal difficult and/or time-consuming. According to ACEA et al. (2013) such designs are chosen for the following reasons:

- Producers want to utilise all available space for batteries and therefore try to save space that would be needed to insure easy removability (e.g. clip connectors);
- In some products, safety reasons such as use in moist environments or under other harsh conditions might limit the design-options facilitating easy removability.
- Battery exchange in the use-phase carried-out by non-qualified personal can lead to damages to the device or the use of non-compatible batteries.

Despite this trend, a variety of products are still design allowing an easy and quick removal of rechargeable batteries in end-of-life processing. This BEMP describes options for the design of

176 Rare earth elements are predominantly used in NiMH batteries.

products facilitating a sound and cost-efficient removal of rechargeable batteries from portable electronic devices.

It includes all design options that allow the extraction of batteries

- without damage to the batteries;
- without the use of tools;
- and with a manual labour input of not more than a few seconds per device.

The rational for these framework conditions is displayed in Table 6-3.

Table 6-3: Criteria for good removability of rechargeable batteries

Criteria	Rational
Without damage to the batteries	Damaged batteries can be subject to short-cuts, overheating and fires. For this reason, battery recyclers do not accept shipments containing damaged batteries.
Without the use of tools	Although Annex VII of the European WEEE-Directive (2012/19/EU) requires that batteries "have to be removed from any separately collected WEEE", the Final Draft of the Standard FprEN 50625-1 on Collection, Logistics & Treatment for WEEE requires that only "batteries that are accessible in the equipment without using tools shall be removed from WEEE before any treatment process that can cause damage to them". Thus, only product designs that allow the removal without tools can ensure high-quality recycling.
With a manual labour input of not more than a few seconds per device[177]	Labour costs are a critical aspect in recycling. If the labour input is too high, manual battery extraction cannot be profitable. Most recyclers only attempt once to extract the battery from a portable electronic device manually. If the battery is not retrieved during this first and only attempt, it will be recycled together with the host device, even if this leads to losses of materials (Manhart 2012).

Source: Own table

The removal of waste batteries is also regulated in Article 11 of the Battery Directive (2013/56/EU amending Directive 2006/66/EC). The aim of this regulation is to improve the exchange of batteries in the use phase of products. Nevertheless, improved removability during the use phase does not necessarily affect end-of-life removability:

- The removal and exchange of the battery during the use phase is significantly less time-sensitive than the battery extraction during product recycling. While labour input in the range of minutes is acceptable for a battery exchange in the use phase, end-of-life removal should not consume more than a few seconds of manual labour per device. Thus, a good use phase removability might be achieved by using e.g. screw connections that do not necessarily support a quick and effective end-of-life removability.

[177] To date, no absolute time limit can be specified for this criterion. Ideally, implementing companies should try to further specify this criterion in co-operation with recycling enterprises.

- The removal and exchange of the battery during the use phase has to be carried out without any damage to the equipment. In contrast, during end-of-life removal of the battery, a certain level of damage to the equipment (not the battery) is acceptable.

This BEMP explicitly addresses battery removability in the recycling stage of portable electronic devices (end-of-life removability). An implementation of this BEMP is therefore not mandatorily required by the new Article 12 of the Battery Directive that enters into force on 1 July 2015.

6.2.1.2. Environmental benefits

This BEMP is particularly relevant in terms of resource efficiency that can be increased by a better recycling of rechargeable batteries. There is an existing infrastructure in the EU for the recycling of Li-Ion and NiMH batteries. Amongst others, the company Umicore Battery Recycling (Belgium) has industrial capacities for the recycling of undamaged Li-Ion and NiMH batteries[178] to recover materials such as copper, cobalt, nickel and rare earth elements (UBR 2014).

Regarding raw material efficiency, recycling is particularly relevant for cobalt. This is due to the following circumstances:

- 27% of the world's primary cobalt supply is used for rechargeable batteries, which is the biggest single application for this metal (BGS 2010).
- Around 50% of the world's primary production of cobalt is mined in the Democratic Republic of the Congo (USGS 2014). Other sources such as the EU (2014) and BGS (2013) suggest an even higher share of this top production rate for that country ranging from 56% to 72% in 2011.
- Cobalt mining in the Democratic Republic of the Congo is associated with widespread informality and absence of social and environmental minimum standards. In addition, some of the mined cobalt deposits are associated with radioactive substances and heavy metals, which are not properly managed in most of the local extraction and concentration processes (Tsurukawa et al. 2011).
- Cobalt and cobalt-containing ores are – despite the importance of conflict-affected DR Congo for cobalt sourcing – currently not classified as "conflict minerals" under Section 1502 of the Dodd-Frank Act[179]. Nevertheless, cobalt might in the future be covered by this conflict mineral regulation once determined by the U.S. Secretary of State to be financing conflict in the Democratic Republic of the Congo or an adjoining country (see section 1502 of the Dodd-Frank Act).
- Cobalt is regarded as "critical raw material" in the EU, which means that it is considered to have a high economic importance to the EU combined with a high risk associated with its supply (EU 2014).

Therefore, design-for-recycling that enables improved cobalt recycling has significant benefits, from the environmental point of view.

[178] Damaged batteries are typically not accepted by recyclers in order to reduce the risks for fires and explosions during transport, storage and handling.

[179] Dodd-Frank Wall Street Reform and Consumer Protection Act.

6.2.1.3. Appropriate environmental performance indicators

The performance should be measured in terms of percentage of devices brought on the market that comply with the criteria displayed in Table 6-3. Ideally, the compliance with the criteria should be tested under real-life conditions, such as in a recycling facility specialised in the pre-treatment of electrical and electronic equipment.

In addition, product quality test should ensure that the chosen design strategies do not negatively affect product durability.

6.2.1.4. Cross-media effects

Design strategies aiming to comply with the criteria displayed in Table 6-3 have to make sure that they do not negatively impact product durability. As illustrated in section 6.3.2.2, a long product lifetime is one of the most important means of reducing the overall life-cycle impacts of many electrical and electronic products. Thus, it is crucial that design strategies do not have any negative impacts on durability.

Other cross-media effects might result from additional material requirements, e.g. in terms of additional parts and components required to implement a design that realises both, a sound use phase removability according to the Battery Directive (2013/56/EU amending Directive 2006/66/EC), as well as a sound end-of-life removability in line with the criteria of Table 6-3.

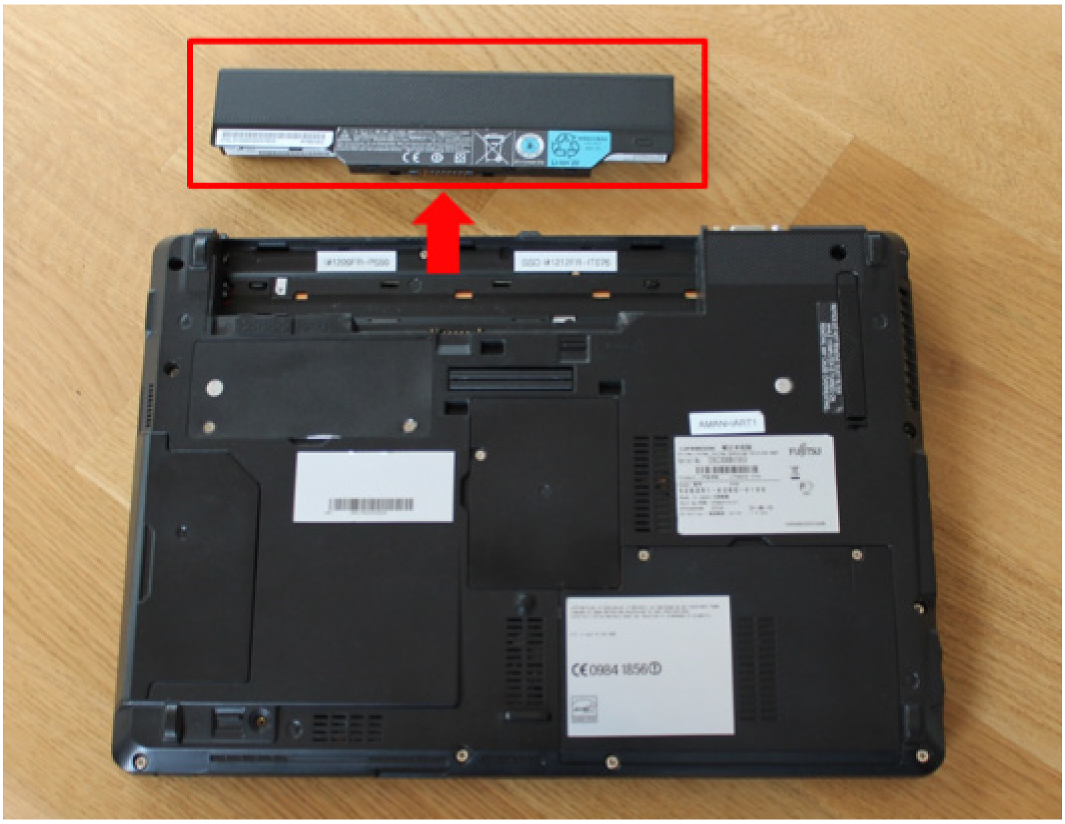
6.2.1.5. Operational data

The type of implementation of the criteria displayed in Table 6-3 strongly depends on the product type. While the batteries of cordless screwdrivers are often clipped to the handle by a simple but reliable mechanism (see Figure 6-2), notebooks are also mostly designed so that the battery pack can be easily removed by activating a clip mechanism without using tools (see Figure 6-3).

Figure 6-2: Rechargeable battery of a cordless power drill

Photography: Manhart, A. (2014), Oeko-Institut e.V.

Figure 6-3: Rechargeable battery of a notebook



Photography: Manhart, A. (2014), Oeko-Institut e.V.

In contrast, most smartphones and tablet PCs have batteries that are either glued into the device, or fixed with several screws. A study by Schischke et al. (2013) found out that only one out of 21 examined tablet PCs on the market was equipped with a battery that could be removed without the use of tools.

Nevertheless, individual product designs such as the one illustrated in Figure 6-4 can provide both, use phase removability in line with the Battery Directive, as well as end-of-live removability in line with the criteria of Table 6-3.

Regarding tablet PCs, devices such as the *Dell Venue 11 Pro*[180] already fulfil the criteria of Table 6-3. This is achieved by a back cover that can be lifted and removed without the use of tools (solely by the use of fingertips/fingernails) and a battery that is readily accessible after lifting the back cover (Brintrup 2014).

[180] The example was chosen to illustrate the general applicability of this product design for tablet PCs. It does not necessarily mean that Dell – with its whole product portfolio – can be regarded as a frontrunner in implementing this BEMP.

Figure 6-4: Rechargeable battery of a smartphone

Photography: Manhart, A. (2014), Oeko-Institut e.V.

6.2.1.6. Applicability

This BEMP is applicable to all portable electrical and electronic equipment powered with rechargeable batteries. This includes (but is not limited to):

- Notebooks
- Tablet PCs
- Mobile phones
- Digital cameras
- Cordless power tools

Devices such as electrical toothbrushes are boundary cases for applicability as they are typically used in conjunction with water and moist environments. Thus, product design must particularly address product safety and durability, which might leave less room for design options allowing a sound end-of-life removability. Nevertheless, also in such cases, end-of-life removability in line with the criteria of Table 6-3 could possibly be achieved by predetermined breaking points that are solid enough to withstand undesirable effects resulting from daily use (e.g. drops onto hard floors), but not wilful damage such as beating the device onto a hard edge.

6.2.1.7. Economics

The implementation of this BEMP is believed to be cost neutral for most devices. This is particular the case for changes in established product designs that use synergies with the efforts to comply with the amendment (2013/56/EU) to the Battery Directive (2006/66/EC) that enters into force on 1 July 2015. As many manufacturers – in particular in the field of tablet PCs and mobile phones – have to adopt their product designs in relation to rechargeable battery as a consequence of this regulation, these re-design efforts could be synchronised with voluntary efforts to improve end-of-life removability.

In the mid- and long-term, design strategies to improve product recycling might have positive economic impacts as this could also positively influence the cost structure of recycling enterprises. As the European WEEE Directive (2012/19/EU) enforces the principle of *extended producer responsibility*, producers will indirectly benefit from these improved cost structures.

6.2.1.8. Driving force for implementation

A driving force for implementation is the economic and political debate around *critical metals* (see section 6.2.1.2), which is widely seen as a starting point to tap improvement potentials in terms of efficient use and recycling[181].

6.2.1.9. Reference organisations

In the field of cordless power tools, notebooks and digital cameras, the BEMP is already applied by a large number of producers. The situation is different in the field of tablet PCs and smartphones. Although a number of models exist where this BEMP is implemented, there is no producer who systematically uses it for all product models.

6.2.1.10. Chapter references

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BGS (2013) British Geological Survey; World Mineral Production 2007-2011; Keyworth 2013.

181 With the amendment (2013/56/EU) of the Battery Directive (2006/66/EC) that enters into force on 1 July 2015, manufacturers have to comply with the new Article 11 on the *Removal of waste batteries and accumulators*. Although this article addresses the exchange of batteries in the use phase of products (see section 6.2.1.1), it will be necessary to change many product design strategies. This change in product design related to rechargeable batteries can be used to develop solutions that also enable a quick and easy removal of batteries at the end of the product life.

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6.3. Description of best environmental management practice concerning recycling operations

6.3.1. Integrated Product Service Offerings (IPSO) with improved collection, repair and recycling

6.3.1.1. Description

Prevention of waste throughout the whole life cycle of products is in the core of environmental management under the framework of EMAS. Companies that aim at continuous improvements of their environmental performance can achieve this target by implementing Integrated Product Service Offerings (IPSO) (Lindahl et al. 2014). This business concept goes by a variety of names, i.e. leasing, Servicing, or Product Service systems (PSS) (Fischer et al. 2012; Plepys et al. 2014; Reim et al.). IPSO business models build on the idea that revenue is created by selling utility instead of products. Selling utility combined with services has a higher degree of value creation than selling products alone. The UNEP states that "*PSS can produce synergies in profit, competitiveness and environmental benefits*" (Manzini & Vezzoli 2002). For the EEE sector, IPSO bring about new opportunities for the creation of revenue and environmental improvements.

The underlying concept of IPSO (or PSS respectively) is based on product service contracts with clients or customers. The UNEP defines a Product-Service System "as the result of *an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands" (Manzini & Vezzoli 2002).* The European vision of a leasing society formulates as follows: "*the aim of business is to meet customer needs in the best possible way. Both innovative business models and customers willing to make greater use of product-service systems are needed to turn the economic and environmental potential of a leasing society into a reality*" (Fischer et al. 2012).

In a business-as-usual regime, product manufacturers create revenue by selling products to customers. However, the customers' prime objective when buying a product is normally to use the function of a product rather than to own the product itself. Thus, the ownership of an EEE product is often a vehicle to acquire a certain utility (e.g. washing machines → cleaning cloths, routers → connecting to the internet). This aspect is particularly relevant for products that come with high purchasing prices and ownership costs (e.g. for maintenance, security updates) and impose liability of ownership (e.g. safety checks, insurance, permissions). The product manufacturer, on the other hand, loses a lot of business opportunity if the customer relation is limited to the point of sale. Many product manufacturers have realised that selling utility instead of products boosts customer retention and generates extra business opportunities. The original product manufacturer can harness competitive advantages in the service market. He can adjust the product design so as to maximise the generation of utility as the source of revenue and benefits from economy of scale to keep ownership costs low. Hence, it is economically beneficial for all parties (product manufacturers and customers) if the product ownership remains with the producer.

Product Service Systems are already well established in a business-to-business (B2B) context. As an example, OEMs in the EEE sector are often themselves customers of Integrated Product Service Offerings (IPSO) for assembly lines and chemical management services. In this context, many OEMs have outsourced the management of manufacturing equipment and instrumentation to service contractors, who own the assembly lines and sell production capacity to OEMs. Installation, maintenance, and operation of equipment remain in the ownership of the subcontractor. In turn, OEMs are relieved from maintenance and can focus on their core business (technology development and marketing of EEE products).

The shift from a product sale to IPSO-oriented business paradigm requires also new pricing models. IPSO pioneers, such as Xerox and Philips Lighting introduced a Pay-per-Use pricing model where the client pays for a service unit instead of a product. In the case of Xerox, the service unit is a copy. Philips Lighting offers customised illumination, for instance in buildings, working places, or streets. The service unit is calculated in lux (SI unit of illuminance). The development of adequate pricing models requires a deep understanding of the provider's own business as well as customer needs in a service-oriented market.

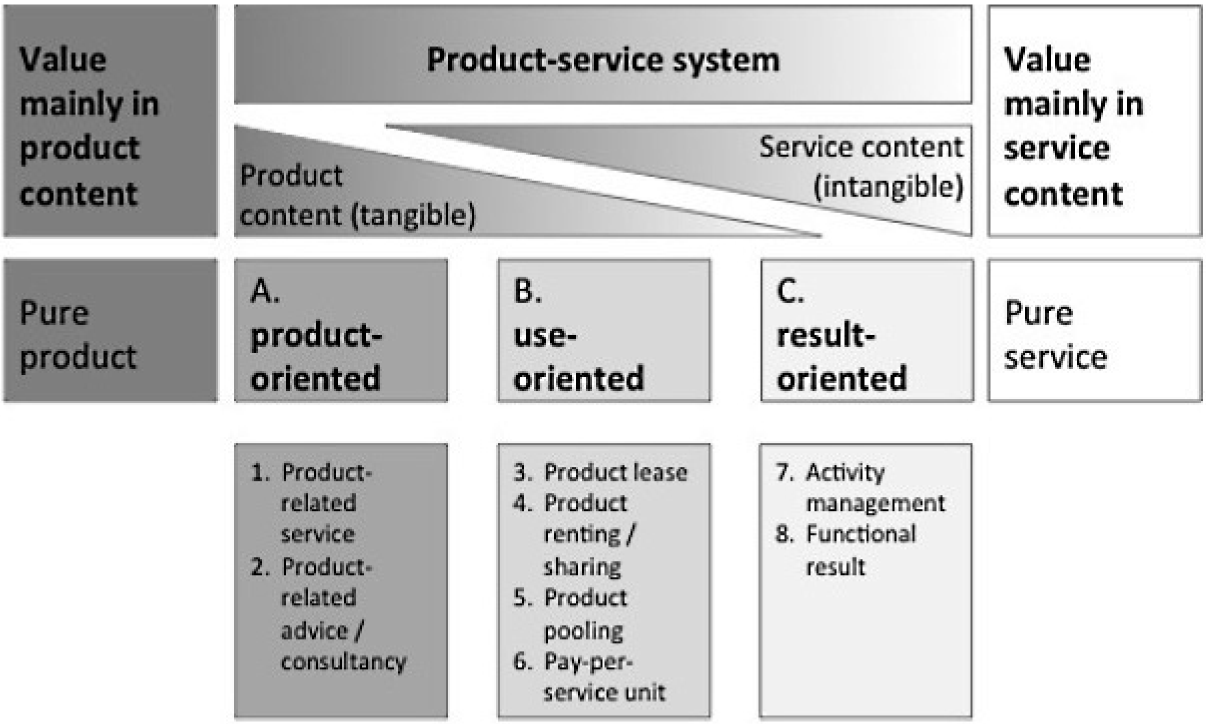
This BEMP provides inspiration on how the business model of product service offerings could be extended into the business-to-consumer (B2C) market and into the domain of public procurement, where IPSO-models are not yet widely established. In the B2C context, product-service bundles are offered to private or public customers just like the aforementioned B2B example of manufacturing equipment. This brings about advantages from the environmental perspective. IPSO business models hold incentives for product manufacturers to optimize the functional and environmental performance of their products, in particular related to product durability, maintenance, reparability and therefore waste prevention and re-use. This is the case, because improvements in hardware design will have a direct impact on the cost structure of the service part of offerings. Depending on the type of IPSO, this might also apply to energy efficiency[182].

Establishing product/service-based business models is an innovation process that requires product manufacturers to extend their perspective beyond the point of sale. Becoming a service provider necessitates much closer communication with consumers and public clients. Typically, this yields better insights into their actual needs and might inspire product innovation. As indicated above, cost-benefit analysis carried out for product development under the conditions of IPSO can also lead to an improved environmental performance.

However, such improvements will not come to pass by mere incident – they should be a separate part of a company's environmental policy and innovation strategy. Therefore, this BEMP explicitly covers IPSO models that lead to an improved collection, repair and recycling of EEE.

[182] Producers only have a direct incentive to optimize energy efficiency, if the costs for energy in the use-phase are part of the integrated product service offering.

Figure 6-5: The product-service system and its subcategories



Source: Fischer et al. (2012), cited after Tukker et al. (2006)

6.3.1.2. Environmental benefits

From the environmental perspective, there are various benefits to be gained from the implementation of product/service-based business offerings. The following environmental benefits can relate to IPSO and are in the core of this BEMP:

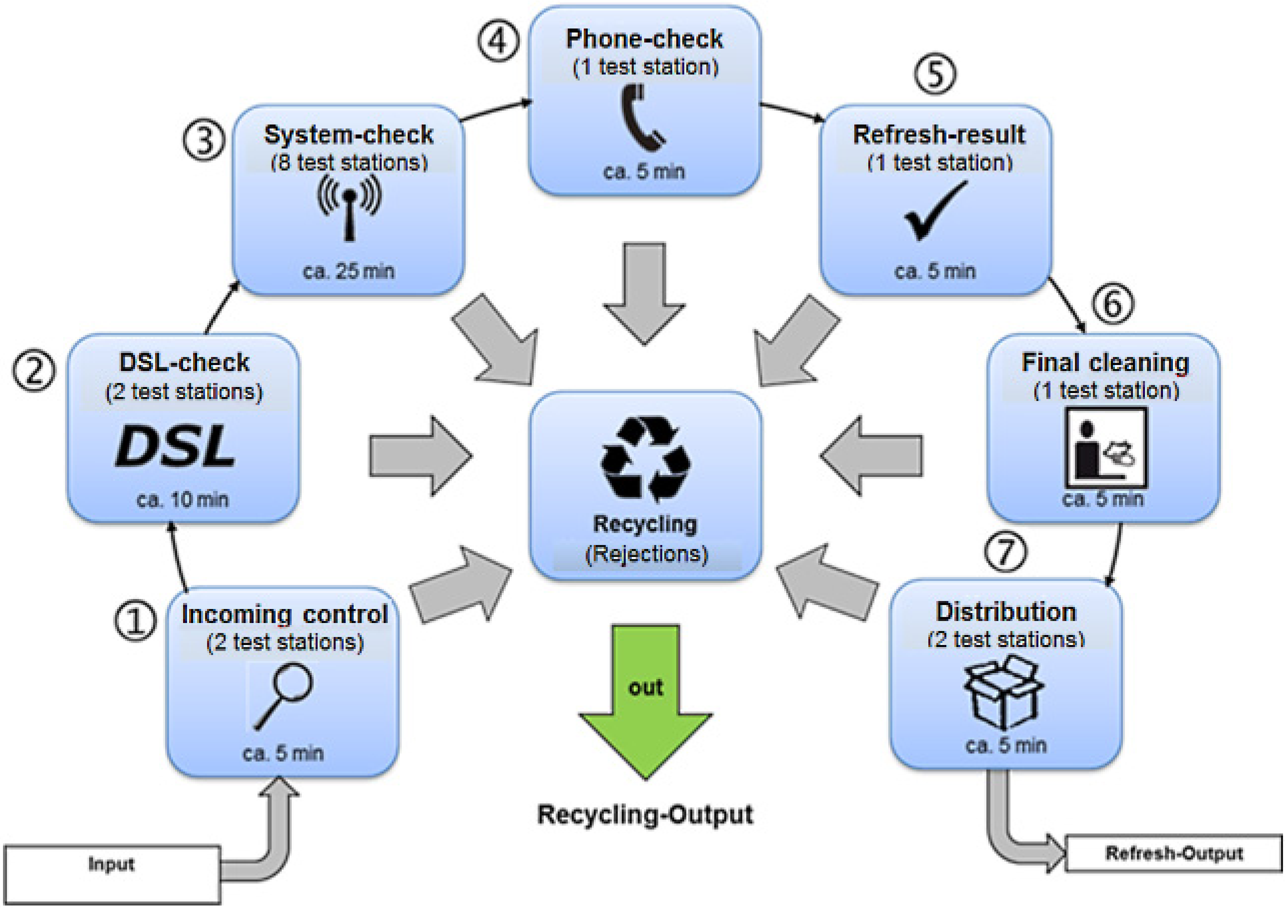
- Extension of product durability by means of design for repair and refurbishment (thus, indirectly resulting in a reduced demand for new products) (Bakker et al. 2014; Tukker 2013);
- WEEE prevention by implementation of operations for repair, refurbishment, repurposing, and recycling.

The primary objective of IPSO business models is to create new market opportunities for companies and to build up better customer relations. Environmental benefits are mostly regarded as side effects of this objective. However, many environmental improvements are beneficial for a company in regard to cost saving and increased revenues from green business operations. Under the IPSO regime, profits are higher if utility can be created with fewer numbers of products produced. UNEP illustrated numerous win-win situations where economic and environmental benefits go hand in hand. For instance, "*minimising costs for a long-lasting serviceable product*" (Manzini & Vezzoli 2002).

Unfortunately, there is limited publicly available data quantifying the environmental benefits of individual IPSO models. One of the few studied cases is the leasing service for internet routers for private households in combination with contracts on internet access offered by Deutsche Telekom AG (Prakash et al. 2011). Since 2009, customer equipment, such as DSL routers, media receivers, telephones, and teleconferencing equipment are rented out to be operated in the customers' premises during the contract period. The used equipment can be returned to Deutsche Telekom in case there is a need for maintenance. Software updates can be done remotely. Deutsche

Telekom's leasing model guarantees a take-back rate of 100% for post-consumer devices, which is a significant improvement compared to an average EU collection rate of 27,8% for IT and telecom equipment (Huisman et al. 2007). In contrast to a purchase model, the post-consumer products do not automatically turn to WEEE after decommissioning from the first user. After take-back, Deutsche Telekom sends the used devices to a so-called 'refreshing process' (Figure 6-6), where the devices are checked and refurbished. Approximately 30% of the devices are refurbished and can be reused. The rest is sent to a WEEE recycling plant where materials are recovered.

Figure 6-6: Router refreshing process at Deutsche Telekom AG



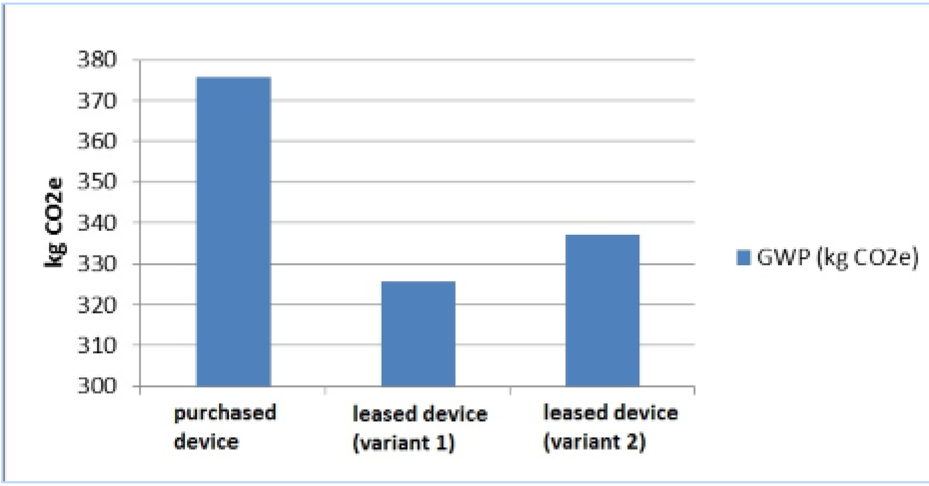
Source: Prakash et al. (2011)

According to Telekom, the environmental benefits comprise two major aspects: 1) the extension of product service life and 2) the increased recovery rate in recycling processes. For instance, the recycling of uniform devices allows for larger amounts of plastic to be recovered due to the absence of foreign plastics (Kröhling 2014). The LCA-based comparison of a leasing vs. buying scenario provides a comprehensive picture of environmental impacts. The LCA results for the Speedport internet router demonstrate that Telekom's leasing offering has environmental benefits. Figure 6-7 illustrates that the Global Warming Potential (GWP) of the leasing model[183] is lower by 11 to 15 percent than that of the "buy model". The environmental benefit stems from the avoided

[183] Functional unit: access to a functioning Internet router for a period of six years

manufacturing of new devices. Even a refurbishment rate of only 50% (variant 2) is shown to result in environmental net benefits in comparison to the buy model[184].

Figure 6-7: Comparison of purchased vs. leased[185] Internet routers in terms of global warming potential (GWP)



Source: Prakash et al. (2011)

Further indications of potential environmental benefits are illustrated in the following examples:

- Xerox has switched from selling printers to offering comprehensive document management to clients (Fischer et al. 2012). The offering encompasses a leasing of its products including full service maintenance at a fixed price per copy. Nowadays, this business model generates about 50% of the company's total revenues. Xerox runs also a product take-back scheme as integral part of the leasing service. The used products and their parts are remanufactured and can be used again. Such operations are profitable because Xerox optimized the design of its products for easy disassembling / remanufacturing and for better material recovery. According to Fischer et al. (2012), this enables a recycling rate of 94% for non-hazardous components of end-of-life copiers.
- Ricoh, a manufacturer of office printing and copying equipment is named as a pioneer in providing managed document production and IT services (Ellen Macarthur Foundation 2012). Ricoh's Comet Circle™ offering encompasses the complete life-cycle of printing and copying equipment, starting with product design for reuse and recycling. The company aims at reducing the consumption of new resources by 25% by 2020 and by 87.5% by 2050, compared to the 2007 level (ibid). Ricoh's GreenLine label expresses the company's commitment to resource recirculation.
- Electrolux has tested the IPSO business model for textile cleaning[186] in private households. The offering encompassed the function of textile cleaning in form of a 'pay-per-wash' contract. In place of selling washing machines, the equipment was leased to households (Fischer et al.

[184] Here, it needs to be stressed that other existing IPSO-models related to telephone and internet access are often not optimized for improved collection, repair and recycling. Despite being the owner of hardware components, in many cases service providers ask consumers to dispose-off used and end-of-life EEE by themselves. With such practices, none of the described environmental improvement potentials are harnessed.

[185] Variant 1 assumes a 100% re-use rate for *service-Pool-devices and* Variant 2 assumes a 50% re-use rate.

[186] http://www.ellenmacarthurfoundation.org/business/toolkit/in-depth-washing-machines#fn11

2012). The demand monitoring of the utility (number of laundry cycles per washing programme) in the users' homes was realised by means of smart meters. Next to the rental cleaning equipment, the servicing concept included training, guaranties on machine performance, and equipment take-back for recycling. Taking Electrolux household appliances as a case study, Sundin (2003) conducted a LCA-based comparison of new product manufacturing and a repair/refurbishment scenario. Table 6-4 shows the LCA results for a washing machine and a refrigerator. The findings suggest that repair/refurbishment of used goods creates substantial environmental benefits over production of new replacement goods. The test run of Electrolux demonstrated that resource savings and WEEE reduction were possible in a profitable business (Sundin 2003, p. 58).

Table 6-4: LCA model of washing machine and a refrigerator: new production versus repair and refurbishment based on an IPSO-model

Functional Unit	Refrigerator			Washing Machine		
Scenario	Remanu-facture	Recycle	New Prod.	Remanu-facture	Recycle	New Prod.
Resources						
Non-renewable material (kg)	1.4 (1.5)	0.8	189.4	1.5 (1.5)	0.1	120
Renewable material (kg)	0.2 (0.2)	-	1.1	0.2 (0.2)	-	2.0
Energy (kWh)	20 (23)	16	1182	24 (24)	2.8	750
Emissions						
Greenhouse Gases (kg CO_2-eqvivalents)	2.5 (3.7)	7	214	2.4 (2.4)	0.2	160
Acidifying gases (mol H^+-eq)	0.0004 (0.2)	1.4	19.5	0.001 (0.01)	0.04	29.1
Ground level ozone gases (kg C_2H_4-eqvivalents)	0.002 (0.004)	0.009	0.004	0.002 (0.002)	-	0.1
Eutrophication compounds (kg O_2-eqvivalents)	0.2 (0.2)	0.3	14.3	1.3 (1.3)	0.05	2.5
Recyclable resources						
Materials (kg)	0 (12.7)	76.4	6.4	0 (7.5)	45.1	5.2
Waste						
Hazardous (kg)	0.003	-	0.23	0.002 (0.09)	0.5	2.0
General (kg)	1.1 (3.3)	13	160	1.3 (1.3)	0.1	198

Source: Sundin (2004)

6.3.1.3. Appropriate environmental performance indicators

Generally, it needs to be stressed that the implementation of an IPSO business models alone does not automatically lead to environmental improvements. According to the definition of this BEMP, IPSO can be used as a means to improve collection, repair and recycling of used and end-of-life EEE. This already sketches the fields where environmental improvements can most likely by achieved. Nevertheless, due to the complexity of such business models, the environmental performance of Integrated Product Service Offerings cannot be measured by simple comparison with products. Due to the larger system boundary of servicing contracts, a more holistic approach should be employed. Life cycle assessment is an appropriate methodology to evaluate and benchmark the environmental benefits of products and services (and combinations thereof).

The implementation of IPSO by manufacturing is thought to generate greater attention for environmental aspects during the use phase and end-of-life stage of products (Sundin & Lindahl 2008). To this end, a rough control of environmental aspects of IPSO can also be done by monitoring the development of the following direct indicators:

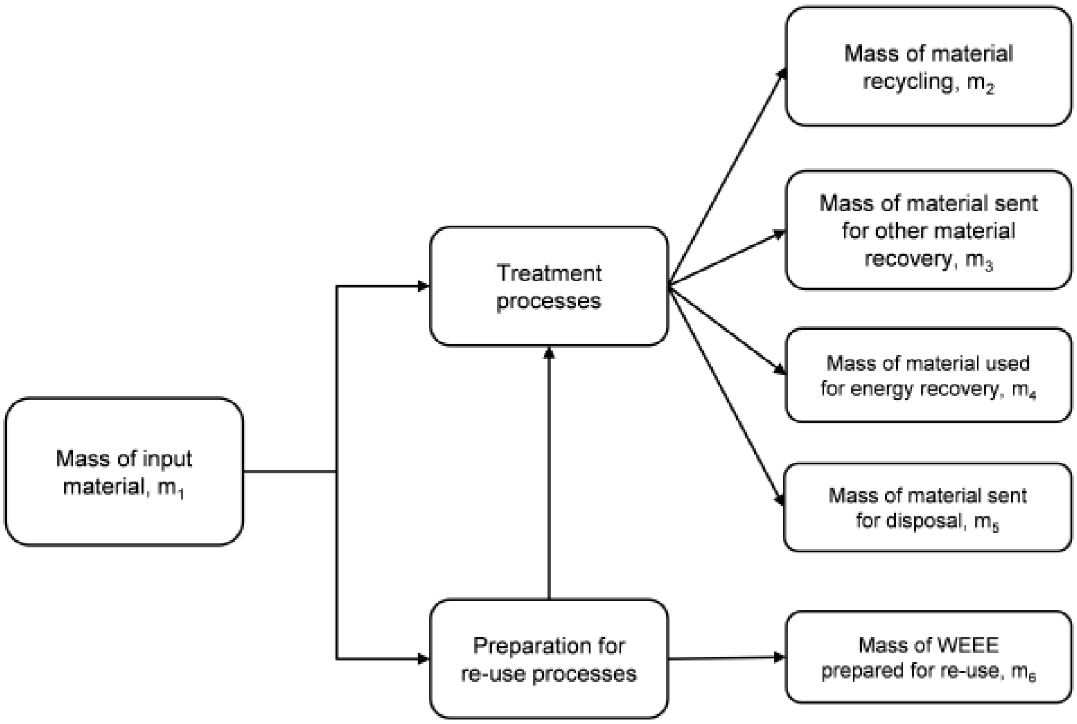
- take-back rates per product category (in percent),
- reused devices in relation to all devices installed (in percent),
- average life-time of hardware,
- re-use rate,
- recycling rate.

The latter two indicators can be measured on the level of the refurbishing and recycling facility by using the procedures laid out in Annex C of the Standard EN 50625-1 on *Collection, logistics & Treatment requirements for WEEE – Part 1* (CENELEC 2013). In general, the calculation of reuse- and recycling rate is based on the glow chart illustrated in Figure 6-8 and uses the following formulas:

Re-use rate = m_6 / m_1

Recycling rate = (m_2 + m_6) / m_1

Figure 6-8: Flow chart used to calculate re-use and recycling rate



Source: CENELEC (2013)[187]

However, the aforementioned simple performance indicators have their disadvantages as they do not sufficiently consider the trade-offs between environmental benefits and the additional environmental benefits resulting from aspects such as transports, energy consumption of the processing of reused devices and spare parts (also see section 6.3.1.4).

[187] Reproduced by permission of DIN Deutsches Institut für Normung e.V. The definitive version for the implementation of this standard is the edition bearing the most recent date of issue, obtainable from Beuth Verlag GmbH, Burggrafenstraße 6, 10787 Berlin, Germany.

It is therefore useful to conduct Life Cycle Assessment (LCA) at least one time to develop a holistic understanding of environmental impacts. LCA is a scientifically grounded and internationally standardised method (see section 5.2.5) used to analyse different processing scenarios or technical treatment alternatives. It also allows a comprehensive comparison on the basis of evidence-based impact categories.

6.3.1.4. Cross-media effects

As illustrated in section 6.3.1.2, measures to extend the life-time of electrical and electronic equipment have mostly environmental net benefits. But it also has to be taken into account that prolonged use-phases also mean that devices stay in use that might have a lower energy efficiency than that of new product models. Nevertheless, various life-cycle studies have shown that in most cases net gains prevail and are particularly pronounced for devices that:

- Have a relatively high percentage of environmental life-cycle impacts during production and transport;
- And that will most likely experience only limited energy efficiency improvements in the foreseeable future.

Other negative environmental side-effects might result from integrated product service offerings that require significant additional transport efforts (e.g. in cases in which hardware for delivering a physical service such as washing clothes is centralised). As laid out in section 6.3.1.3, it is recommended to conduct an LCA analysis on individual IPSO models to get an overview about environmental benefits and additional efforts.

In case that repair, refurbishing or re-use require the movement across country-boundaries, it is noteworthy that this might require notification procedures according to the rules of the Basel Convention (see section 6.3.2).

6.3.1.5. Operational data

The implementation of IPSO can be approached in coherence with the core idea of EMAS, i.e. the continuous improvement of environmental performance. Against this background, the establishment of IPSO can be seen as an iterative process. It may start with small pilot projects which serve as a base for market exploration and generation of operational know-how. The plan-do-check-act cycle (see Figure 6-9) serves as a management instrument for the transition process towards improved resource efficiency (European Commission 2011). Along these lines, the implementation of integrated product service offerings requires a number of elements, which can be classified as follows:

Plan:	1. Introduction of a service-oriented culture in a company 2. Revision of a new pricing model for products and service offerings
Do:	3. Interlinking support offerings with customer relations and new product design processes 4. Capacity building for customer support, maintenance services, and delivery/take-back logistics 5. Set-up or contracting of repair/refurbishing centres
Check:	6. Establishing a monitoring system for economic and environmental improvements
Act:	7. Review of lessons learned from IPSO implementation and decision making towards next steps to be taken

Figure 6-9: The plan-do-check-act cycle according to EMAS

Source: European Commission (2014)

The remainder of the section suggests best practice approaches to implement the IPSO model through the application of the plan-do-check-act cycle. This work may be undertaken in the framework of an EMAS registered corporate environmental management system (Worthington, 2012).

Regarding 1:

The shift towards IPSO necessitates the endorsement of a service-oriented culture within a company. Top management commitment is a key driver in the proliferation of client-oriented attitudes among employees. For instance, service and repair requests should not be considered as costs but rather as opportunities for better customer relations. Furthermore, the take-back of used-product from customers should be organised as part of the offering rather than as an act of waste disposal. This is instrumental for the creation of awareness and acceptance for refurbished products, and will also return insights in the actual performance of products in the context of a service life cycle.

Regarding 2:

The development of IPSO necessitates a paradigm shift in the ways of revenue creation: the sale of products to customers is being replaced by revenue creation via long-term customer relationships. To be profitable, many IPSO providers have developed modular product portfolios that are easily adoptable to their service portfolio. For instance, the scalability and compatibility of product modules should be increased. Market research may be necessary in order to pinpoint competitive price models for product/service offerings. Price models should not only encompass production and service offerings but also reverse logistics, refurbishment, and recycling operations. These aspects of the pricing models should be clearly communicated to the customers in order to raise their awareness for hidden costs of ownership (which can be lowered by means of IPSO).

Regarding 3:

IPSO necessitates the creation of tailored offerings for their clients and implies a much deeper interaction with them. For instance, service staff will be the primary interface between the company and clients. This influences the organisation of the whole value creation process in a company. The economic success of IPSO providers depends on the fruitful cooperation of different corporate divisions, including design & development, supply chain management, production, customer relations and marketing, changes. The design of products for the service market requires initial investments in product innovation and customer relations. An overhaul of product design specifications may be necessary in order to establish repair and refurbishment as important aspects in the design brief of new products. This may require closer interlinkage between service and product design. Thus, the internal communication channels between different departments should be improved. This is essential in order to tap the knowledge of service personnel and utilize it for the improvement of next product generations.

Regarding 4:

The introduction of combined product/service offerings necessitates the strengthening of a company's own service capacities. The service personnel will be more responsible for sales and also acts as a source of knowledge for the design division. Against this background, the service must become part of the core business. Outsourcing the maintenance service is no longer a sufficient strategy, as it hinders intense customer interactions. Instead, the company's own service capacities should be enhanced. The strategic build-up of capacities encompasses staff training and the acquisition of external know-how. Moreover, the take-back of used products from service contracts requires the development of reverse-logistics capacities. This can be supported by subcontractors, but the company should make sure that the outsourcing of customer contacts does not impede the communication with clients.

Regarding 5:

Product-service providers can benefit from economy-of-scale in end-of-life treatment because they get access to large amounts of identical post-consumer devices. Thus, the set-up of adequate repair and refurbishment capacities is necessary. For this purpose, a company may seek for business alliances, for instance with logistic providers and recycling businesses. Some companies opt for the internalisation of this business segment in order to take better advantage of knowledge generated in the course of product maintenance. Information regarding hardware performance and possible failure modes can be fed into the improvement of future products. Moreover, some companies internalise the recycling operations of own products in order to get hold on critical raw materials contained therein. This objective may require innovations in recycling processes (sorting, dismantling, separation, and conditioning) because existing recycling technologies are often insufficient to retrieve critical materials from WEEE (Chancerel 2010). Innovations in end-of-life treatment go hand in hand with innovations in 'design for recycling' because the product design determines the economic and environmental feasibility of refurbishment and recycling.

Regarding 6:

The process of implementation IPSO business cases generated a lot of new experiences for companies. A systematic monitoring is indispensable for a successful transition from product-sales towards product-service market. The monitoring program is a long-term undertaking that must be established right from the beginning. It starts with planning for appropriate performance indicators, such as number and duration of service contracts, customer needs satisfaction, product performance under condition of leasing models (e.g. product lifetime, frequency of maintenance requests, failure rates and modes, speed of service response). Further, the effectiveness of reverse logistics and product refurbishment should be monitored as well as refurbishment and

recycling rates. For the sake of further improvements, it is not enough to gather data, but also to aggregate and analyse them appropriately. It is helpful to establish key performance indicators. Moreover, the environmental performance can be analysed in detail by means of LCA. This tool allows an in-depth analysis of possible trade-offs between different aspects in an IPSO business, such as the balance of environmental impacts of hardware recovery versus transports. Section 5.2.5 provides more details on best practices in LCA implementation.

Regarding 7:

The quest for continuous improvements does not stop after implementation of a first IPSO pilot. Whether successful or not, lessons can be learned and conclusions for strategic improvements can be drawn in both cases. The check step includes a review of implementation strategies, strengths and weaknesses of the company in the product service market, and the identification of new opportunities and threats. The review should also reconsider the servicing approach and the customers' response to it. Here, the hand-on experiences gathered by service staff is a valuable asset. In regard to the environmental performance, the achievements in resource efficiency can be evaluated based on key-figures regarding refurbishment rates and recovery rates of secondary raw materials during recycling. The balance may indicate improvement potentials towards better utilisation of used components. This recognition would lead to revision of design briefs for new product generations (aiming at higher use of refurbished components). That leads directly to the next plan-do-check-act cycle.

6.3.1.6. Applicability

IPSO models are already widely established in the B2B segment. Regarding the application in the B2C segment, there are only few examples that have taken over significant market shares in the last years. One such example is internet access, which is today commonly enabled by product/ service bundles.

As a conclusion of these experiences, it is assumed that applicability of IPSO is best in fields where installation and use of electrical and electronic hardware requires specific know-how, attention and maintenance. Furthermore, the example of Electrolux related to a pay-per-wash product/service bundle points towards the assumption that IPSO might have a higher market potential in fields where it can help consumers to reduce high initial purchasing costs.

This means that applicability is comparatively low in the field of electrical household appliances with limited purchasing costs (e.g. toaster, vacuum cleaners). In turn, applicability is higher in the fields of electronic equipment and capital intensive devices (e.g. IT-equipment, washing machines).

Regarding applicability, another aspect needs to be considered when IPSO is implemented by non-manufacturing companies. In such cases where an implementing company uses EEE manufactured by others, the feedback-loop to the design-stage is likely to be limited. Under such conditions, IPSO can be used for improved end-of-life management, but not necessarily in improve design-for-reuse or recycling[188].

[188] Depending on the situation, companies might still be able to positively influence product-design, either by their supply-chain communication, or by choosing product models and suppliers that fit best to the case-specific requirements for improved end-of-life management.

6.3.1.7. Economics

In the B2B segment, integrated product/service offerings are widely established, suggesting that significant economic benefits are enabled by such business models. According to Fischer et al. (2012), these benefits mostly result from the following factors:

- Better customer retention and loyalty: The service orientation leads to closer customer relations and subsequently to a greater customer loyalty. Deutsche Telekom's leasing model for routers, for instance, boosted customer retention and added to the generation of additional income (Kröhling 2014).
- New market opportunities: Increased service orientation opens market segments, in particular in fields where potential customers are reluctant to purchase products due to high ownership costs or inconvenience of possession (e.g. high maintenance efforts, security issues). Deutsche Telekom uses the leasing model also as an enabler for new service tariffs, including discount options for long use of leased routers.
- Saving costs for raw materials and waste disposal: By implementing a take-back and refurbishing loop for hardware equipment, as well as by potential strategies to design and manufacture longer lasting and repairable products, companies can avoid early product replacement. This saves resource and energy that would be required for the production of new products.
- New business opportunities due to value-adding strategies in a circular economy: For companies coming from a sales focused business, IPSO enable a widening of business activities in the fields of service and maintenance, as well as in take-back, repair and recycling. Deutsche Telekom, for instance, offers remote device management that relieves customers from constant care for firmware updates and data security issues.
- Improved social responsibility: The environmental benefits from IPSO (see section 6.3.1.2) can form an integral part of a company's social responsibility and CSR communication. Deutsche Telekom, for instance, introduced a Green Product Certification for new router models.

On a more general level, Beuren et al. (2013) summarise the benefits of product/service systems for various stakeholder groups:

- <u>Consumer</u>: Flexible and personalized service; quality advantages in products and services; continuous satisfaction. Product data collected during use in order to improve the products in different life stages
- <u>Provider:</u> Higher loyalty and customer confidence. Innovation potential from the monitoring of product and services while using them. Reduction of costs and resources; maximization of results; knowledge created during the development process is sold as consulting and training services; products reused in combination with several different services
- <u>Environment</u>: Reduction in consumption through alternative of product use; Provider responsible for the products and services through take-back, recycling, and refurbishment/ reducing waste through the product's life; services planned throughout the life cycle of the products
- <u>Society</u>: Public pressure on environmental issues grows, Increase the supply of services; new jobs

6.3.1.8. Driving force for implementation

A major driving force for integrated product service offerings are the economic benefits described in section 6.3.1.7. In general, the combination of hardware and service activities becomes increasingly relevant in many competitive segments of the EEE industry. This is particular the case for product segments requiring specific know-how, attention and maintenance during installation

and use. Producers mainly focusing on equipment sale are likely to face difficulties in such market segments.

In the IT sector, services such as cloud data storage and distributed computing become more and more dominant. These web-based offerings relieve consumers from the inconveniences of dealing with computer hardware and might offer an entry point to business models that care for full service systems, including computing hardware.

6.3.1.9. Reference organisations

- Deutsche Telekom: Leasing routers to private households
- Xerox: Pay-per-copy
- Philips Lighting: Pay-per-lux
- Electrolux: Selling cleaning function “pay-per-wash”
- Ricoh: Comet Circle™

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6.3.2. High quality refurbishment of used products[189]

6.3.2.1. Description

Many electrical and electronic products are replaced not because they have reached their technical end-of-life, but because users favour the purchase of new devices, possibly with additional functionalities or improved performance. Such old devices can be refurbished and brought onto the market for reuse. This BEMP describes refurbishing activities that achieve product quality levels identical with those of the device when it was first placed on the market. This BEMP solely addresses refurbishing that generates second-hand equipment that complies with all applicable standards related to safety and reliability that were in place at the time of manufacture[190]. Thus, it describes one specific segment out of a range of activities that support the reuse of used and waste electrical and electronic equipment.

High quality refurbishment typically focuses on devices of one specific manufacturer and is very often carried out by (or in close co-operation with) the OEM. This is because the OEM is the only entity that has all information on product development, design and applied in-house quality tests. In addition, OEMs have established access to the suppliers of original parts and components that might be required for refurbishing activities.

Generally, high quality refurbishment activities involve a series of activities ranging from the selection of used devices to service and maintenance activities. These steps are further described in Table 6-5.

[189] Please note that the term "high quality refurbishment" has been chosen as it is used by the medical sector when referring to refurbished equipment that fulfils a number of criteria, designed to ensure that in terms of performance, the refurbished product will be at least "as good as when new" (see section 6.3.2.5 for detail). The use of this term is not to say that other forms of refurbishment will not result in high quality products, but rather that fulfilling the suggested criteria is to ensure a minimum performance of the product.

[190] In this concern, changes to legislation that affect product design can create obstacles for refurbishment, if new requirements apply retroactively to products first placed on the market before such requirements came into force. An interesting example is Directive 2011/65/EU (RoHS 2) and its application to refurbishment practices in the medical sector. As a few RoHS restricted substances could be present in medical devices sourced for refurbishment, the medical industry has raised concern that refurbished articles could not be placed on the EU market without an exemption for the presence of substances in such products being in place. An exemption request submitted in the past led to the addition of Ex. 31 in Annex IV of the RoHS Directive: "*Lead, cadmium and hexavalent chromium in reused spare parts, recovered from medical devices placed on the market before 22 July 2014 and used in category 8 equipment placed on the market before 22 July 2021, provided that reuse takes place in auditable closed-loop business-to-business return systems, and that the reuse of parts is notified to the consumer. Expires on 21 July 2021.*" The formulation of this exemption has been reconsidered lately and may be amended in 2015.

Table 6-5: Activities for high quality refurbishing

Step No.	Name	Description
1	Selection	During this step, decisions regarding the type and condition of devices for refurbishing are taken. Typically, the selection process is based on criteria related to the types of models, age and condition of devices, and possibly also service history and performance. These criteria are used to enable a targeted sourcing and to avoid the purchase of devices, which will prove unsuitable for high-quality refurbishing.
2	Sourcing	The sourcing is the transaction of the equipment from the owner and/or user to the refurbishing entity. Sourcing mostly includes some form of incentives such as direct payments or trade-in models, the logistics to transport the used equipment to a refurbishing facility in a safe manner (e.g. protection against damages), and activities and measures to communicate information on incentives and transaction processes to a target audience. Depending on the type of product, sourcing might also include de-installation (e.g. necessary for large equipment) and paperwork to comply with legislative requirements.
3	Technical Refurbishing	The technical refurbishing encompasses all steps necessary to bring a device back to the original level of functionality, including in terms of safety, reliability and aesthetics. This typically includes cleaning and disinfection, the conduct of necessary repairs, the exchange of individual parts/components, aesthetic refurbishment, system testing and packaging.
4	Sale/Delivery	This step includes all activities to bring the devices into (second) use. This includes marketing, sale, delivery and possibly also installation at the customers' premises.
5	Warranty	High quality refurbishment also requires technical support, including repair and maintenance within the warranty conditions and periods.

Source: Own table with information adopted from Plumeyer et al. (2014)

It is important to note that the term 'refurbishing' is not uniformly defined. In addition, the term 'remanufacturing' is often used synonymously. It should therefore be noted that in the context of this document 'refurbishing' is defined as all activities carried out in order to re-establish the original functionality of a product (when it was new) in order to enable its re-use.

6.3.2.2. Environmental benefits

The environmental benefits of this BEMP result from the savings by reduced production: The production of electronic equipment is associated with significant environmental impacts, mostly caused by the energy-intensive production of mounted circuit boards and microchips. O'Connell & Stutz (2010) calculated that 47% of the greenhouse gas emissions of the life cycle of a notebook used in the EU is emitted during production. Other calculations showed that this value might even be above 50% depending on various assumptions for the use-phase (Prakash et al. 2012). Based on scenario calculations, Prakash et al. (2012) demonstrated that an extension of life-time provides the biggest leverage in terms of reducing the overall environmental impacts of notebook PCs. Thus, it is clearly recommended to use notebook PCs longer than the average five years.

And this recommendation also proves relevant for other types of electrical and electronic equipment:

Bakker et al. (2014) suggest that not only laptops should be used longer than usual. Also refrigerators, which are assumed to be in use for 14 years on average in the EU, should be used for around 20 years to reduce overall environmental impacts[191]. This is particular noteworthy, as in 2007 it was still common sense that old and inefficient refrigerators should be replaced by new and high efficient devices to reduce electricity consumption and the net environmental impacts (Rüdenauer & Gensch 2007). Thus, the general approach has changed in the last years: Most electrical and electronic devices are significantly more energy-efficient than older models. With a time lag of several years, this development is also reflected in the devices that are taken out of active use.

Furthermore, future efficiency gains for consumer products will most likely be below the achieved improvements of the last decade. Thus it can be concluded that for consumer products – apart from very old cooling and freezing devices and washing machines (age ~ > 10 years) – lifetime extension mostly has net environmental benefits. This finding is also reflected in the European waste hierarchy, which is laid out in the EU Waste Framework Directive (2008/98/EC) which rates *reuse* and *preparing for reuse* clearly above *recycling*. This principle is also taken up by the WEEE-Directive (Directive 2012/19/EU)[192].

With regard to equipment such as machines, installations and medical equipment, it has to be calculated individually whether lifetime extension has environmental net benefits, also by taking into account energy efficiency gains of new devices.

6.3.2.3. Appropriate environmental performance indicators

The environmental net benefits are very difficult to be determined at an impact level, such as primary energy consumption or greenhouse gas emissions – at least during day-to-day operations. Therefore, it is advised to base monitoring on two pillars:

- Firstly, it must be demonstrated that refurbishing activities have environmental net benefits, also in light of energy efficiency gains of new product models. While refurbishing activities targeting consumer products can refer to existing literature and studies (see section 6.3.2.2), refurbishing of other devices should ideally conduct own LCA-based assessments to make sure that the activities have environmental net benefits.
- In the case that net environmental benefits prevail, monitoring should be based on sales numbers in relation to the sale of new equipment. Although the potential market share will vary depending on the type of product group, Siemens Healthcare reported that up to 10% of its sales volume for medical imaging equipment is comprised of refurbished equipment (Plumeyer et al. 2014). Generally, it is assumed that market shares ranging between 5 and 10% can be regarded as quite high.

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[191] This calculation applies to models that are first brought onto the market in 2011. Thus, it cannot be concluded that refrigerators that are 14 years old today should be used for six more years.

[192] The term “preparing for reuse” is used because the intended reuse of devices does not only depend on repair and refurbishing activities, but also on a market demand for second-hand devices. As this demand cannot be regulated by the Waste Framework Directive or the WEEE Directive, both Directives can only encourage all operations that lead to functional products suitable for re-use.

6.3.2.4. Cross-media effects

Although the extension of product lifetime has mostly significant environmental net benefits (see section 6.3.2.2), it also leads to a situation in which old devices that are mostly less energy-efficient than new models, remain in use. Thus, the environmental benefits resulting from reduced production of new devices also generates higher electricity consumption in the region where the devices are used, if compared to a business-as-usual scenario.

Nevertheless, various life-cycle studies have shown that net gains prevail and are particularly pronounced for devices that:

- have a relatively high percentage of environmental life-cycle impacts during production and transport;
- and will most likely experience only limited energy-efficiency improvements in the near future.

6.3.2.5. Operational data

High quality refurbishment begins with criteria for the **selection** of used equipment. Apart from criteria on product types and models addressed for refurbishing, also other criteria such as age and condition are typically taken into account. Siemens Healthcare also checks available information related to the service history of devices, which will not be possible for all types of electrical and electronic equipment[193].

These criteria are then used for the **sourcing** of used equipment. Sourcing can be done by a variety of stakeholders such as private or corporate consumers, or entities involved in the management of Waste Electrical and Electronic Equipment (WEEE). Nevertheless, high quality refurbishment mostly focuses on sourcing directly from the last user, as this strategy can best ensure a high share of devices fit for refurbishing[194]. For sourcing, typically incentives – coupled with information on take-back logistics – are notified to users/consumers. While communication on the sourcing from private consumers is mostly effected via internet-based information and the established sale and distribution channels for new products, more capital-intensive devices such as medical imaging equipment is usually bought back on the basis of financial offers or discounts for new purchases (trade-in models). Under the recycling programme of Apple – that is carried out in co-operation with Dataserv GmbH – owners can use an interactive website to calculate the remaining value of their Apple products. The calculated sum is also an indicative offer by Dataserv GmbH, coupled with information on how to pack and send the device free of charge to a refurbishing centre (Apple 2014). A comparable sourcing strategy is also applied by HP (HP 2014).

Transport logistics is an important part of sourcing as it should organise a smooth and undamaged transport of used devices from the customers' location to the refurbishing facility. While some smaller equipment can be transported by currier service (e.g. packed in cushioned envelopes or boxes), larger equipment might require de-installation and packaging by qualified personnel. It is important to note that equipment that is not functional at the time of de-installation is likely to be

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[193] Siemens Healthcare refurbishes medical imaging equipment of its own brand. In this specific case, the company often has a track record of service and maintenance activities – at least those carried out by Siemens Healthcare itself.

[194] Another potential source of used equipment is the general WEEE collection. Nevertheless, collection and transport of WEEE is often associated with risks of damages. In addition, devices disposed via the established WEEE-collection systems are on average older than equipment sourced directly from consumers. This is due to the widespread consumer habit of storing EEE for several months or years prior to disposal.

categorised as waste (WEEE or e-waste) and will therefore require notification according to the procedures of the Basel Convention[195] for any transboundary movement.

Technical refurbishing is often carried out in, or close to the location where the new devices are manufactured. This is because such a location enables synergies in terms of in-house know-how, access to spare parts, as well as know-how of suppliers. As illustrated in Figure 6-10, the technical refurbishing encompasses:

- Visual inspection;
- Safety test;
- Function test;
- Data eradication;
- Software removal/uploading;
- Disassembly;
- Repair (and retesting);
- Cleaning.

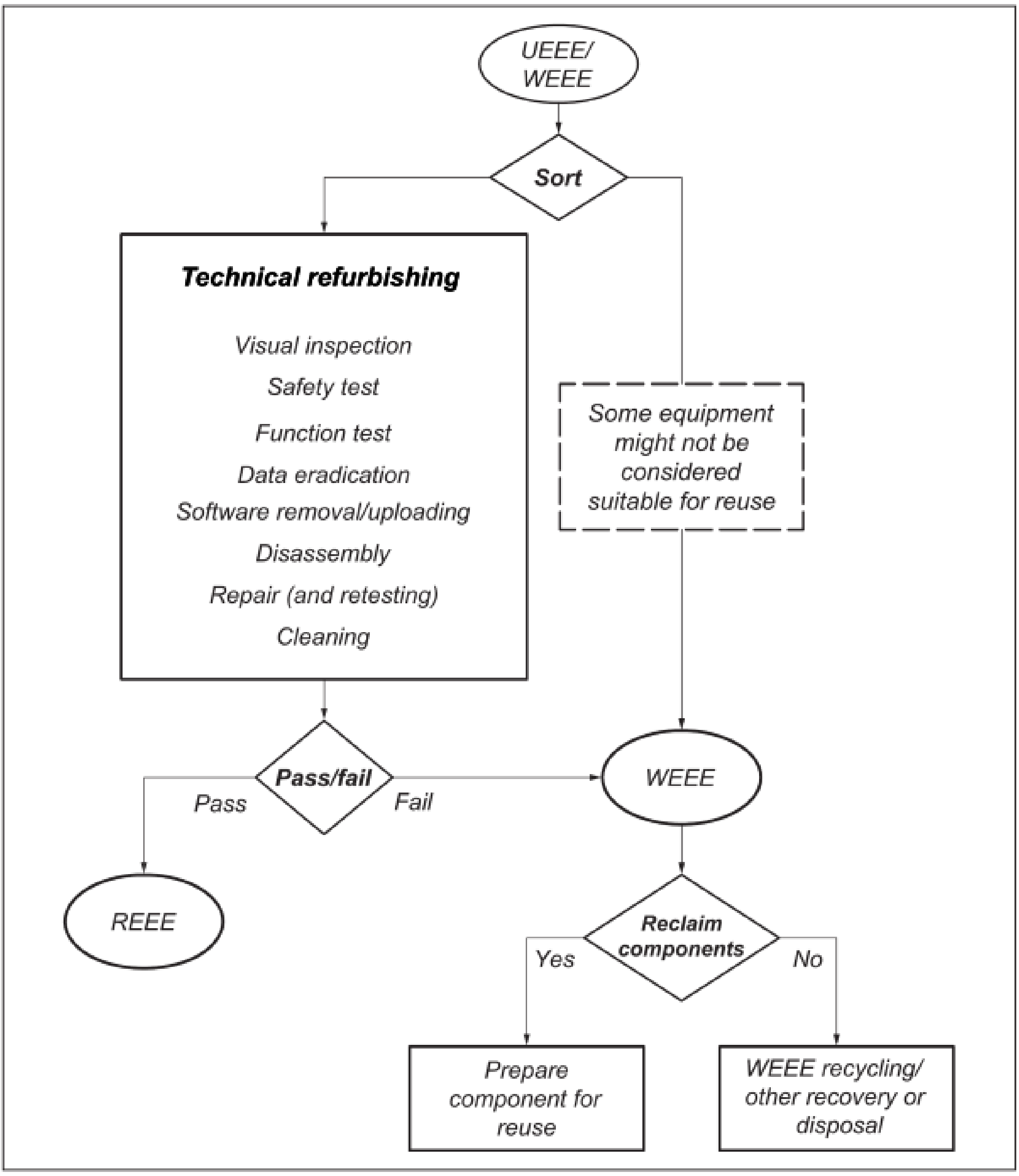
Depending on the type of equipment, very specific process steps might be required additionally (e.g. cleaning and disinfection prior to any other handling). Furthermore, in some cases, more intensive activities might be required to re-establish the optical appearances of devices. This might require varnishing of surfaces or the exchange of certain parts such as control units.

As illustrated in Figure 6-10, devices that prove unsuitable for refurbishing, can be used to extract spare parts for other repairs (component reuse).

Further guidelines for technical refurbishing are laid out in COCIR (2009) for medical equipment and in the Standard PAS 141:2011 (BIS 2011). The latter is also supported by a series of so-called *Re-use protocols* that provide check lists for quality testing after completion of technical refurbishing. These protocols are currently available for a whole range of products and can be downloaded from http://www.wrap.org.uk/content/re-use-protocols-electrical-products.
Nevertheless, for high quality refurbishment as described in section 6.3.2.1, further product testing might be required to guarantee product quality levels corresponding to those at the time the device was first placed on the market.

[195] Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal.

Figure 6-10: Overview of activities for refurbishing activities



EEE = electrical and electronic equipment; REEE = reuse EEE; UEEE = used EEE; WEEE = waste EEE

Source: adopted from BSI (2011)[196]

For **sale and delivery**, the high quality refurbished products are typically offered at prices between 10% and 30% below the market price of a comparable new system (Plumeyer et al. 2014). For marketing, different refurbishers use different terminologies, whereby the main aim is to highlight the environmental and cost benefits of refurbished products. At the same time, it is important to avoid the impression of cheap, sub-standard equipment that is often associated with second-hand

[196] Permission to reproduce extracts from PAS 141:2011 is granted by BSI. British Standards can be obtained in PDF or hard copy formats from the BSI online shop: www.bsigroup.com/Shop or by contacting BSI Customer Services for hardcopies only: Tel: +44 (0)20 8996 9001, e-mail: cservices@bsigroup.com.

use. For this reason, Siemens Healthcare is selling high quality refurbished equipment under the term “ecoline”. The mode of delivery strongly depends on the type of product and the sale-infrastructure in place. For some types of equipment delivery requires special protection as well as qualified personnel for installation.

In order to further differentiate high quality refurbishment from other second-hand products, it is important to offer a full and convenient **warranty** package that involves technical support, repair and maintenance for a pre-defined time period. Generally, these warranty packages should be comparable to those of new products so that customers can be sure that they do not carry any additional risks that are often related to the use of second-hand products (e.g. reduced performance, product failure).

6.3.2.6. Applicability

This BEMP is applicable to a wide range of electrical and electronic products. Typically, applicability is higher for devices that are mid- or high-capital intensive, as the re-use market for products with purchasing prices below around 700–1000 Euros for new equipment is not strongly developed (Plumeyer et al. 2014).

Generally, high quality refurbishment is best carried out by, or in close co-operation with OEMs, as this can create synergies in terms of access to spare parts and know-how. Regarding the age of used equipment for refurbishing, the remaining service life should be taken into account. This is because warranty packages with technical support, repair and maintenance can best be guaranteed within the timespan a product model is serviced by the OEM.

6.3.2.7. Economics

High quality refurbishment of capital-intensive products is reported to be economically profitable. According to Plumeyer et al. (2014), the market for high quality refurbishment products usually does not negatively affect the sales volumes of new devices as it addresses a market segment of consumers that are cost- and quality-conscious customers. Where trade-in incentives are used, such activity may even encourage some consumers to purchase new equipment, while having a positive impact on the supply of refurbished devices available to others.

6.3.2.8. Driving force for implementation

High quality refurbishing is typically conducted for two reasons:

- To respond to consumer demand for cost-efficient but high-quality alternatives to new models;
- To demonstrate environmental responsibility within the core hardware business.

In addition, another driving force is the European waste hierarchy that promotes re-use above recycling (see section 6.3.2.1).

6.3.2.9. Reference organisations

- Siemens Healthcare;
- Other OEMs in the medical sector, including Philips and General Electrics;
- FEI (manufacturer of electron microscopes);
- HP;
- Apple in co-operation with Dataserv GmbH;
- Deckel Maho Gildenmeister (manufacturer of machines).

6.3.2.10. Chapter references

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6.3.3. Non-destructive extraction of circuit boards

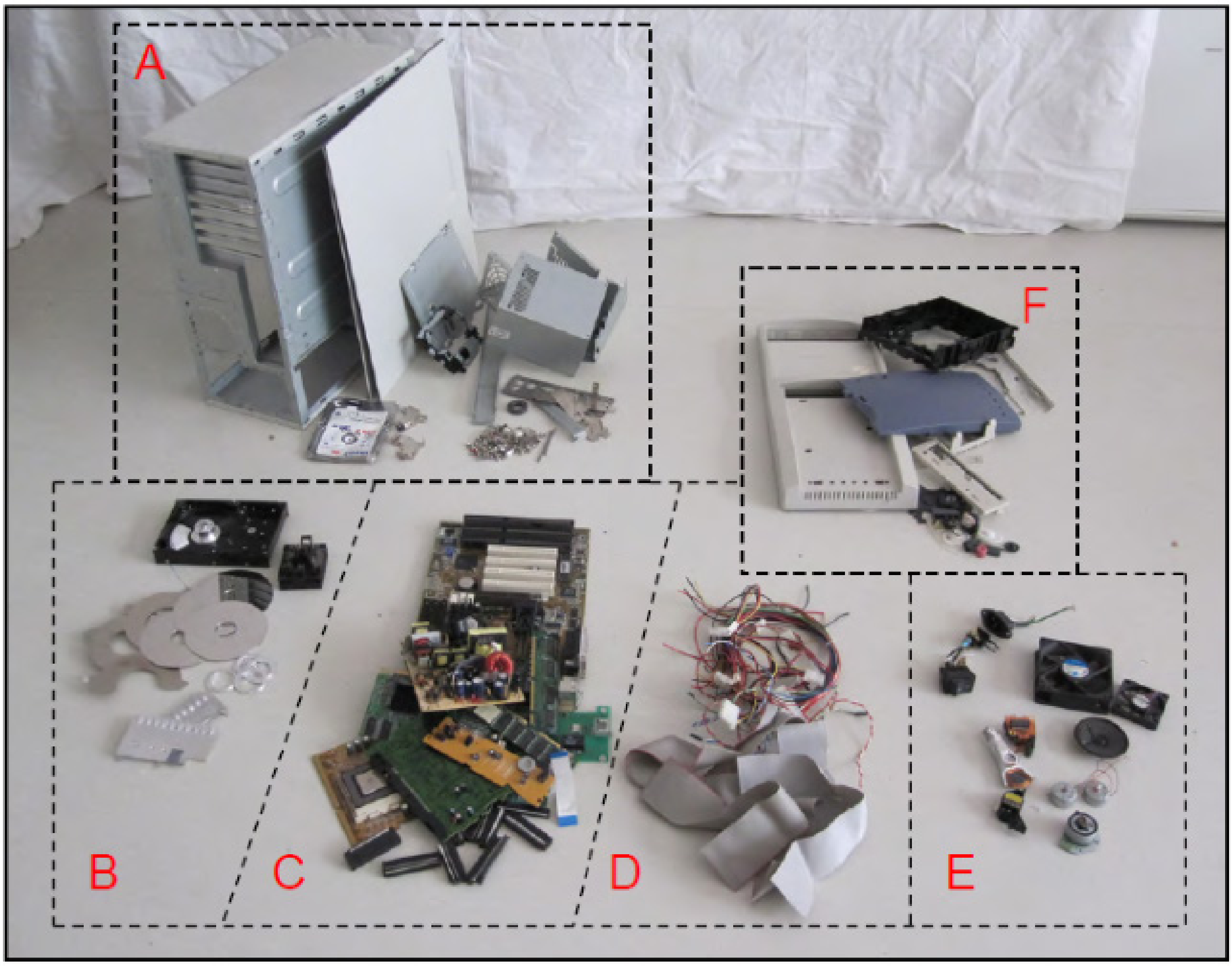
6.3.3.1. Description

The pre-processing of end-of-life Electrical and Electronic Equipment (EEE) is of crucial importance in allowing high recycling yields for precious metals embedded in the components and solder of mounted printed circuit boards of EEE. Thereby, this section exclusively focuses on options in the pre-processing stage of EEE recycling, which includes detoxification, liberation of materials and sorting into main output fractions. While the processes applied for end-processing (e.g. hydro- or pyrometallurgical processing of precious metals containing fractions) are not described in this section, high recycling yields for precious metals always depend on a well-tuned process chain involving pre-processing operations that are tailored to the needs of end-processing units.

In order to optimize the link between pre-processing and end-processing, pre-processing operations need to deliver output fractions that fit best to the needs of the various end-processing units. With regards to precious metals, several recent studies have shown that a **non-destructive extraction of printed circuit boards** can significantly reduce the precious metals losses compared to destructive extraction measures (Chancerel et al. 2009; Salhofer et al. 2006; Hagelüken 2006). This is because destructive extraction methods – which typically make use of shredders, rotary shears or cross flow cutters (VDI 2012) – cannot perfectly liberate all materials from complex material compositions so that some precious metals bearing parts and components are still attached to steel, aluminium and plastic parts. In the subsequent mechanical sorting cascade, these conglomerates are to a certain extent sorted into output fractions such as the ferrous metals or aluminium fraction, which are not destined for precious metals recycling (unintended co-separation). Subsequently, a significant share of precious metals contained in EEE is delivered to end-processing units, which cannot recycle precious metals. Furthermore, mechanical stress caused by destructive pre-processing methods can also cause losses of precious metals into the dust fraction.

Figure 6-11 shows a fully dismantled desktop PC (without monitor and peripherals), whereof the fraction indicated with C contains 100% of the device’s precious metals. Although such clear separation of precious metals bearing parts and components requires significant labour input, it significantly increases the recycling rates for precious metals (Manhart et al. 2011).

Figure 6-11: Manually dismantled desktop PC sorted into its main fractions for recycling

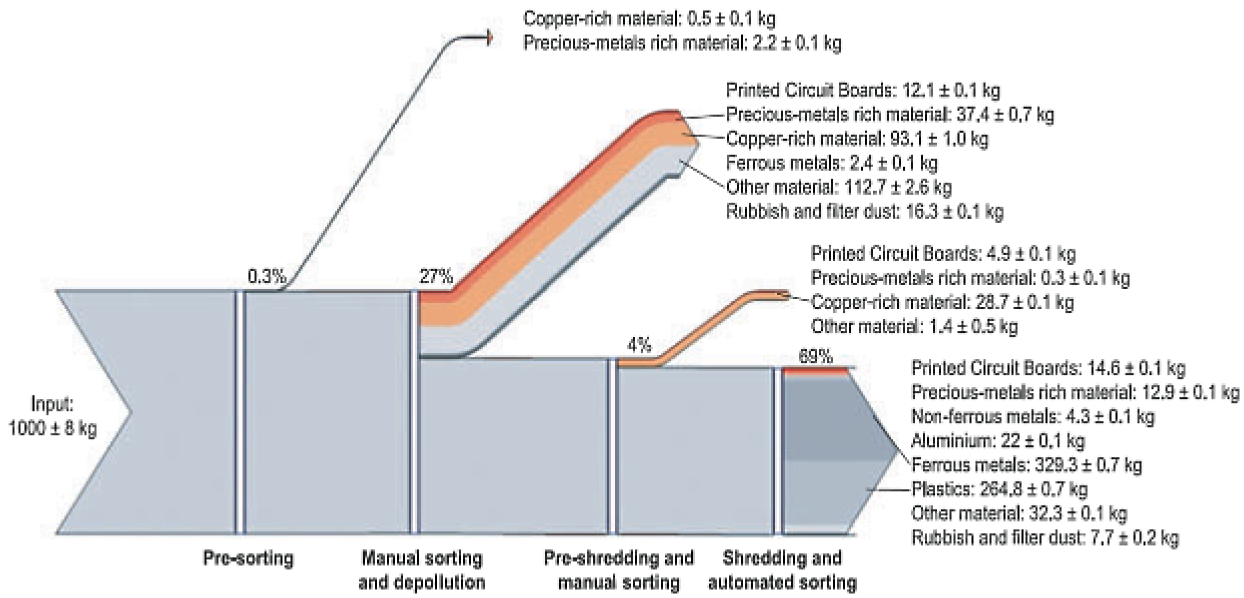


Source: Manhart et al. (2011)

Chancerel et al. (2009) measured the precious metals flows in one facility in Germany that deployed a mechanical (destructive) extraction of printed circuit boards and came to the result that, in this specific case, only 25.6% of the gold and palladium and 11.5% of the silver contained were sorted into fractions which are destined for precious metals recovery.

As shown in Figure 6-12, shredding and automated sorting processes are not ideal for separating precious metals bearing parts and components, as the manual process steps prior to shredding (pre-sorting, manual sorting and depollution, pre-shredding) retrieve much bigger amounts of gold compared to the destructive process of shredding and automated sorting. Here, it has to be stressed that Figure 6-12 is based on an evaluation in one particular facility and that many other pre-processing recyclers deploy even fewer manual process steps prior to shredding.

Figure 6-12: Flowchart for gold contained in 1 tonne of e-waste being pre-processed with a combination of non-destructive and destructive processes



Source: Chancerel et al. (2009)

Table 6-6: Recovery Rates for Gold, Silver and Palladium Yielded in a Mechanical Extraction of Printed Circuit Boards

Material	Amount contained in a 1 t test volume of WEEE	Amount sorted into output fractions for precious metals recycling	Amount unintendedly sorted into other fractions	Recovery rate
Gold	22.2 ± 2.5 g	~ 5.7 g	~ 16.5 g	~ 25.6%
Silver	313.3 ± 35.0 g	~ 36 g	~ 277 g	~ 11,5%
Palladium	7.16 ± 0.87 g	~ 1.9 g	~ 5.3 g	~ 25,6%

Source: Chancerel et al. (2009)

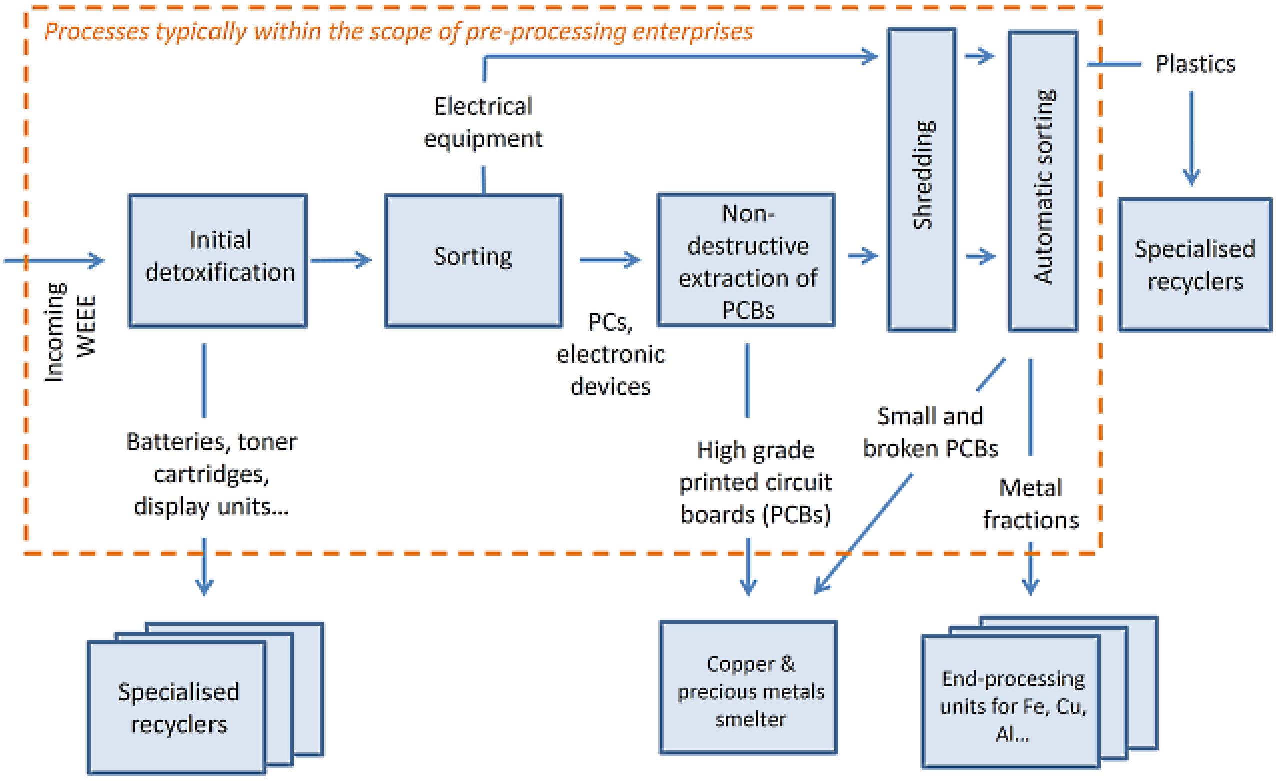
Salhofer et al. (2009) compared various types of non-destructive extraction methods for printed circuit boards from waste desktop computers with destructive mechanical pre-processing operations. The analysis came to the conclusion that manual dismantling into main components can already yield over 80% of the gold, approx. 50% of the silver and 66% of the palladium contained, which is a significant improvement to pure shredder-based pre-processing. With further dismantling of components such as optical drives and hard disk drives, the result could further be improved to above 92% for all three metals.

Non-destructive extraction methods are based on manual dismantling using standard tools such as (pneumatic) screwdrivers, pliers and cutters. It typically involves the opening of cases and the extraction of motherboards and other printed circuit boards, which can be directly passed on to the standard end-processing facilities for copper- and precious metal rich fractions. Non-destructive extraction is mostly carried out as part of the first WEEE treatment steps – often combined with first

sorting and detoxification steps. Most enterprises focus their manual dismantling operations on desktop PCs and other large IT equipment as these devices are easy to open while containing large and precious-metal rich printed circuit boards. A typical flow-chart of pre-processing companies applying non-destructive extraction of PWBs is illustrated in Figure 6-12.

Figure 6-13 represents a typical flow-chart for a WEEE pre-processing enterprise applying non-destructive extraction of printed circuit boards.

Figure 6-13: Typical flow-chart for WEEE pre-processing enterprises applying non-destructive extraction of printed circuit boards



Source: Own illustration

Schöps (2014) reports that – despite improvements in mechanical pre-processes in the last years – destructive extraction methods still cause unintended co-separation and gold losses in a range of 20% compared to non-destructive extraction, which is roughly equivalent to 4 g of gold per tonne of desktop PCs.

6.3.3.2. Environmental benefits

Environmental benefits result from reduced demand for primary materials. By reducing demand for primary production, it indirectly has positive impacts related to the environmental impacts of mining (e.g. land-use, emission of mercury).

In addition, the primary production of precious metals is associated with significant primary energy consumption and greenhouse gas emissions. Compared with primary production, the secondary production (recycling) of precious metals from waste electrical and electronic equipment requires between 93% and 98% less primary energy and emits 87% to 95% less greenhouse gases (Manhart et al. 2011). Given that non-destructive extraction of large printed circuit boards yields

additional 4 g of gold per tonne of waste desktop PCs, this results into a saving potential of 68 kg CO_2 equivalents (CO_{2e}) per tonne of treated waste desktop PCs (calculated with data from Manhart et al. 2011). While this calculation is solely based on the saving potential of greenhouse gas emissions from gold recycling, other improvement potentials like those from the recycling of other metals have not yet been quantified.

Regarding impacts on the place of recycling, it is known that non-destructive extraction methods generate less dust emission, which is a matter of particular concern in relation to destructive extraction technologies (VDI 2012).

6.3.3.3. Appropriate environmental performance indicators

Ideally, the performance is measured using the achieved **recovery rates for gold, silver and palladium in percent (%)**, which in turn can be used to quantify the environmental benefits from recycling operations (like reduced primary energy demand, reduced greenhouse gas emissions, etc.).

Nevertheless, this indicator requires detailed knowledge of the precious metals concentrations in the input WEEE, which is mostly not available for routine operations. As an alternative pathway of performance measurement, recyclers can use the assumption that desktop PCs contain on average around 20 g of gold, 100 g of silver and 5 g of palladium per tonne. By monitoring their **achieved precious metal output** (typically recyclers get this information after delivering batches of printed circuit boards to end-processing units), companies can compare their performance with the indicative maximum values above.

6.3.3.4. Cross-media effects

While non-destructive extraction of printed circuit boards leads to a higher recovery of precious metals, it also causes some losses of aluminium and steel (some grams per device). This is because aluminium and steel parts of the mounted printed circuit boards are channelled towards copper and precious metals end-processing units, which are not capable of recycling steel and aluminium. With regards to environmental performance, this effect is clearly of secondary importance compared with the benefits of improved precious metals recycling.[197]

6.3.3.5. Operational data

The background and improvement measures are described in Salhofer et al. (2009). Information in English is available in Meskers and Hagelüken (2009) and Chancerel et al. (2009).

Non-destructive extraction of printed circuit boards is particularly relevant for enterprises focusing on the pre-processing of WEEE classified as *IT and telecommunication equipment* (category 3) under the European WEEE-Directive as this category encompasses most devices with printed circuit boards with high precious metals concentration. In addition, flat screen TVs (grouped under

[197] The primary production of aluminium and steel has significant lower per-unit impacts as precious metals. The production of 1 kilogram steel is associated with the emission of ~2 kg CO_2e, and the primary production of 1 kilogram aluminium generates ~10 kg CO_{2e}. In contrast, the primary production of 1 kg gold is on average responsible for almost 18 t of CO_2e (Manhart et al. 2011).

category 4 - *consumer equipment*) and video game consoles (grouped under category 7 – *toys, leisure and sports equipment*) also contain large and precious metals rich PWBs.[198]

Typically, pre-processing enterprises conduct the non-destructive extraction process after initial detoxification and sorting of equipment into devices unsuitable for non-destructive extraction (electrical equipment, devices difficult to dismantle) and such devices that contain precious metals rich and accessible PCBs (e.g. desktop PCs, servers) (Bergamos 2014). Subsequently, the non-destructive extraction of PWBs is carried out by:

1. Opening the case (by loosening screws and / or releasing clip-connections);
2. Locating main accessible printed circuit boards (by visual inspection);
3. Removing the identified printed circuit boards (by clipping cable connections with pliers and by loosening screws and / or releasing clip-connections).

The recovered printed circuit boards can be directly passed on to end-processing units for copper and precious metals scrap, where they can be fed into smelters without further processing.

Further dismantling may be carried out in order to also retrieve printed circuit boards contained in less accessible locations (e.g. hard disk drives, optical drive, power supply). Nevertheless, the additional precious metals yields also require higher labour input (see section 6.3.3.7).

6.3.3.6. Applicability

Applicability is best in cases where recyclers receive well-sorted WEEE input consisting of electronic equipment with a high share of desktop computers and other large IT equipment such as servers. Thus, equipment of the WEEE category 3 (IT and telecommunication equipment) as well as flat-screen TVs (WEEE-category 4 – consumer equipment) and video game consoles (WEEE-category 7 – toys, leisure and sports equipment) are most suitable for non-destructive extraction of printed circuit boards. Generally, well-sorted equipment (e.g. batches of computers of similar construction) has the advantage that manual operations can be carried out more efficiently than with unsorted equipment.

Electrical equipment has typically quite low concentrations of precious metals so that recyclers have to carefully consider the additional investments and process costs for non-destructive extraction. With the implementation of the BEMP described in section 4.2.1, the gold content of new electronic devices is likely to decline over the next years. With a time-lag of several years, this might also have implications for the applicability of this BEMP, requiring careful monitoring of recycling enterprises.

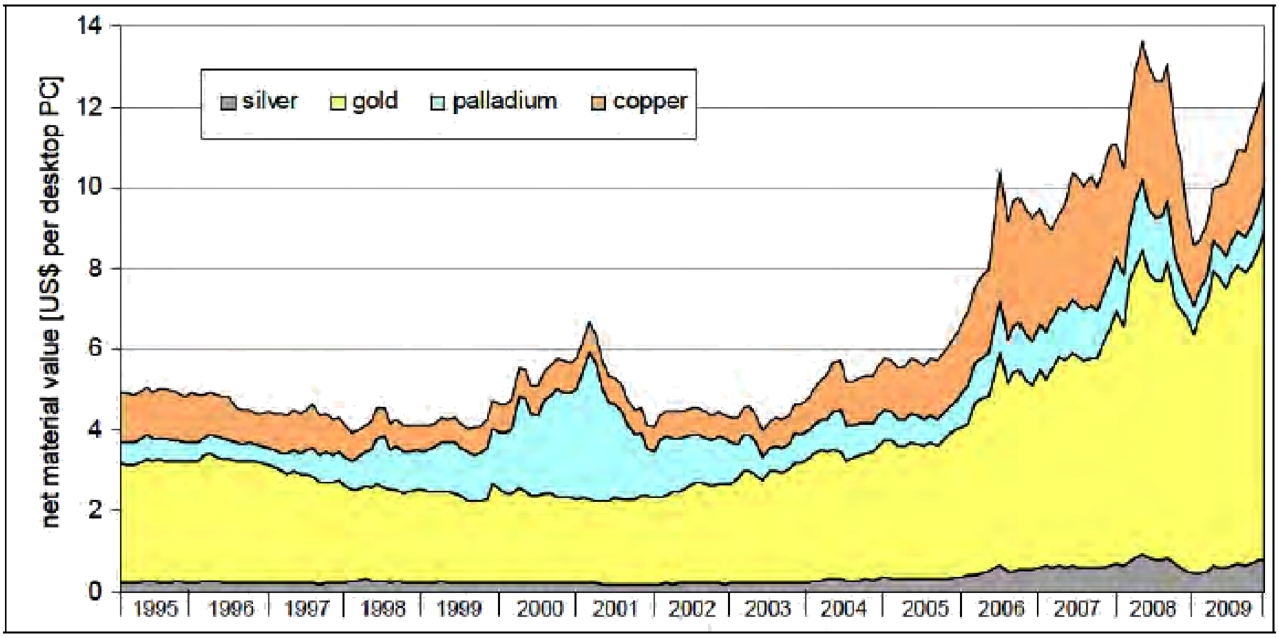
6.3.3.7. Economics

Recyclers applying non-destructive extraction methods typically face higher labour costs, as labour intensity is higher compared to destructive extraction methods. Generally, for 1 t of desktop PCs, around 5 to 10 hours of manual labour are required. This yields on average 4 g of additional gold.

[198] While flat-screen TVs and monitors contain large and precious metals rich PCBs, many devices are also equipped with mercury-containing backlights. While many enterprises dealing with TVs and monitors conduct dismantling in order to retrieve the mercury-containing backlights, they usually also extract the embedded PCBs. Nevertheless, enterprises dealing with such devices need to carefully consider the health aspects of dismantling operations and take appropriate precaution measures.

Assuming a gold price of 950 Euro per troy ounce,[199] additional revenues of 122 Euro per tonne of waste desktop computers can be generated using these methods. As gold is the main value carrier in printed circuit boards of electronic equipment, it has the highest economic relevance for this management practice (see Figure 6-14).

Figure 6-14: Net material value of copper and precious metals of an average desktop PC from 01/1995 to 10/2009



Source: Manhart et al. (2011)

Nevertheless, improved recycling of silver and palladium can add around 10% to 20% to this value so that the additional income can be estimated to be around 140 Euro per tonne of waste desktop computers.

Figure 6-15 displays the estimated additional revenue per hour of manual work from non-destructive extraction of large and well accessible printed circuit boards in the recycling of desktop PCs (motherboards). The graphic can be used as an initial outline to establish the economic equilibrium between the increased labour costs (which are largely dependent on national and local wage levels) and the subsequent effects in terms of additional revenues generated from improved recycling of precious metals.

[199] 1 troy ounce is equivalent to 31.1034768 g.

Figure 6-15: Estimated additional revenues from non-destructive extraction of large printed circuit boards of desktop PCs at various gold price levels

Source: Own calculation

The recovery of precious metals can be further increased by also extracting smaller and less accessible printed circuit boards (e.g. from hard disk drives and optical drives). According to Salhofer et al. (2009), such deep manual dismantling can further increase the gold recovery from 80% to above 92%. Nevertheless, this requires higher labour input, which needs to be assessed on an individual facility level.

6.3.3.8. Driving force for implementation

Increased recovery of precious metals is the most relevant driving force for implementation, in particular in situations in which higher resource recovery can compensate for increased labour costs of non-destructive extraction (see section 6.3.3.7).

In addition, non-destructive extraction is also carried out to fulfil the requirements of the Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE). This Directive requires the removal and separate treatment of printed circuit boards greater than 10 square centimetres as well as of other parts and components listed in its Annex VII. Although this requirement is often interpreted in a way that also destructive and imperfect removal is considered to be compliant with this requirement, its basic aim is to fully separate all printed circuit boards > 10 cm^2, which can be best achieved by non-destructive extraction.

6.3.3.9. Reference organisations

- ELPRO Elektronik-Produkt Recycling GmbH (Germany)
- Demontage- und Recyclingzentrum (Austria)

6.3.3.10. Chapter references

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Chancerel & Rotter (2009)	Chancerel, P.; Rotter, V.S.; Edelmetallrückgewinnung aus Elektro- und Elektronikaltgeräten durch Aufbereitung; in: Müll & Abfall 02/2009.
Hagelüken (2006)	Hagelüken, C.; Improving metal returns and eco-efficiency in electronic recycling – a holistic approach to interface optimization between pre-processing and integrated metal smelting and refining. Proc. 2006 IEEE International Symposium on Electronics and the Environment, 08.-11. May 2006, San Francisco.
Manhart et al. (2011)	Manhart, A.; Osibanjo, O.; Aderinto, A.; Prakash, S.; Informal e-waste management in Lagos, Nigeria – socio-economic assessment and feasibility of international recycling co-operations; Oeko-Institut e.V. 2011.
Meskers and Hagelüken (2009)	Meskers, C.; Hagelüken, C.; The impacts of different pre-processing routes on the metal recovery from PCs; in: Proceedings of R'09 Twin World Congress: Resource Management and Technology for Material and Energy Effiociency. Nagoya & Davos, 14-16.09.2009.
Salhofer et al. (2009)	Salhofer, S.; Spitzbart, M.; Meskers, C.; Hagelüken, C.; Schöps, D.; Kriegl, M.; Panowitz, G.; Vergleich von manueller Demontage und mechanischer Aufbereitung von PCs; Technical Paper; Vienna 2009
Schöps (2014)	Schöps, D. (Managing Director of ELPRO Elektronik-Produkt Recycling GmbH); personal communication; 20.02.2014
VDI (2012)	Verein Deutscher Ingenieure (VDI); VDI-Richtlinie 2343: Recycling of electrical and electronic equipment preparation techniques; Düsseldorf 2012

6.3.4. Innovative sorting solutions for black plastics from waste electrical and electronic equipment

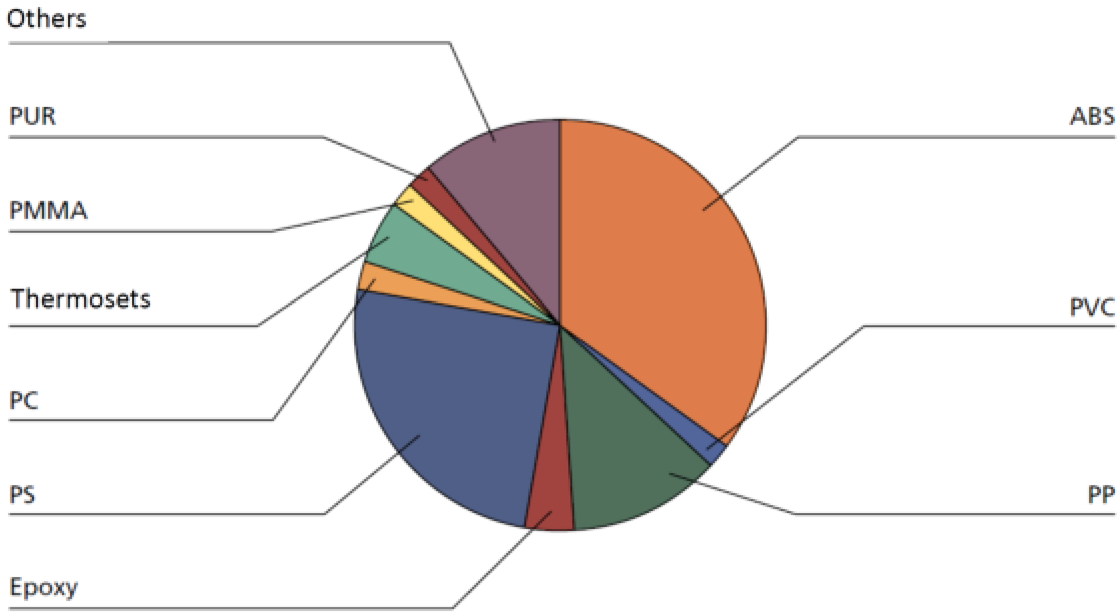
6.3.4.1. Description

Cases and structural elements of electrical and electronic equipment are mostly made from thermoplastics such as acrylonitrile-butadiene-styrene (ABS), polypropylene (PP) and polystyrene (PS). In order to achieve high recycling rates, the plastic fraction needs to be sorted according to its main polymer types and according to its level of contamination with flame retardants. While density separation is an important and well established technology for first sorting, the two most important fractions – PS and ABS – cannot be differentiated on the basis of their specific weight. Sorting of these two thermoplastics was formerly achieved using near infrared (NIR) sensor technologies, however, this technology requires a certain reflection of the sensor beam from the particle surface (Bennett et al. 2009). As black colours increasingly dominate the post-consumer plastics retrieved from WEEE, the application of this technology shall become more and more inefficient[200].

As a response, a new sorting technology has been developed and is used in a few plastic recycling and sorting enterprises. It is based on the different electrostatic properties of PS and ABS and has been proved to achieve PS and ABS output fractions of sufficient quality for use in production processes. More specifically, a purity of 98.5% is achieved for the PS-fraction and 99% for the ABS-fraction. In terms of volumes, ABS and PS are the most relevant fractions for WEEE plastics and make up 50-55% of the total volume (see Figure 6-16). Thus, this sorting technology can achieve a recycling rate of > 50% of mixed plastics from WEEE. Although some other polymer types could theoretically also be recycled, they make up a significantly smaller share of the total WEEE plastic stream and are therefore less relevant for recycling.

[200] In order to reduce the difficulties for end-of-life plastic sorting, it can also be advised to use other plastic colours in product design. Nevertheless, black designs can also yield multiple benefits such as the use of post-consumer recycling plastics: As plastics from recycling sources is often not uniform in color, blackening can be used as a means to guarantee uniform product design – even when using considerable shares of secondary plastics.

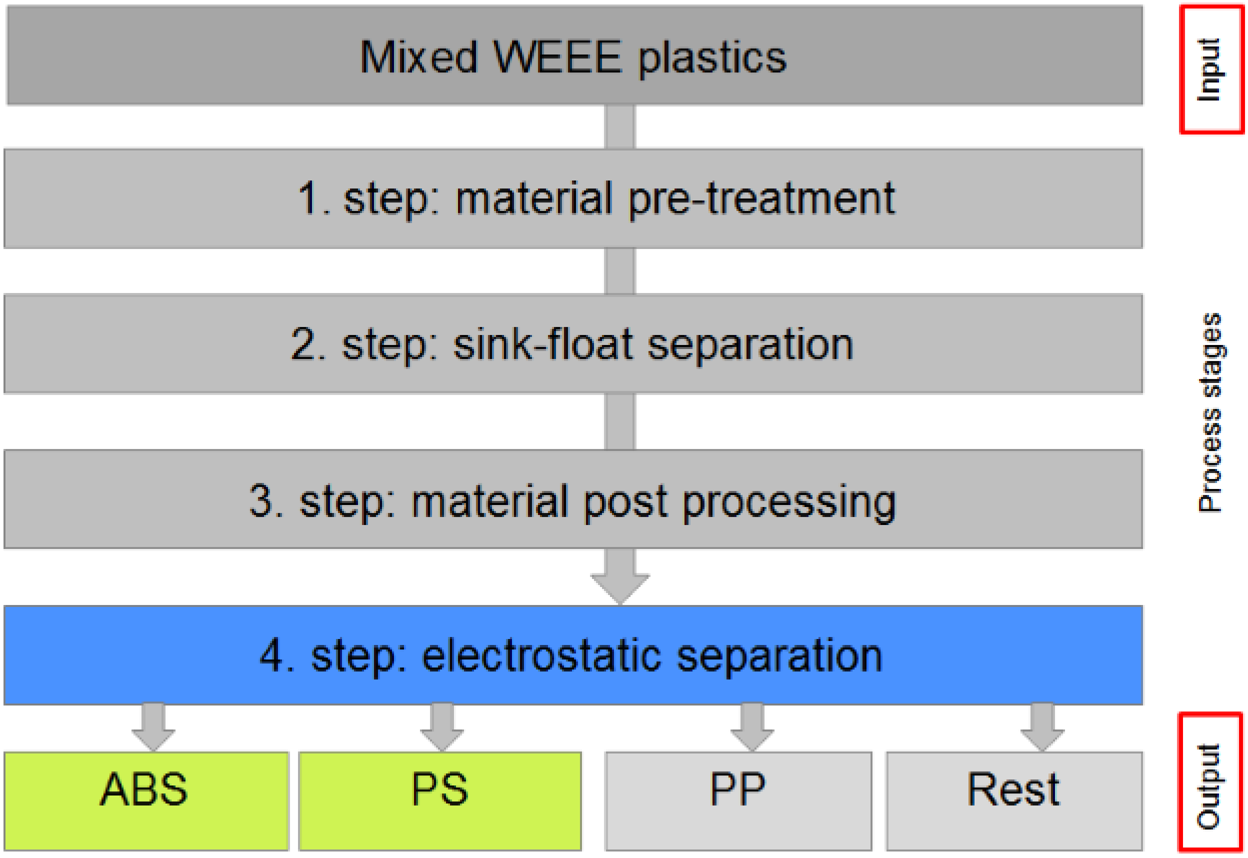
Figure 6-16: Average composition of mixed plastics from WEEE-recycling



Source: Köhnlechner (2014a)

The electrostatic separation needs to be added as a subsequent step after a series of processing and sorting steps. Figure 6-17 gives an overview over these process steps. A more detailed description of the processes is given in section 6.3.4.5.

Figure 6-17: Process steps for plastics recyclers applying electrostatic separation for generating pure ABS and PS fractions



Source: Own figure according to Hamos & WERSAG (n. y.)

6.3.4.2. Environmental benefits

Recycling of plastics from WEEE reduces the demand for primary resources – in this case crude oil. The recycling of 1 metric tonne of ABS and PS replaces around 2 tonnes of crude oil. Considering the fact that the WEEE-Directive requires significantly increased collection rates until 2019, it is estimated that 3 million tonnes of plastics from WEEE will require appropriate management in 2019 in the EU, whereof 50-55% of this volume is expected to be ABS and PS (Köhnlechner 2014b).

Thus, it is estimated that a systematic application of this BEMP has the potential to save around 3 million tonnes of crude oil in 2019. Taking into account the required energy input, this still leads to considerable savings (see section 6.3.4.4).

6.3.4.3. Appropriate environmental performance indicators

The performance should be monitored on the basis of the achieved recycling rates for WEEE plastics and the quality/purity of produced secondary plastics, in particular ABS and PS. Generally, the following benchmarks might be used for monitoring:

- Recycling of > 45% of the WEEE plastics,
- ABS and PS fractions with minimum purities of 98.5% and 99% respectively.

6.3.4.4. Cross-media effects

While electrostatic separation of PS and ABS secures the recyclability of 50-55% of the plastics from WEEE, it requires additional energy input. An electrostatic separation unit with a capacity of 750 kg/h requires 4.5 kW of electricity. This results in an additional electricity consumption of 5.6 kWh per tonne of sorted ABS/PS.

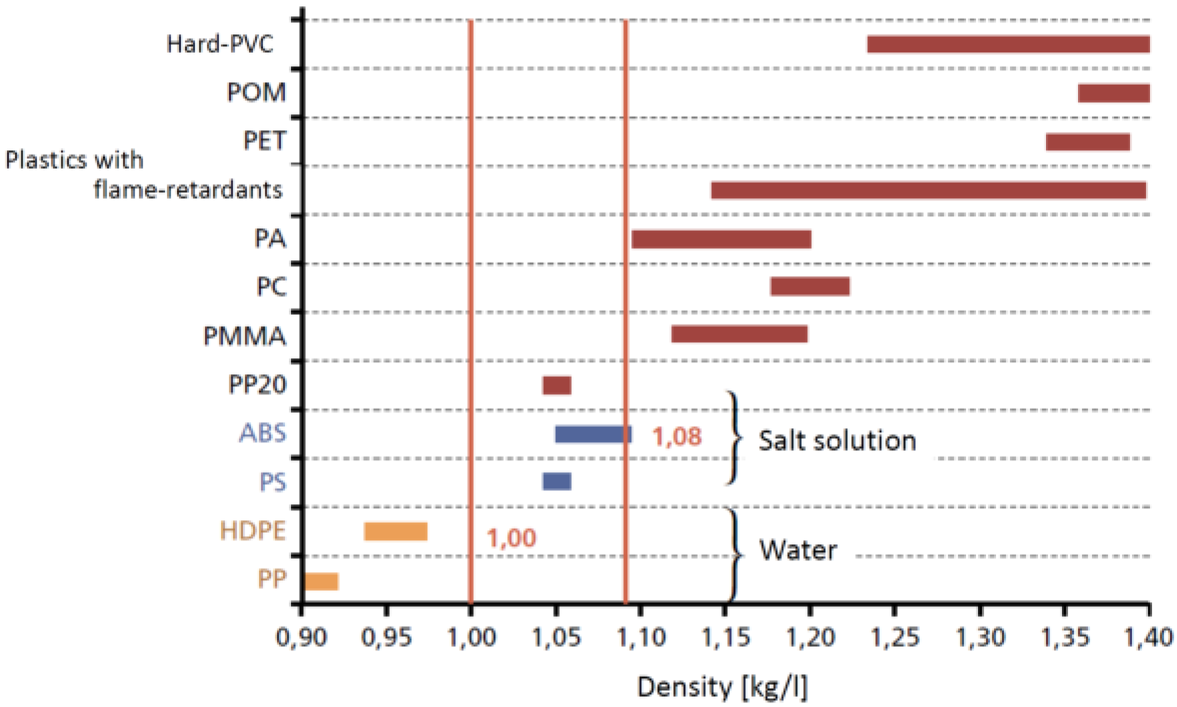
Compared to the embedded energy of the 2 tonnes of saved crude oil per tonne of recycled ABS/PS (see section 6.3.4.2) – which sums up to ~ 23,000 kWh[201] – this is a quite small energy investment. Even if the required electricity involves an around 2.5-times higher primary energy input, the energy balance is still positive.

6.3.4.5. Operational data

The electrostatic sorting is done after a series of dry- and wet-sorting steps that involve sieving and winnowing to remove dust particles, foils, textiles and foams (material pre-treatment). An overview over the process steps is given in Figure 6-17.

After this first process step, the mixed plastics with a particle size of < 50 mm undergo density separation. This step exploits the fact that the various plastic types in WEEE have quite different densities ranging from 0.9 kg/l to 1.4 kg/l (see Figure 6-18).

Figure 6-18: Densities of different types of plastics in WEEE



Source: Köhnlechner (2014a)

[201] Assumption: 42MJ/kg crude oil

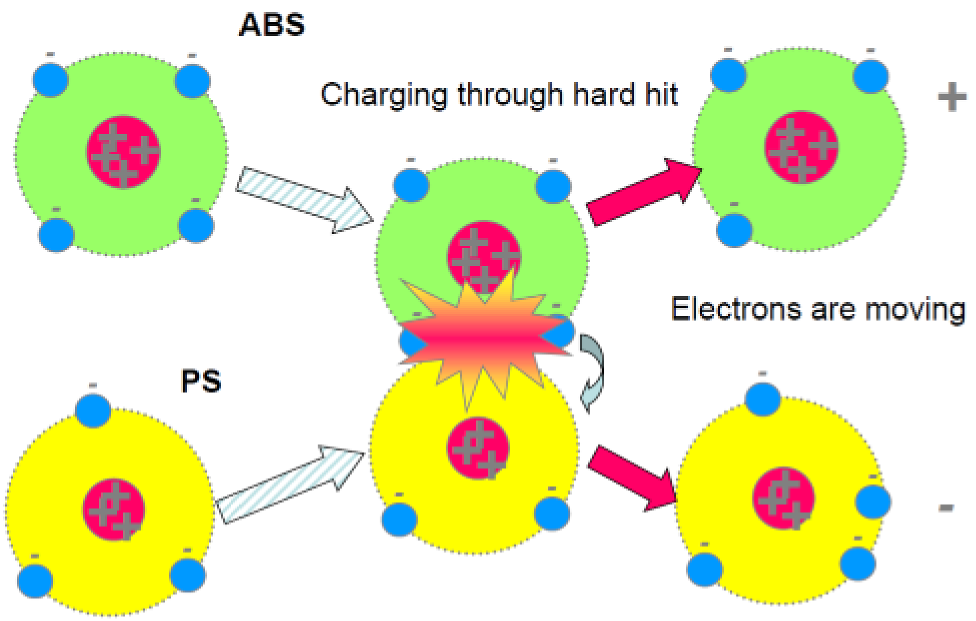
By using a salt solution with a density of 1.08 kg/l, plastics with higher densities – including plastics with high concentrations of flame retardants – sink, while PP20, ABS, PS, HDPE and PP float. This floating fraction is given into water (density = 1.00 kg/l), which separates DDPE and PP (floating) from PP20, ABS and PS (sinking).

In the third process step, this sinking fraction is milled to a particle size < 10mm, which is necessary for both, the subsequent electrostatic separation steps, as well as the use in extruders. The milling is conducted straight after density separation. This means that the particles entering the mill are still wet. While the process heat in the mill dries plastic parts, wood and paper particles stay wet, a fact that is exploited in the subsequent first electrostatic separation of wood and paper particles. In this process, all particles are given onto an earthed rotating separation drum in the 12 o'clock position. A high-voltage electrode positioned over the drum is charging all particles. As wet wood, textile and paper particles discharge more rapidly compared to dry plastic particles, they fall off the drum earlier and can be effectively sorted out.

After separating wood and paper particles, the mix is composed of around 50% PS and 50% ABS with some contamination of PP20 and PPO. In the first phase of the electrostatic separation, the plastic parts are electrically charged through the collisions created between particles of different electrostatic properties. This results in ABS particles being positively loaded, while PS and PP20 are negatively loaded. This tribo-electrical charging is illustrated in Figure 6-19.

The charged particles are transferred to a free fall separator with a high voltage field. While the positively charged ABS is pulled towards the cathode, the negatively charged PS and PP20 are pulled towards the anode, which enables the separation of fractions (see Figure 6-20).

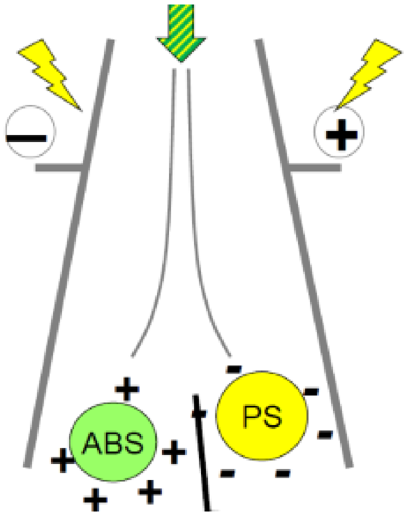
Figure 6-19: The principle of tribo-electric charging used for electrostatic separation of ABS and PS



Source: Hamos & WERSAG (n.y.)

While this sorting step yields ABS of high purity (99%), the remaining fraction composed of PS, PP20, PPO and some remaining ABS is again fed into an electrostatic separator to generate a pure ABS fraction.

Figure 6-20: Sorting in a high voltage free fall separator



Source: Hamos (n.y.)

The electrostatic sorting equipment produced by Hamos achieves throughput rates between 750 to 1,200 kg/h (Köhnlechner 2012).

6.3.4.6. Applicability

The technology is suited for recyclers of mixed plastic streams from WEEE and end-of-life vehicles (ELV). Contamination of the input stream with glass and/or metal parts is acceptable as these particles are effectively sorted out during sink-float separation and therefore cannot cause any damage to equipment.

6.3.4.7. Economics

According to Köhnlechner (2014b), the costs for the electrostatic sorting of 1 t of plastics range between 20 and 25 Euros, including costs for electricity, maintenance and depreciation. The costs for process steps 1-3 (see Figure 6-17) are not accounted for in this figure.

Virgin plastic resin is traded at a price ranging between 450 and 620 Euro/t for PS and 355 and 575 Euro/t for ABS in August 2014 (Plastic News 2014).

6.3.4.8. Driving force for implementation

High quality sorting of plastics from waste electrical and electronic equipment is a crucial pre-condition for recycling, which – according to the European waste hierarchy – has clear priority over (energy) recovery. The WEEE Directive specifies quantitative minimum targets for reuse and recycling ranging between 50% and 80% of the average weight of the appliances. While the targets laid out in the WEEE-Directive have already been a key factor for the recycling of WEEE-plastics in the past (Schlummer et al. 2007), these targets will be increased by 5% as from 15 of August 2015 (see Table 6-7). In order to achieve these targets, recyclers must optimize their recycling processes in a way that more output material will be recycled. While many recyclers already achieve quite good recycling rates for base-metal fractions such as ferrous metals, aluminium and copper, waste plastic still holds potential for increasing rates. Thus, the future compliance with Directive 2012/19/EU is a key motivation for recyclers for implementation of this BEMP.

Table 6-7: Re-use and recycling targets specified in Directive 2012/19/EU

WEEE category		Current re-use and recycling targets	Re-use and recycling targets after 14 August 2015
1	Large household appliances	75%	80%
2	Small household appliances	50%	55%
3	IT and telecommunications equipment	65%	70%
4	Consumer equipment	65%	70%
5	Lighting equipment	50%	55%
6	Electric and electronic toys	50%	55%
7	Toys, leisure and sports equipment	50%	55%
8	Medical devices	50%	55%
9	Monitoring and control instruments	50%	55%
10	Automatic dispensers	75%	80%
-	Gas discharge lamps	80%	80%

Source: Own table according to Directive 2012/19/EU[202]

6.3.4.9. Reference organisations

- Hamos GmbH (Equipment manufacturer, Germany)
- WERSAG GmbH & Co. KG (Dresden, Germany)

6.3.4.10. Chapter references

Bennett et al. (2009) Bennett, M.; Edwards, L.: Goyos-Ball, L.; Hilder, R.; Hall, P.; Morrish, L.; Morton, R.; Myles, N.; Separation of mixed WEEE plastics; WRAP, Banbury, 2009.

Hamos (n.y.) Hamos; Black Out – Recycling of black plastics; presentation; Penzberg; no year.

Hamos & WERSAG (n.y.) Hamos & WERSAG; Separation Technologies for WEEE Plastics – hamos KRS; presentation; Penzberg & Großschirma; no year.

Köhnlechner (2012) Köhnlechner, R.; Black Out; in: Recycling Today, Volume 03, 2012.

Köhnlechner (2014a) Köhnlechner, R.; Erzeugung sauberer PS- und ABS-Fraktionen aus gemischtem Elektronikschrott; in: Thomé-Kozmiensky, K.T.; Goldmann, D.; Recycling und Rohstoffe, Volume 7, 2014.

Köhnlechner (2014b) Köhnlechner, R.; personal communication; 26.05.2014.

Plastic News (2014) Plastic News; Current Resin Pricing; internet: http://www.plasticsnews.com/resin/commodity-thermoplastics/current-pricing (retrieved 13.08.2014).

Schlummer et al. (2007) Schlummer, M.; Gruber, L.; Mäurer, A.; Wolz, G.; van Eldik, R.; Characterisation of polymer fractions from waste electrical and electronic equipment (WEEE) and implications for waste management; in: Chemosphere 2007, 67, 1866-1876.

[202] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast), http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0019

7. Concluding remarks

The objective of this background report was to collect technological, environmental and economic information in order to enable the European Commission's Joint Research Centre (JRC) to prepare the Sectoral Reference Documents (SRD) on Best Environmental Management Practice (BEMP) for the manufacture of Electronic and Electrical Equipment (EEE). In order to achieve this goal, this report shall consider the whole value chain and with specific focus on supply chain management, manufacturing and recycling of end-of-use products. Since industrial systems like the manufacturing of EEE are characterized by processes and activities which complexly intersect and are closely related to each other, this study has primarily applied a process- / technology-oriented approach.

Ultimately, the SRD aims to help companies in the EEE sector to identify relevant, proven and reliable technical information for the process of continuous improvement of their environmental performance. Within this context, companies that have implemented or consider implementing the Eco-Management and Audit Scheme (EMAS) are the most important target group. Besides EMAS verified production sides, also organisations with other environmental management systems (especially ISO 14001) or intending to move on towards greater sustainability are invited to use this document.

During drafting of this report numerous publications and web-sites have been reviewed and interviews have been conducted with experts of the enterprises concerned as well as other stakeholders. Expert consultation has been used as source of information right from the beginning, especially concerning the identification and feasibility of possible best environmental management practices. In addition to this, visits of EEE production sites have been carried out in order to understand frontrunner techniques and to obtain specific information for their description as well as to describe limitations of the environmental performance indicators.

All contributions, feedback and suggestions within this context have been of outstanding value for the report and are highly appreciated.

Concerning the scope of best environmental management practices, the following environmental pressures were identified:

- Resource efficiency;
- Energy and climate change;
- Emissions to air;
- Hazardous substances;
- Water;
- Waste;
- Biodiversity.

Besides this environmental filter, also a component filter (focusing, but not limiting both assessment and recommendations on integrated circuits and printed circuit boards) as well as a geographical filter (addressing primarily the production of EEE in EU-28) have been applied.

For all of the environmental pressures mentioned above, altogether 21 best practice approaches were developed. The following table provides an overview of the different best environmental management practices and the environmental pressures they address.

Table 7-1: Overview of best environmental management practices and the addressed environmental pressures

No.	BEMP	Environmental pressures addressed: Resource efficiency	Water	Waste	Emis-sions to air	Energy & climate change	Bio-diversity	Hazar-dous sub-stances
	MANUFACTURING							
1	Energy-efficient cleanroom technology	X				X		
2	Efficient supply and substitution of compressed air	X				X		
3	Energy-efficient cooling technology	X				X		
4	Energy-efficient soldering	X			X	X		
5	Minimising the use of PFC				X	X		X
6	Substitution / reuse of VOC-based solvents	X		X	X			X
7	Water savings and recovery in cascade rinsing systems		X	X				
8	On-site recycling of metals in process chemicals	X	X	X				
9	Protecting and enhancing biodiversity						X	
10	Use of renewable energy in EEE manufacturing	X				X		
	SUPPLY-CHAIN MANAGEMENT							
11	Assessment tools for substitu-tion of hazardous substances							X
12	Elimination of certain phthalates							X
13	Elimination of BFR and PVC							X
14	Disclose and set targets for supply chain GHG emissions					X		
15	Conducting LCA		X	X	X	X		
16	Increasing the content of recycled plastics in EEE	X				X		
	END-OF LIFE							
17	End-of-life removability of rechargeable batteries	X		X				X
18	Integrated Product Service Offerings	X		X		X		
19	High quality refurbishment of used products	X		X		X		
20	Non-destructive extraction of circuit boards	X		X	X	X		X
21	Innovative sorting solutions for black plastics from WEEE	X		X				

As one of the key elements of these best practice approaches appropriate environmental performance indicators have been developed that enable companies to assess the current status as well as to set targets within the continuous optimization process. Most of these metrics are on qualitative level and expressed in physical units (e.g. electricity consumption in kWh/m²). However, especially concerning the less process-oriented best environmental management practices in the field of supply chain management this was not possible in many cases and thus quantitative metrics had to be developed.

8. Annexes

8.1. Annex 1: Number of companies registered under EMAS according to EEE NACE codes

NACE code	NACE code explanation	No. of companies currently listed
26.11	26.11 Manufacture of electronic components	21
26.12	26.12 Manufacture of loaded electronic boards	9
26.20	26.20 Manufacture of computers and peripheral equipment	10
26.30	26.30 Manufacture of communication equipment	9
26.40	26.40 Manufacture of consumer electronics	6
26.51	26.51 Manufacture of instruments and appliances for measuring, testing and navigation	16
26.52	26.52 Manufacture of watches and clocks	10
26.60	26.60 Manufacture of irradiation, electromedical and electrotherapeutic equipment	6
26.70	26.70 Manufacture of optical instruments and photographic equipment	4
27.80	26.80 Manufacture of magnetic and optical media	4
27.11	27.11 Manufacture of electric motors, generators and transformers	12
27.12	27.12 Manufacture of electricity distribution and control apparatus	14
27.20	27.20 Manufacture of batteries and accumulators	6
27.31	27.31 Manufacture of fibre optic cables	6
27.32	27.32 Manufacture of other electronic and electric wires and cables	10
27.33	27.33 Manufacture of wiring devices	8
27.40	27.40 Manufacture of electric lighting equipment	4
27.51	27.51 Manufacture of electric domestic appliances	7
27.52	27.52 Manufacture of non-electric domestic appliances	5
27.90	27.90 Manufacture of other electrical equipment	9
28.11	28.11 Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	16
28.12	28.12 Manufacture of fluid power equipment	16
28.13	28.13 Manufacture of other pumps and compressors	15
28.14	28.14 Manufacture of other taps and valves	14
28.15	28.15 Manufacture of bearings, gears, gearing and driving elements	14
28.21	28.21 Manufacture of ovens, furnaces and furnace burners	12
28.22	28.22 Manufacture of lifting and handling equipment	13
28.23	28.23 Manufacture of office machinery and equipment (except computers and peripheral equipment)	12
28.24	28.24 Manufacture of power-driven hand tools	12
28.25	28.25 Manufacture of non-domestic cooling and ventilation equipment	16
28.29	28.29 Manufacture of other general-purpose machinery n.e.c	17
28.30	28.30 Manufacture of agricultural and forestry machinery	12
28.41	28.41 Manufacture of metal forming machinery	11

NACE code	NACE code explanation	No. of companies currently listed
28.49	28.49 Manufacture of other machine tools	12
28.91	28.91 Manufacture of machinery for metallurgy	17
28.92	28.92 Manufacture of machinery for mining, quarrying and construction	16
28.93	28.93 Manufacture of machinery for food, beverage and tobacco processing	17
28.94	28.94 Manufacture of machinery for textile, apparel and leather production	16
28.95	28.95 Manufacture of machinery for paper and paperboard production	20
28.96	28.96 Manufacture of plastics and rubber machinery	19
28.99	28.99 Manufacture of other special-purpose machinery n.e.c.	20

8.2. Annex 2: Phthalates on the REACH Candidate List sorted by date of inclusion

Reason for inclusion in each case is toxic to reproduction (REACH Article 57 c) (as of Aug. 2014)

Substance Name and Acronym	CAS	EC	Date of inclusion
1,2-Benzenedicarboxylic acid, dihexyl ester, branched and linear (Diisohexyl phthalate, DIHP)	68515-50-4	271-093-5	2014/06/16
Dihexyl phthalate (DHP)	84-75-3	201-559-5	2013/12/16
Dipentyl phthalate (DPP)	131-18-0	205-017-9	2013/06/20
1,2-Benzenedicarboxylic acid, dipentylester, branched and linear	84777-06-0	284-032-2	2012/12/19
N-pentyl-isopentylphthalate	776297-69-9	-	2012/12/19
Diisopentylphthalate (DIPP)	605-50-5	210-088-4	2012/12/19
Bis(2-methoxyethyl) phthalate (DEMP)	117-82-8	204-212-6	2011/12/19
1,2-Benzenedicarboxylicacid, di-C6-8-branched alkyl esters, C7-rich (Diisoheptyl phthalate, DIHP)	71888-89-6	276-158-1	2011/06/20
1,2-Benzenedicarboxylic acid, di-C7-11-branched and linear alkyl esters (DHNUP)	68515-42-4	271-084-6	2011/06/20
Diisobutyl phthalate (DIBP)	84-69-5	201-553-2	2010/01/13
Bis (2-ethylhexyl) phthalate (DEHP)	117-81-7	204-211-0	2008/10/28
Butyl benzyl phthalate (BBP)	85-68-7	201-622-7	2008/10/28
Dibutylphthalate (DBP)	84-74-2	201-557-4	2008/10/28

Source: Own table according to ECHA Candidate List as of August 2014; http://echa.europa.eu/candidate-list-table (August 2014)