

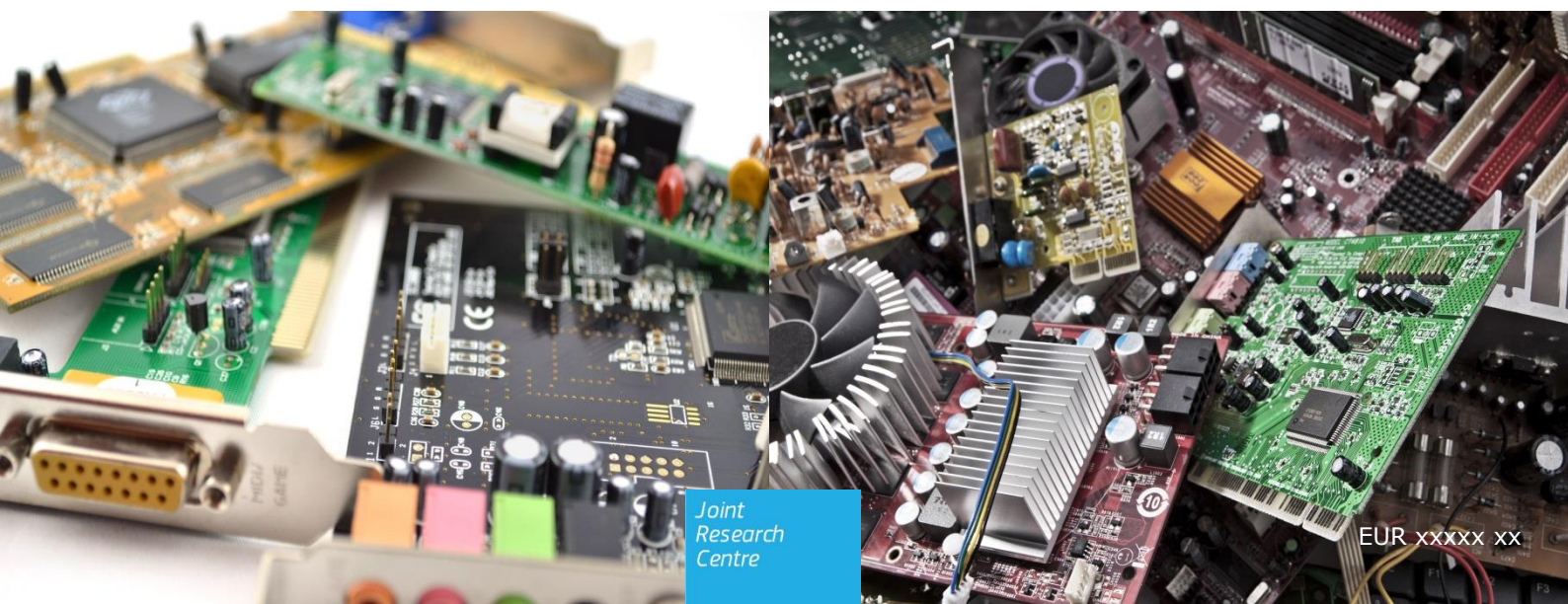
JRC SCIENCE FOR POLICY REPORT

Best Environmental Management Practice for the Electrical and Electronic Equipment Manufacturing Sector

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*Learning from
frontrunners*

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December 2016



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EUR xxxxx xx

Print	ISBN xxx-xx-xx-xxxxx-x	ISSN xxxx-xxxx	doi:xx.xxxxx/xxxxxx
PDF	ISBN xxx-xx-xx-xxxxx-x	ISSN xxxx-xxxx	doi:xx.xxxxx/xxxxxx

Luxembourg: Publications Office of the European Union, 2016

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How to cite this report: Antonopoulos I.S., Canfora P., Dri M., Gaudillat P., Best Environmental Management Practice for the Electrical and Electronic Equipment Manufacturing Sector, Learning from frontrunners, EUR, doi

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Best Environmental Management Practice for the Electrical and Electronic Equipment Manufacturing Sector

Abstract

This report describes information pertinent to the development of Best Environmental Management Practice (BEMP) techniques for the Sectoral Reference Document on the Electrical and Electronic Equipment manufacturing sector, to be produced by the European Commission according to Article 46 of Regulation (EC) No 1221/2009 (EMAS Regulation). The report firstly outlines scientific information on the contribution of Electrical and Electronic Equipment manufacturing to key environmental burdens in the EU, alongside data on the economic relevance of the sector. Afterwards, the scope and the target group of this report and eventually the BEMPs are presented. The presented BEMPs deal with the manufacturing and supply chain management activities whereas a set of techniques that fall under the circular economy package, focusing on how to extend the life time of the used products are listed.

Table of Contents

Preface.....	10
Acknowledgements	14
Executive summary	15
1 Introduction.....	17
2 General information about the sector	18
2.1 Definition and structural overview.....	18
2.2 Economic relevance	20
2.3 Environmental relevance	30
2.4 Environmental aspects of the EEE sector	34
2.4.1 Resource efficiency	36
2.4.2 Water	36
2.4.3 Waste.....	37
2.4.4 Emissions to air	38
2.4.5 Energy and climate change	39
2.4.6 Biodiversity	39
2.4.7 Hazardous substances	39
2.5 Implementation of environmental management systems	40
2.5.1 EU Eco-Management and Audit Scheme (EMAS)	40
2.5.2 ISO 14000 family of standards	41
2.6 Reference literature	41
3 Scope of the document.....	44
4 BEMPs for manufacturing processes	46
4.1 Techniques portfolio.....	46
4.2 Description of best environmental management practice	49
4.2.1 Energy-efficient cleanroom technology	49
4.2.1.1 Description.....	50
4.2.1.2 Achieved environmental benefits.....	53
4.2.1.3 Appropriate environmental performance indicators.....	54
4.2.1.4 Cross-media effects.....	54
4.2.1.5 Operational data	54
4.2.1.6 Applicability	56
4.2.1.7 Economics.....	57
4.2.1.8 Driving force for implementation.....	57
4.2.1.9 Reference organisations.....	57
4.2.1.10 Reference literature	57
4.2.2 Energy-efficient cooling	59

4.2.2.1	Description.....	59
4.2.2.2	Achieved environmental benefits.....	61
4.2.2.3	Appropriate environmental performance indicators.....	61
4.2.2.4	Cross-media effects.....	62
4.2.2.5	Operational data	62
4.2.2.6	Applicability	66
4.2.2.7	Economics.....	66
4.2.2.8	Driving force for implementation.....	68
4.2.2.9	Reference organisations.....	68
4.2.2.10	Reference literature	68
4.2.3	Energy-efficient reflow soldering.....	70
4.2.3.1	Description.....	71
4.2.3.2	Achieved environmental benefits.....	72
4.2.3.3	Appropriate environmental performance indicators.....	72
4.2.3.4	Cross-media effects.....	73
4.2.3.5	Operational data	73
4.2.3.6	Applicability	74
4.2.3.7	Economics.....	75
4.2.3.8	Driving force for implementation.....	75
4.2.3.9	Reference organisations.....	75
4.2.3.10	Reference literature	76
4.2.4	On-site copper recycling in process chemicals	78
4.2.4.1	Description.....	78
4.2.4.2	Achieved environmental benefits.....	79
4.2.4.3	Appropriate environmental performance indicators.....	80
4.2.4.4	Cross-media effects.....	80
4.2.4.5	Operational data	80
4.2.4.6	Applicability	81
4.2.4.7	Economics.....	81
4.2.4.8	Driving force for implementation.....	82
4.2.4.9	Reference organisations.....	82
4.2.4.10	Reference literature	83
4.2.5	Cascade rinsing systems and water use optimisation.....	84
4.2.5.1	Description.....	84
4.2.5.2	Achieved environmental benefits.....	85
4.2.5.3	Appropriate environmental performance indicators.....	86
4.2.5.4	Cross-media effects.....	87
4.2.5.5	Operational data	87

4.2.5.6	Applicability	88
4.2.5.7	Economics.....	88
4.2.5.8	Driving force for implementation.....	89
4.2.5.9	Reference organisations.....	89
4.2.5.10	Reference literature	89
4.2.6	Minimising perfluorocompounds emissions	90
4.2.6.1	Description.....	91
4.2.6.2	Achieved environmental benefits.....	93
4.2.6.3	Appropriate environmental performance indicators.....	93
4.2.6.4	Cross-media effects.....	93
4.2.6.5	Operational data	94
4.2.6.6	Applicability	95
4.2.6.7	Economics.....	95
4.2.6.8	Driving force for implementation.....	96
4.2.6.9	Reference organisations.....	96
4.2.6.10	Reference literature	97
4.2.7	Rational and efficient use of compressed air	98
4.2.7.1	Description.....	99
4.2.7.2	Achieved environmental benefits.....	101
4.2.7.3	Appropriate environmental performance indicators.....	101
4.2.7.4	Cross-media effects.....	102
4.2.7.5	Operational data	102
4.2.7.6	Applicability	105
4.2.7.7	Economics.....	106
4.2.7.8	Driving force for implementation.....	106
4.2.7.9	Reference organisations.....	106
4.2.7.10	Reference literature	107
4.2.8	Protecting and enhancing biodiversity on-site.....	108
4.2.8.1	Description.....	108
4.2.8.2	Achieved environmental benefits.....	109
4.2.8.3	Appropriate environmental performance indicators.....	110
4.2.8.4	Cross-media effects.....	111
4.2.8.5	Operational data	111
4.2.8.6	Applicability	116
4.2.8.7	Economics.....	116
4.2.8.8	Driving force for implementation.....	117
4.2.8.9	Reference organisations.....	118
4.2.8.10	Reference literature	118

4.2.9	Use of renewable energy	120
4.2.9.1	Description.....	120
4.2.9.2	Achieved environmental benefits.....	121
4.2.9.3	Appropriate environmental performance indicators.....	123
4.2.9.4	Cross-media effects.....	123
4.2.9.5	Operational data	124
4.2.9.6	Applicability	126
4.2.9.7	Economics.....	127
4.2.9.8	Driving force for implementation.....	128
4.2.9.9	Reference organisations.....	130
4.2.9.10	Reference literature	130
4.2.10	Optimised waste management within manufacturing facilities.....	132
4.2.10.1	Description	132
4.2.10.2	Achieved environmental benefits	134
4.2.10.3	Appropriate environmental performance indicators.....	135
4.2.10.4	Cross-media effects	135
4.2.10.5	Operational data	136
4.2.10.6	Applicability	137
4.2.10.7	Economics	138
4.2.10.8	Driving force for implementation.....	138
4.2.10.9	Reference organisations.....	139
4.2.10.10	Reference literature.....	140
5	BEMPs for supply chain management	141
5.1	Techniques portfolio.....	141
5.2	Description of best environmental management practice	142
5.2.1	Assessment tools for cost-effective and environmentally sound substitution of hazardous substances.....	144
5.2.1.1	Description.....	144
5.2.1.2	Environmental benefits	153
5.2.1.3	Appropriate environmental performance indicators.....	154
5.2.1.4	Cross-media effects.....	155
5.2.1.5	Operational data	155
5.2.1.6	Applicability	158
5.2.1.7	Economics.....	158
5.2.1.8	Driving force for implementation.....	159
5.2.1.9	Reference organisations.....	159
5.2.1.10	Chapter references	160
5.2.2	Disclosing and setting targets for supply chain GHG emissions	162
5.2.2.1	Description.....	162

5.2.2.2	Achieved environmental benefits.....	166
5.2.2.3	Appropriate environmental performance indicators.....	167
5.2.2.4	Cross-media effects.....	167
5.2.2.5	Operational data.....	167
5.2.2.6	Applicability	178
5.2.2.7	Economics.....	178
5.2.2.8	Driving force for implementation.....	179
5.2.2.9	Reference organisations.....	182
5.2.2.10	Reference literature	183
5.2.3	Conducting life cycle assessment	185
5.2.3.1	Description.....	185
5.2.3.2	Achieved environmental benefits.....	187
5.2.3.3	Appropriate environmental performance indicators.....	188
5.2.3.4	Cross-media effects.....	189
5.2.3.5	Operational data.....	189
5.2.3.6	Applicability	194
5.2.3.7	Economics.....	195
5.2.3.8	Driving force for implementation.....	196
5.2.3.9	Reference organisations.....	196
5.2.3.10	Reference literature	198
5.2.4	Increasing the content of recycled plastics in EEE	201
5.2.4.1	Description.....	201
5.2.4.2	Achieved environmental benefits.....	206
5.2.4.3	Appropriate environmental performance indicators.....	208
5.2.4.4	Cross-media effects.....	209
5.2.4.5	Operational data.....	210
5.2.4.6	Applicability	213
5.2.4.7	Economics.....	214
5.2.4.8	Driving force for implementation.....	214
5.2.4.9	Reference organisations.....	215
5.2.4.10	Reference literature	216
5.2.5	Protecting and enhancing biodiversity along the EEE supply chain.....	220
5.2.5.1	Description.....	220
5.2.5.2	Achieved environmental benefits.....	222
5.2.5.3	Appropriate environmental performance indicators.....	223
5.2.5.4	Cross-media effects.....	224
5.2.5.5	Operational data.....	225
5.2.5.6	Applicability	229

5.2.5.7 Economics.....	229
5.2.5.8 Driving force for implementation.....	230
5.2.5.9 Reference organisations.....	230
5.2.5.10 Reference literature	231
6 BEMPs fostering circular economy	233
6.1 Techniques portfolio.....	233
6.2 Description of best environmental management practice	234
6.2.1 Strategic guidance on designing products for the circular economy	234
6.2.1.1 Description.....	235
6.2.1.2 Achieved environmental benefits.....	237
6.2.1.3 Appropriate environmental performance indicators.....	237
6.2.1.4 Cross-media effects.....	238
6.2.1.5 Operational data	239
6.2.1.6 Applicability	241
6.2.1.7 Economics.....	241
6.2.1.8 Driving force for implementation.....	241
6.2.1.9 Reference organisations.....	242
6.2.1.10 Reference literature	242
6.2.2 Integrated Product Service Offerings	244
6.2.2.1 Description.....	244
6.2.2.2 Achieved environmental benefits.....	247
6.2.2.3 Appropriate environmental performance indicators.....	248
6.2.2.4 Cross-media effects.....	248
6.2.2.5 Operational data	249
6.2.2.6 Applicability	252
6.2.2.7 Economics.....	252
6.2.2.8 Driving force for implementation.....	253
6.2.2.9 Reference organisations.....	253
6.2.2.10 Reference literature	253
6.2.3 Remanufacturing or high quality refurbishment of used products	255
6.2.3.1 Description.....	255
6.2.3.2 Achieved environmental benefits.....	258
6.2.3.3 Appropriate environmental performance indicators.....	259
6.2.3.4 Cross-media effects.....	259
6.2.3.5 Operational data	259
6.2.3.6 Applicability	263
6.2.3.7 Economics.....	263
6.2.3.8 Driving force for implementation.....	263

6.2.3.9 Reference organisations.....	263
6.2.3.10 Reference literature	264
7 Conclusions	266
List of abbreviations and definitions	274
List of figures	278
List of tables	281

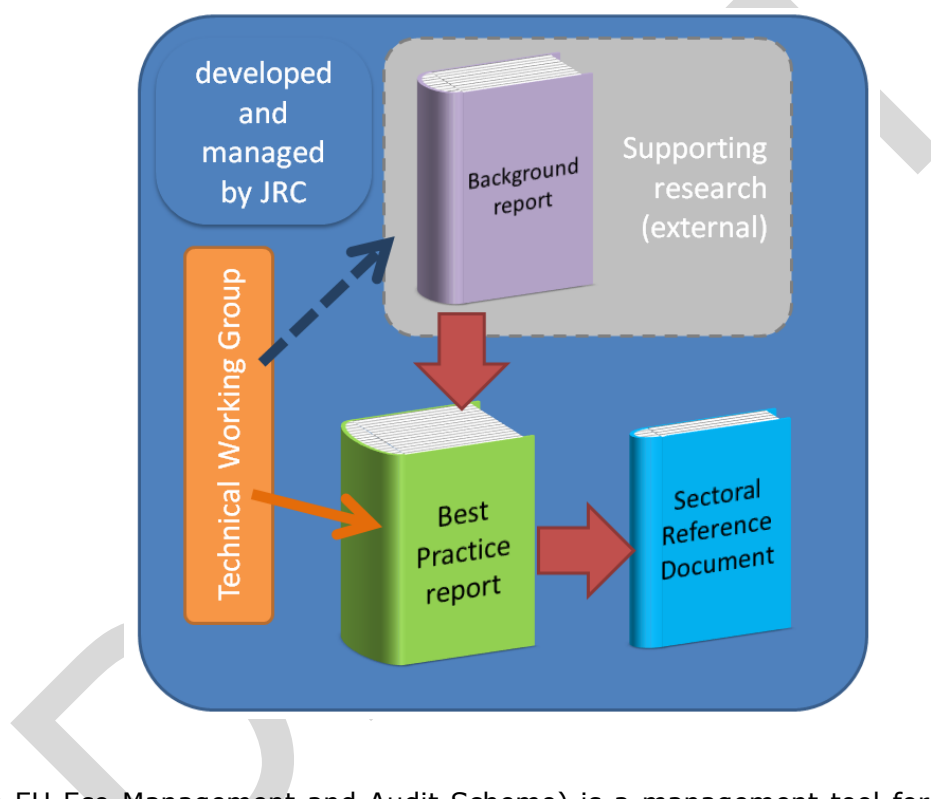
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Preface

This Best Practice Report¹ provides an overview of techniques that are Best Environmental Management Practices (BEMPs) in the Electrical and Electronic Equipment (EEE) manufacturing sector. The document was developed by the European Commission's Joint Research Centre (JRC) on the basis of desk research, interviews with experts, site visits and in close cooperation with a Technical Working Group (TWG) comprising experts from the sector. It is based on a preparatory external study carried out by Oeko-Institut e.V (Germany), whose findings are presented in a Background Report².

This Best Practice Report provides the basis for the development of the EMAS Sectoral Reference Document (SRD) for the electrical and EEE manufacturing sector (Figure A.1). The structured process for the development of this best practice report is outlined in the guidelines on the "Development of the EMAS Sectoral Reference Documents on Best Environmental Management Practice" (European Commission, 2014), which are available online³.

Figure A.1: The present best practice report (pictured below in green) in the overall development of the Sectoral Reference Document



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 Article 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 EEE manufacturing sector.

Nevertheless, it is important to note that the guidance on BEMP is not only for EMAS registered companies, 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.

¹ This report is part of a series of 'best practice reports' published by the European Commission's Joint Research Centre covering a number of sectors for which the Commission is developing Sectoral Reference Documents on Best Environmental Management Practice. More information on the overall work and copies of the 'best practice reports' available so far can be found at: <http://susproc.jrc.ec.europa.eu/activities/emas/>

² The background report produced by Oeko-Institut on which this report is based is available online at: <http://susproc.jrc.ec.europa.eu/activities/emas/eeem.html>

³ The methodology for the development of the EMAS Sectoral Reference Documents is available online at: <http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf>

BEMPs encompass techniques, measures or actions that can be taken to minimise environmental impacts. These can include technologies (such as more efficient machinery) and/or 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 EEE 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 A.1.

Table A.1: 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 <i>benefits</i> to be gained through implementing the BEMP.
Environmental performance indicators	Indicators and/or metrics used to monitor the implementation of the BEMP and its environmental benefits.
Cross-media effects	Potential <i>negative</i> 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.

The sector-specific Environmental Performance Indicators and Benchmarks of Excellence presented in this report were agreed by a technical working group, comprising a broad spectrum of experts in the manufacturing and end-of-life of electrical and electronic equipment, at the end of its interaction with the JRC.

Role and purpose of this document

This document is intended to support the environmental improvement efforts of all companies in the EEE manufacturing sector by providing guidance on best practices. Companies from this sector can use this document to identify the most relevant areas for action, find detailed information on best practices to address the main environmental aspects, as well as company-level environmental performance indicators and related benchmarks of excellence to track sustainability improvements.

In addition, this Best Practice Report provides the technical basis for the development of the EMAS SRD for the EEE Manufacturing Sector according to Article 46 of the EMAS Regulation⁴.

How to use this document

This document is not conceived to be read from beginning to end, but as a working tool for professionals willing to improve the environmental performance of their organisation and who seek reliable and proven information in order to do so.

Different parts of the document will be of interest and will apply to different professionals and at different stages.

The best way to start using this document is by reading the short section below about its structure to understand the content of the different chapters and, in particular, the areas for which BEMPs have been described and how these BEMPs have been grouped.

Then, Chapter 2 would be a good starting point for readers looking for a general understanding of the sector and its environmental aspects.

Those looking for an overview of the BEMPs described in the document could start from Chapter 7 (Conclusions) and in particular with Table 7.1 outlining all BEMPs together with the related environmental performance indicators and benchmarks of excellence, i.e. the exemplary performance level that can be reached in each area.

For readers looking for information on how to improve their environmental performance in a specific area, it is recommended to start directly at the concrete description of the BEMPs on that topic (Chapters 4, 5 and 6), which can be easily found through the table of contents (at the very beginning of this report).

Structure

Chapter 1 introduces briefly the approach and the perspective adopted to develop this report while Chapter 2 provides general information about the EEE manufacturing sector, such as economic and environmental relevance and main environmental aspects and pressures. Chapter 3 defines the target group and the scope of the report. Chapter 4 presents in detail the Best Environmental Management Practices for the core manufacturing activities of EEE manufacturers. Chapter 5 presents the Best Environmental Management Practices that EEE manufacturers can implement to improve the environmental performance of their supply chain. Chapter 6 presents the Best Environmental Management Practices that foster a move towards a circular economy. Finally, Chapter 7 lists all the BEMPs of Chapters 4, 5 and 6, highlighting their applicability and listing, where available, the environmental performance indicators and benchmarks of excellence that were agreed by the TWG.

⁴ When published, the EMAS SRD for the EEE manufacturing sector will be available online at: <http://susproc.jrc.ec.europa.eu/activities/emas/eeem.html>

Chapter	Topics and BEMPs
Chapter 1	Introduction
Chapter 2	General information about the sector
Chapter 3	Scope of the best practice report
Chapter 4	<p>Best Environmental Management Practices for the <u>EEE manufacturing activities</u>:</p> <ul style="list-style-type: none"> - Energy-efficient cleanroom technology - Energy-efficient cooling - Energy-efficient reflow soldering - On-site copper recycling in process chemicals - Cascade rinsing systems and water use optimisation - Minimising perfluorocompounds emissions - Rational and efficient use of compressed air - Protecting and enhancing biodiversity on-site - Use of renewable energy - Optimised waste management within manufacturing facilities
Chapter 5	<p>Best Environmental Management Practices for <u>supply chain management in the EEE manufacturing sector</u>:</p> <ul style="list-style-type: none"> - Assessment tools for cost-effective and environmentally sound substitution of hazardous substances - Disclosing and setting targets for supply chain GHG emissions - Conducting Life Cycle Assessment - Increasing the content of recycled plastics in EEE - Protecting and enhancing biodiversity in EEE supply chain
Chapter 6	<p>Best Environmental Management Practices fostering Circular Economy:</p> <ul style="list-style-type: none"> - Strategic guidance on designing products for the circular economy - Integrated product service offering (IPSO) - Refurbishment or high quality refurbishment of used products
Chapter 7	Conclusions: BEMPs, key environmental performance indicators and benchmarks of excellence for the EEE manufacturing sector

Acknowledgements

This report was prepared by the European Commission's Joint Research Centre in the framework of supporting the development of an EMAS Sectoral Reference Document for the electrical and electronic equipment manufacturing sector⁵. It is based on a preparatory study carried out by Oeko-Institut (Germany)⁶.

Moreover, a technical working group, comprising a broad spectrum of experts in the manufacturing and end-of-life of electrical and electronic equipment supported the development of the document by providing input and feedback.

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⁵ Further information on the development of the EMAS Sectoral Reference Documents is available online at: <http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf>

⁶ The background report and further information on its development are available online at: <http://susproc.jrc.ec.europa.eu/activities/emas/eeem.html>

Executive summary

This Best Practice Report provides an overview of techniques that may be considered **Best Environmental Management Practices (BEMPs)** in the Electrical and Electronic Equipment (EEE) manufacturing sector. The report was developed by the European Commission's Joint Research Centre in the framework of supporting the development of an EMAS Sectoral Reference Document for the EEE sector⁷. This report is based on an extensive background study carried out by the Oeko Institut (Germany). Additionally, a technical working group, comprising a broad spectrum of experts in the manufacture of EEE sector, supported the development of the document throughout this process by providing inputs and feedbacks.

The target group of this report is the **EEE manufacturing companies** and the BEMPs described were identified as best practices that can support their efforts in improving environmental performance. The selected BEMPs are practices already implemented by some EEE manufacturers, leading to very high levels of environmental performance and with large potential to be adopted more broadly.

The report covers core business activities of companies belonging to the EEE manufacturing sector. It specifically targets companies that belong to NACE codes 26 and 27, as well as some companies belonging to NACE code 28 and particularly to the NACE sub-codes 28.12, 28.13, 28.22 and 28.23.

The report encloses BEMPs for the three following areas:

- Manufacturing processes;
- Supply chain management;
- Practices fostering circular economy.

These areas are briefly presented below.

A. Manufacturing

The BEMPs in this area offer guidance on some of the core manufacturing activities of the production of electrical and electronic equipment, as well as some more general supporting processes, such as plant utilities. The BEMPs identified in this area are briefly listed below:

- A BEMP presenting the principles on how to operate an *energy efficient cleanroom*, a very energy intense process in semiconductor production sites.
- A BEMP on operating *energy efficient cooling systems*, dealing with reducing the need for cooling and improving the energy efficiency of the cooling systems used in production processes and production halls.
- A BEMP on applying efficiently *reflow soldering* contributing to significant energy savings.
- A BEMP on *on-site copper recycling in process chemicals*, which refers to recovering copper from the etching process agents used in printed circuit boards manufacturing.
- A BEMP on water savings thanks to *cascade rinsing systems* with at least four stages and other water use optimisation techniques.
- A BEMP on *minimising perfluorocompound emissions* in semiconductor fabrication facilities.
- A BEMP on reducing energy use by implementing *rational and efficient use of compressed air* which deals with mapping and assessing the use of compressed air and a series of measures to optimise the compressed air system.
- A BEMP on a range of concrete actions for *promoting and enhancing biodiversity* at the production facilities.
- A BEMP on *use of renewable energy* in EEE manufacturing plants either by purchasing or generating electricity or heat from renewable sources.
- A BEMP on *optimised waste management within manufacturing facilities*, which deals with the development and implementation of an integrated strategy that encompass both hazardous and non-hazardous waste and prioritises prevention, reuse and recycling over energy recovery and finally disposal.

⁷ Further information on the development of the EMAS Sectoral reference Documents is available online at: <http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf>

B. Supply chain management

The BEMPs in this area cover actions that EEE manufacturers can implement to improve the environmental performance of the supply chain of the EEE manufacturing sector. The BEMPs in this area are:

- *Assessment tools for cost-effective and environmentally sound substitution of hazardous substances*, where reference tools are used to identify hazardous substances in purchased materials in order to substitute them.
- *Disclosing and setting targets for supply chain GHG emissions* to foster the application of measures to reduce indirect GHG emissions.
- *Conducting Life Cycle Assessment* as a decision support instrument in the context of: strategic planning, design and planning of products, facilities, and processes and monitoring the environmental performance of the company.
- *Increasing the content of recycled plastics in products* by recycling plastics production waste, or applying closed-loop recycling of post-consumer plastics or procurement of recycled polymers.
- *Protecting and enhancing biodiversity along the EEE supply chain* based on a mapping of products and materials provided by the supply chain and of their relevant impacts on biodiversity, and thanks to procurement guidelines and requirements, targeting changes in relation to those products and components with a larger potential to impact biodiversity.

C. Fostering Circular Economy

These are techniques dealing with integrated solutions that EEE manufacturers can implement to support the transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised:

- *Strategic guidance on designing products for the circular economy*, which presents the approaches to ensure that the design process integrates the relevant circular economy considerations.
- *Integrated product service offering* (also known as IPSO) with improved collection, repair and recycling practices, and focusing both on business to business and business to customers
- *Remanufacturing or high quality refurbishment of used products*, which focus on preventing waste by giving a second life to products which would otherwise reach their end-of-life.

Most of the BEMPs are broadly applicable to companies of the sector of any size. When specific technological, economical or geographical limitations exist for the implementation of each identified BEMP, these are described in the relevant sections and summarised in the conclusions⁸.

Policy context

EMAS is a management tool for companies and other organisations to evaluate, report and improve their environmental performance. The latest revision of the EMAS Regulation (EC No. 1221/2009) introduced a particular focus on promoting best environmental management practices. To support this aim, the European Commission is producing Sectoral Reference Documents to provide information and guidance on BEMPs in eleven priority sectors, including the Electrical and Electronic Equipment manufacturing sector.

The present Best Practice Report provides the technical basis for the development of the EMAS Sectoral Reference Document for the EEE Manufacturing Sector according to article 46 of the EMAS Regulation.

⁸ Table 7.1 in Chapter 7, summarises the key environmental performance indicators and benchmarks of excellence (where available) for each identified BEMP.

1 Introduction

This report on Best Environmental Management Practices (BEMPs) for the Electrical and Electronic Equipment (EEE) manufacturing sector covers actions that electrical and electronic equipment manufacturers can implement which results in improvements in the environmental performance over the whole electrical and electronic equipment value chain.

It identifies both direct and indirect environmental aspects⁹ and describes the best practices implemented by EEE manufacturers as well as the indicators and benchmarks of excellence that can be used to measure the environmental performance and to compare this against best performance. The document includes 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 EEE, are characterised by processes and activities which complexly intersect and are closely related to each other, this report primarily applies a **process (technology)-oriented approach**.

Furthermore, the identification of the best practice was carried out on the basis of a **life cycle thinking approach**. This allows identification of the most important (positive as well as negative) impacts of a product system, with due consideration of trade-offs among life cycle phases or environmental pressures.

In particular, this approach helps to detect, where relevant, existing conflicts and problem shifting, e.g. 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, CO₂ 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 optimisation 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 optimising 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 report, all three perspectives are covered. However, the use phase (being part of the downstream perspective) is considered out of scope in order to minimise overlap with existing studies and policy instruments such as Ecodesign, the EU Ecolabel and the EU green public procurement criteria.

Where possible, this report even goes beyond the cradle-to-grave approach and also considers a closed-loop value chain with secondary resources derived from end-of-life 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.

⁹ According to the EMAS Regulation, the terms 'direct aspects' and 'indirect aspects' are used to distinguish the activities where a manufacturer has full control ('direct environmental aspects') from those resulting from the interaction with third parties but which can be influenced to a reasonable degree by the electrical and electronic equipment manufacturer ('indirect environmental aspects').

2 General information about the sector

2.1 Definition and structural overview

The term 'Electrical and electronic equipment' (EEE) refers to "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" (Directive 2011/65/EU¹⁰)

EEE manufacturing covers the production of a wide variety of products and devices, including, but not limited to, Information and Communication Technology (ICT) equipment, household appliances, lighting equipment, electrical tools, medical devices, etc.

According to the European classification of economic activities (Regulation (EC) No 1893/2006¹¹), the EEE manufacturing sector falls into the following NACE codes:

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
- 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

¹⁰ 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), available online at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32011L0065:EN:NOT>

¹¹ 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>

- 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.

Specifically relevant is the manufacturing of household appliances, covered under NACE code 27.51¹² (Manufacture of electric domestic appliances). 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,

¹² See details under the webpage:
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

hotplates; toasters; coffee or tea makers; fry pans, roasters, grills, hoods; electric heating resistors etc.

Also particularly relevant are ICT¹³ equipment, which is instead represented in the NACE codes by the following sub-categories¹⁴:

- 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

2.2 Economic relevance

Statistical data from Eurostat¹⁵, concerning the value of production, 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

¹³ Based on the classification provided under:

http://is.jrc.ec.europa.eu/pages/ISG/PREDICT/2da/documents/06ICT_TUR_27APR.xlsx

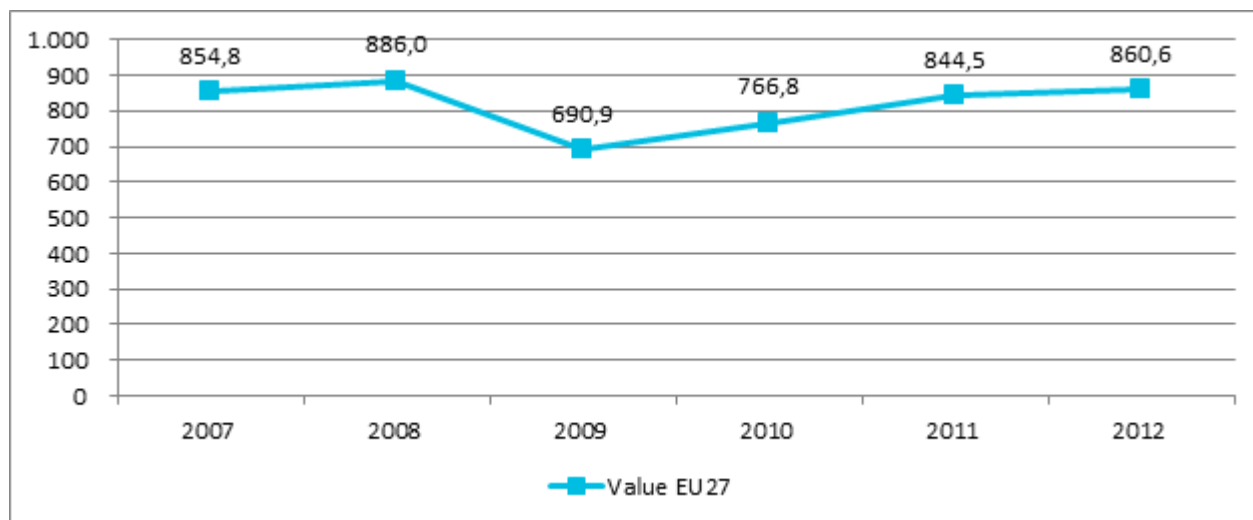
¹⁴ See details under:

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

¹⁵ 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

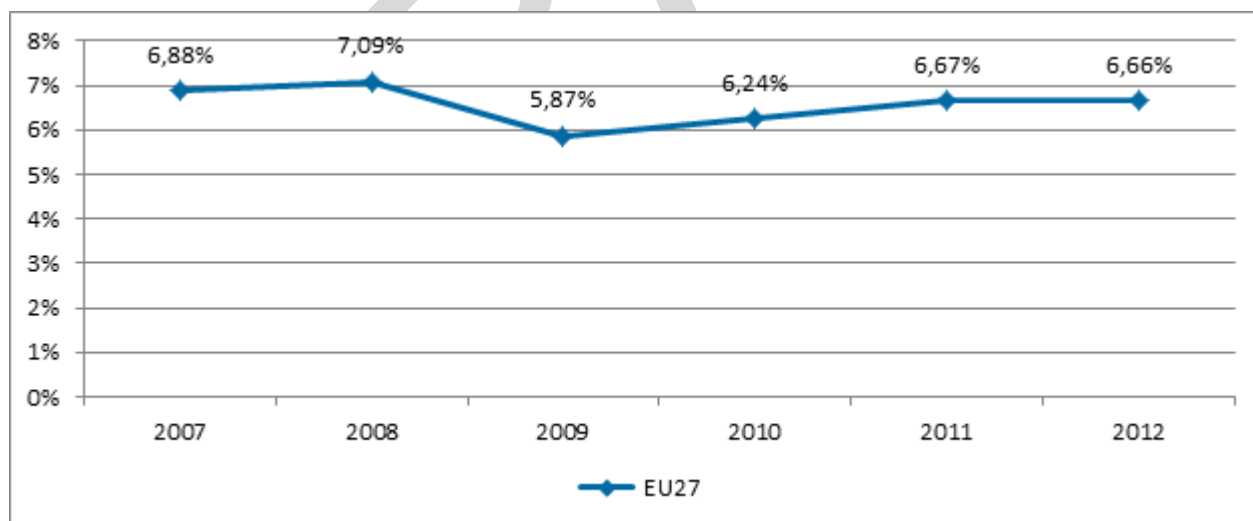
products (Figure 2.1). To provide insight as to the contribution of the EEE sector to the economy, the value of production can be analysed in terms of its share from the GDP for the EU 27 in Figure 2.2, as well as for specific countries in Figure 2.3 and Figure 2.4 below. From this demonstration it can 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 2.1. 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

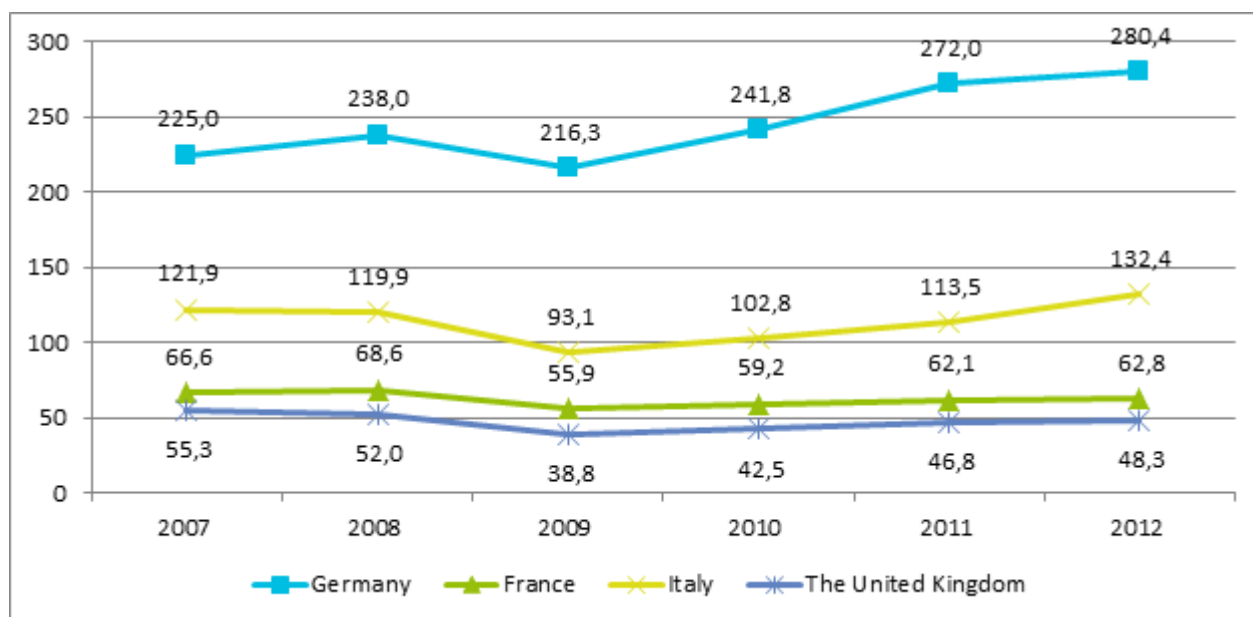
Figure 2.2. Contribution of EEE production value to GDP, EU27 (%)



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

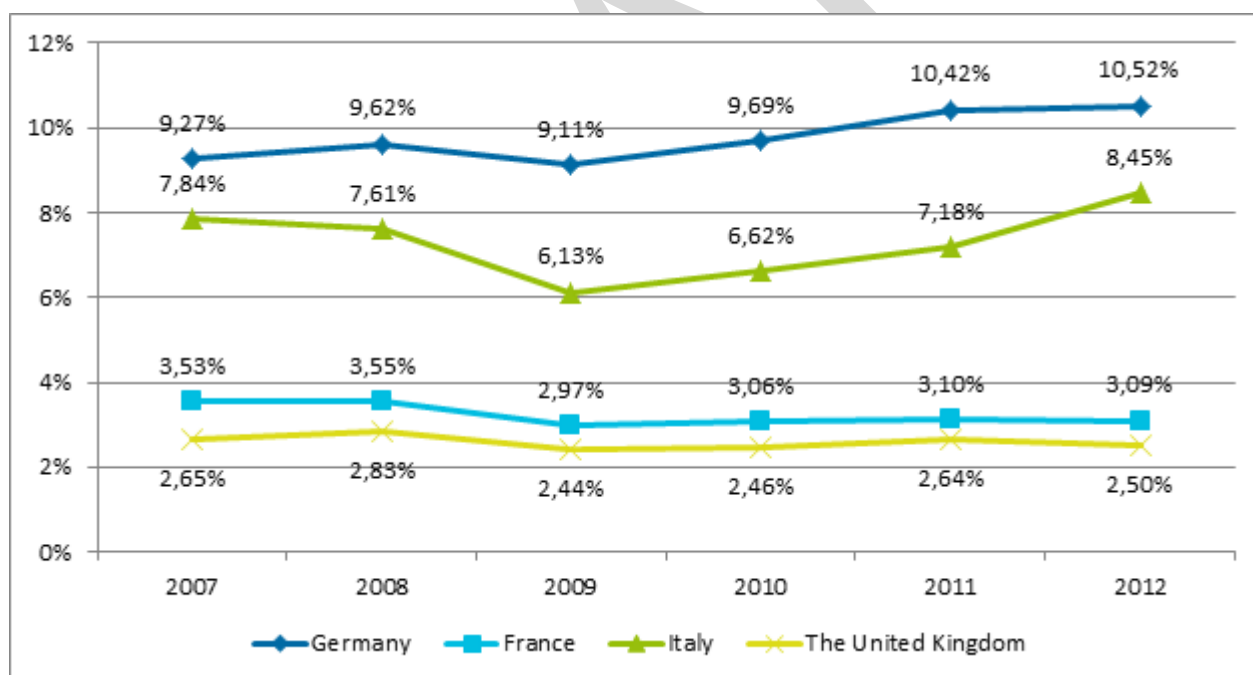
The main countries contributing to production throughout this period were Germany, Italy, France and the UK, with production values having decreased since 2007 in both France and the UK. This decrease is also reflected in Figure 2.4, which also shows that activity in Germany and Italy has increased beyond the pre-crisis levels.

Figure 2.3. 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

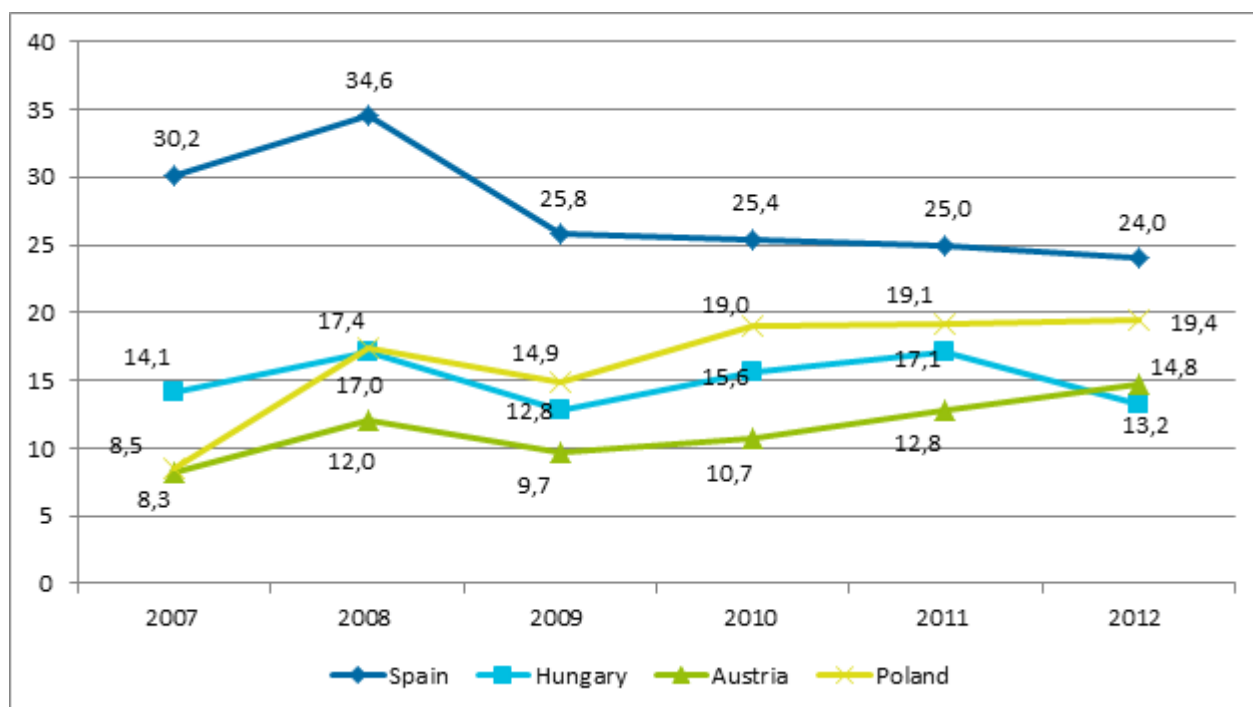
Figure 2.4. Contribution of EEE Production Value to GDP for Germany, Italy, France, and the UK (%)



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

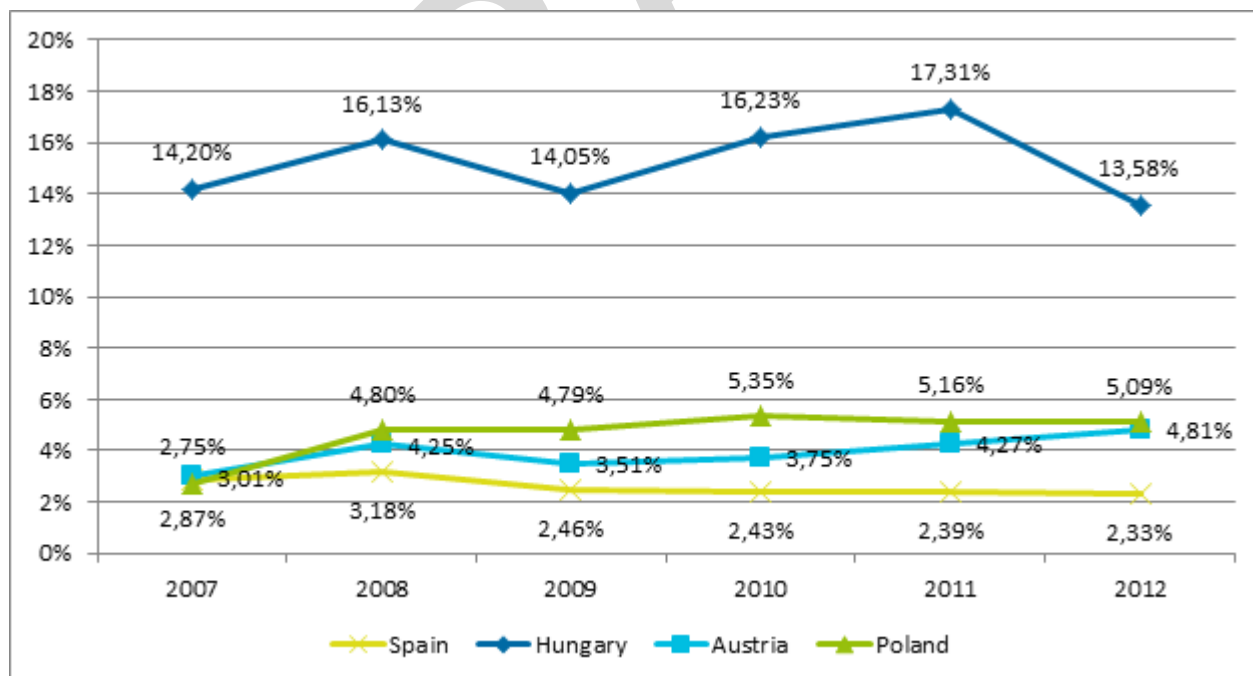
From EU 15, Spain and Austria are also of interest, Spain showing a significant decrease in production value throughout this period compared to Austria, showing a significant growth. In the eastern European countries, Hungary and Poland are observed to be the largest contributors, whereas in this concern Poland more than doubled its production volume in this period (Figure 2.5). 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 (Figure 2.6).

Figure 2.5. 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

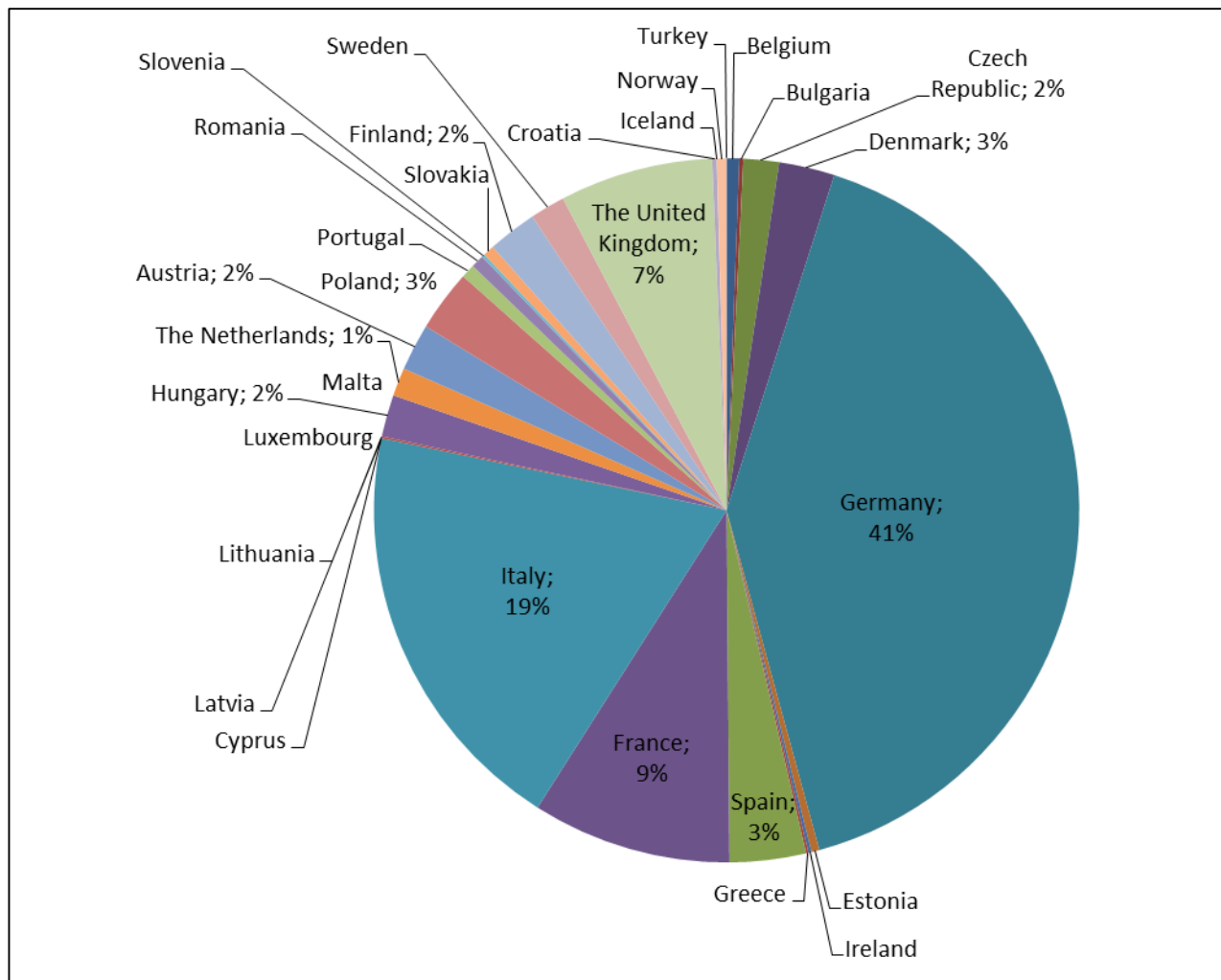
Figure 2.6. Contribution of EEE Production Value to GDP for Spain, Austria, Hungary, and Poland (%)



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 2.7. In this figure, manufacturing shares are detailed only for the larger manufacturing countries.

Figure 2.7. 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 the year 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 2.1. 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 showed that in 2011 there were over 5.5 million individuals employed in the manufacture of EEE in EU countries. For detailed data see Table 2.2 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.

Also, Germany has 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 (reference year 2011).

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 2.2. 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
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 (Target group and scope) 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 countries) 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).¹⁶

European Commission (2013)¹⁷ 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"¹⁸ development, aiming at higher performance, lower costs and less energy consumption. In parallel, the diversifying of the 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" (European Commission 2013, p. 4-5).

"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 telecommunications. 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."

The strategy outlined by European Commission (2013) 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."

¹⁶ EMF (2005): Trends and developments in the white goods sector in Europe A working paper of the EMF; available online at: <http://www.emf-fem.org/Industrial-Sectors/White-Goods/Background-documents-and-studies-on-the-white-goods-sector>

¹⁷ 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 online at: <http://ec.europa.eu/digital-agenda/en/news/communication-european-strategy-micro-and-nanoelectronic-components-and-systems>

¹⁸ 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.

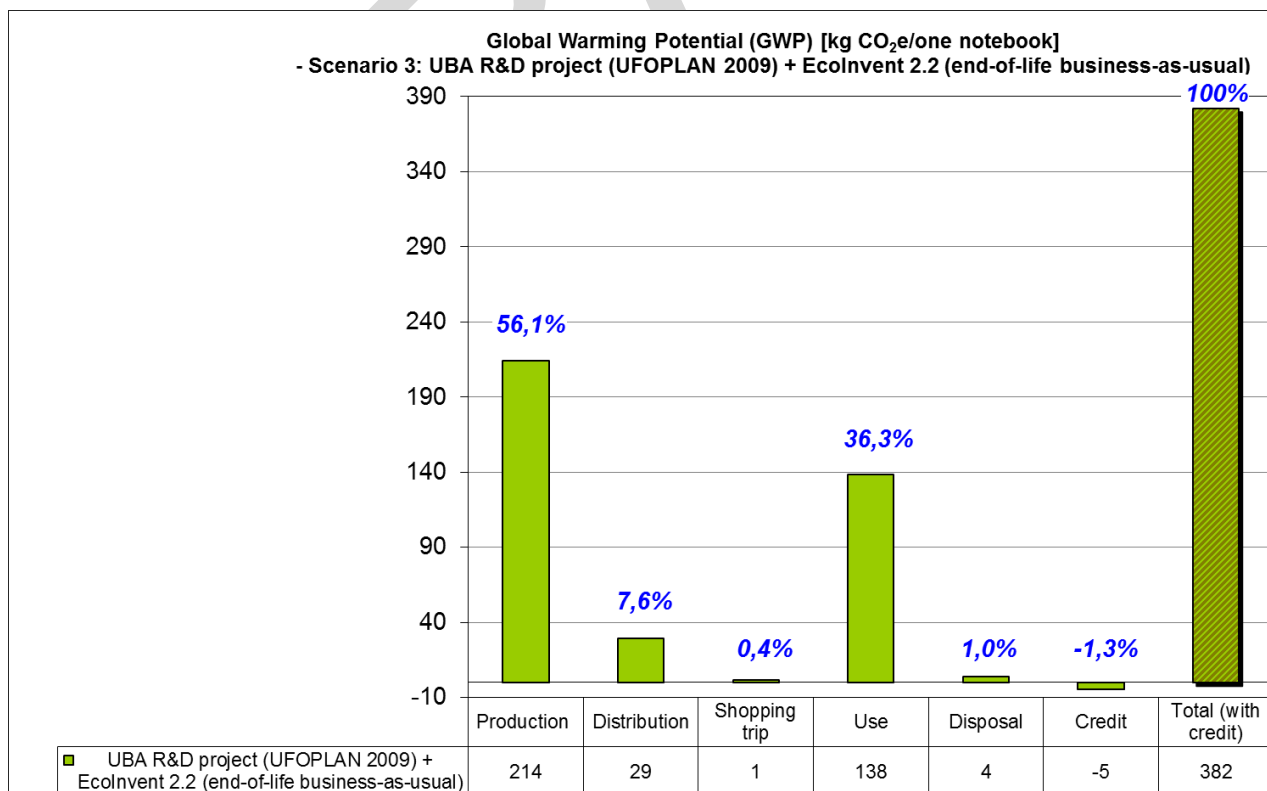
Within the EU strategy to reinforce Europe's industrial and technology leadership in ICT, an atlas of a European ICT Pole of Excellence (EIPE) has been compiled (Nepelski & De Prato 2014). This study gives an overview of geographical areas in the EU with best performing activities in ICT production as 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.

2.3 Environmental relevance

The EEE manufacturing sector has both large environmental impacts and large potential for improvement. In particular, the miniaturisation trend that EEE manufacturing currently follows, results in large environmental impacts, especially in terms of resource efficiency. Precious metals and rare earths are needed for the manufacturing, which create further environmental burden. On the other hand, the introduction of new innovative technologies that can be applied on-site and new business models can definitely improve the overall environmental performance and eventually balance the caused environmental impacts of a manufacturing site.

This is particularly relevant for ICT subsector where IT and telecommunication equipment, is both one of the most relevant and most innovative concerning environmental issues. 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 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, Prakash et al. (2011b) has found that more than 60% of the environmental impact of notebook computers is attributable to their production and distribution (Figure 2.8).

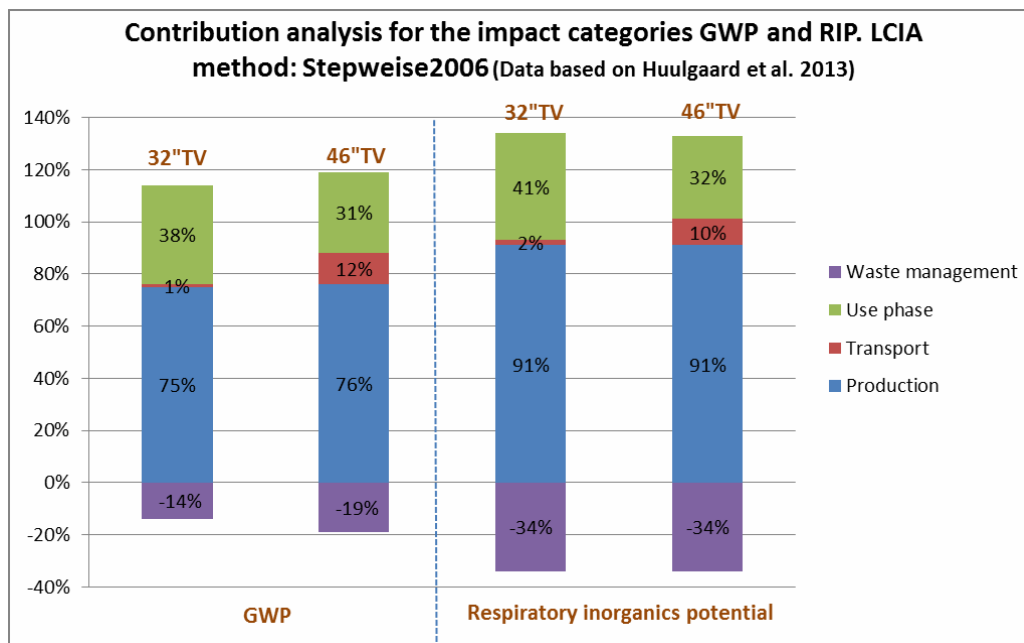
Figure 2.8. Absolute GWP values and percentage proportions of life cycle phases



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). Figure 2.9 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).

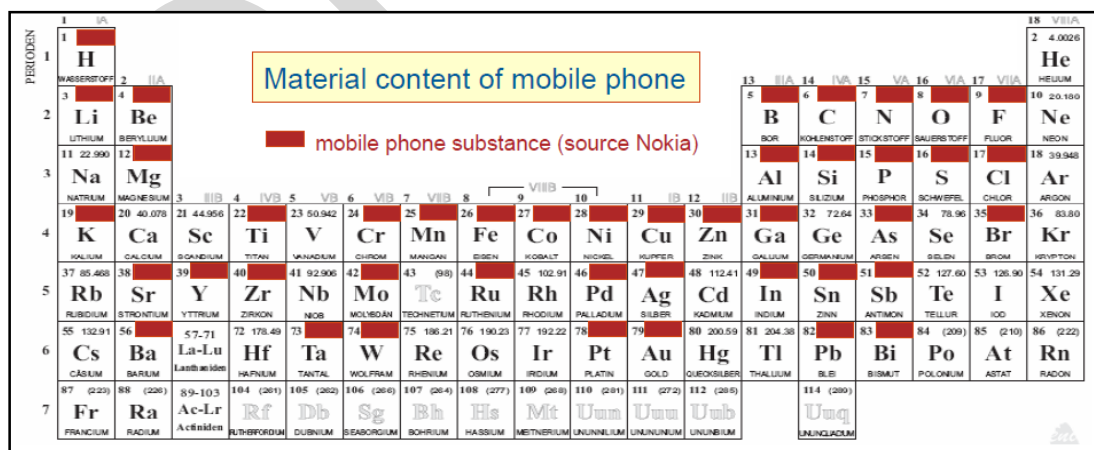
Figure 2.9: Contribution analysis for the impact categories GWP and RIP



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 (Figure 2.10).

Figure 2.10: Metals in a mobile phone



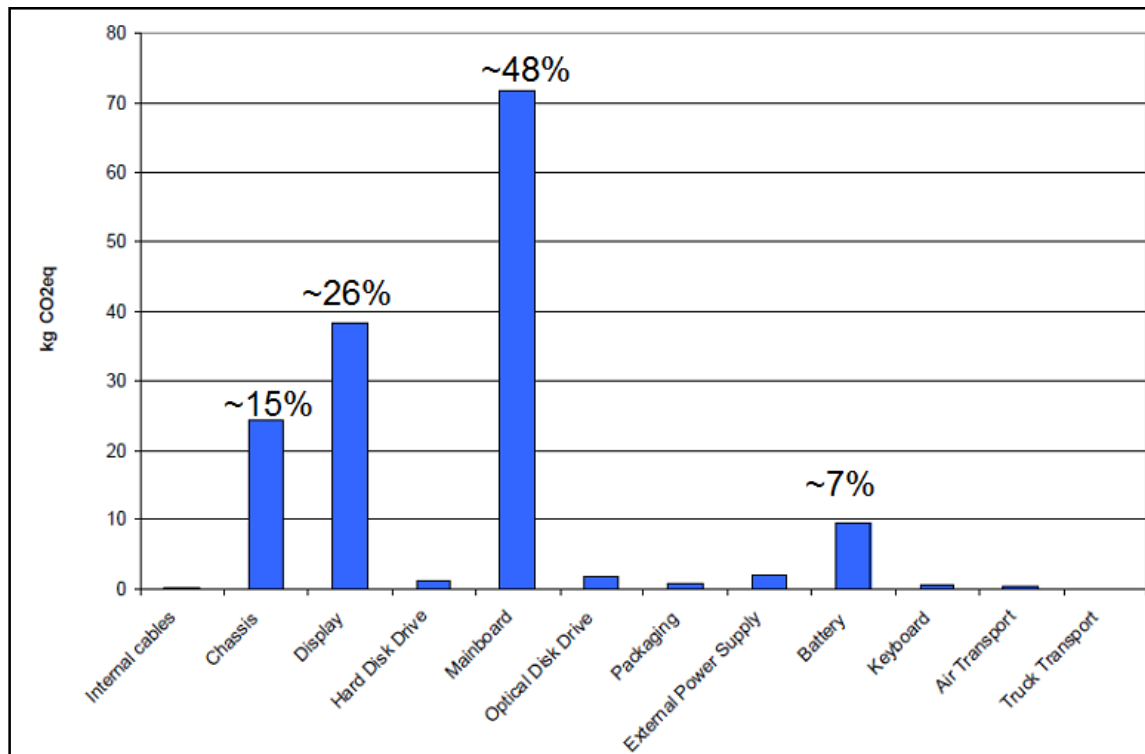
Source: Hagelüken & Buchert (2008)

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, 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 CO₂e and has a cumulative resource requirement¹⁹ 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 CO₂e, representing almost 50% of the overall emissions of the production phase. Other relevant components in this respect are display, chassis and battery (Figure 2.11).

Figure 2.11. Breakdown of component-specific greenhouse gas emissions (CO₂e) from the production phase of a Dell notebook



Source: O'Connell & Stutz (2010)

In addition, chemicals of high purity and with highly diversified functionalities as well as important peripheral processes such as cleanroom technology are required in more and more cases. These circumstances tighten the trend of a manufacturing phase with an increasing impact on the environment.

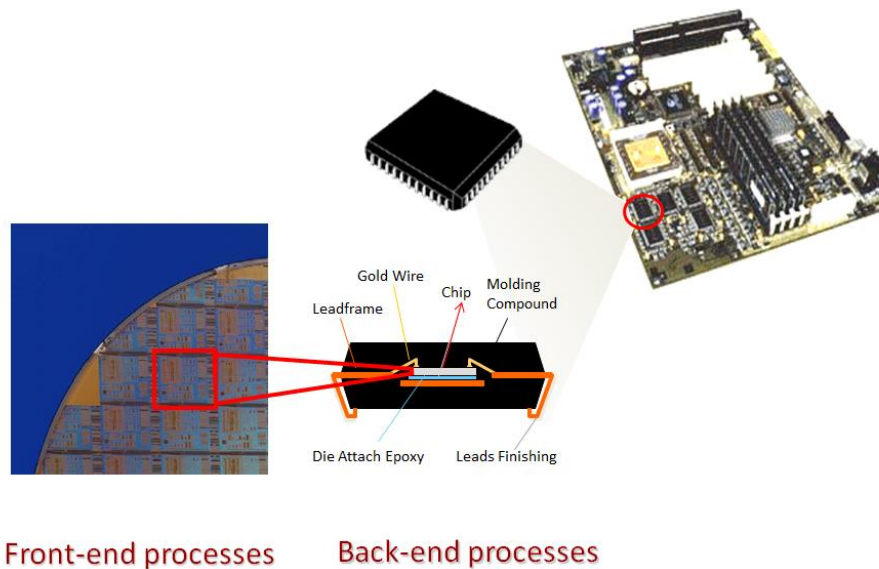
Furthermore, the extremely high speed of innovation as well as the specialisation and globalisation of supply chains make it necessary to transport components and EEE products often several times over long distances during their manufacturing, with air transportation becoming increasingly important.

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). These processes can be clustered into two groups (Figure 2.12):

- 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.

¹⁹ "Cumulative resource requirement" comprises energy and metal resources, earths and stones, and other mineral resources.

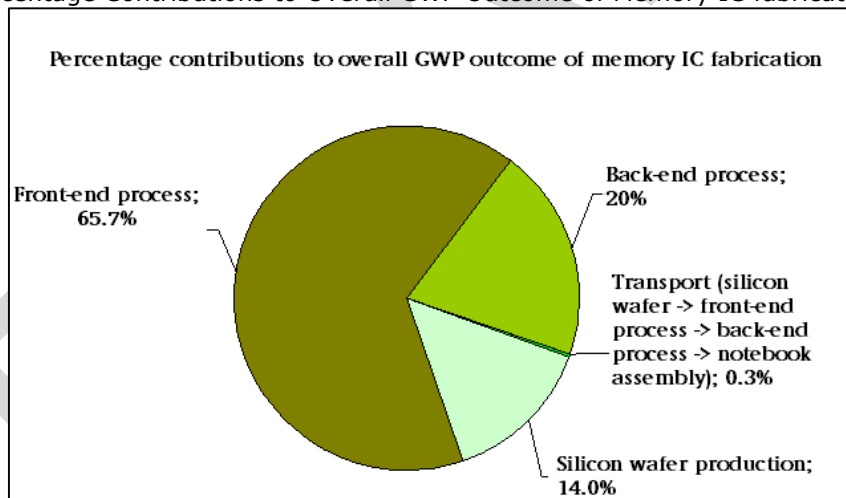
Figure 2.12. Front-end Processes and Back-end Processes of IC Manufacturing



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). However, 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 (Figure 2.13).

Figure 2.13. Percentage Contributions to Overall GWP Outcome of Memory IC fabrication

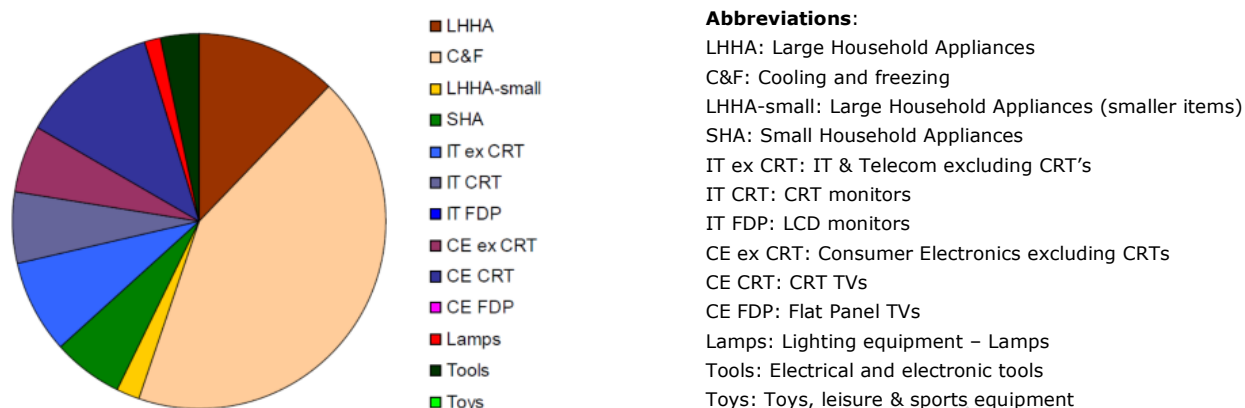


Source: Prakash et al. (2011b)

UNU (2008) attributed different weights to the various EEE categories outlined above in light of their contribution to the environmental impacts of waste from EEE (Figure 2.14). 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 results identified 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 appliances²⁰) and various categories of ICT equipment.

²⁰ 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

Figure 2.14. Contribution of categories to environmental impacts of WEEE total (Eco Indicator '99 H/A)



Source: UNU (2008)

On the other side, ICT can make an important contribution to mitigating climate change in many sectors of the economy and realms of society. The estimates of mitigation potential cited most frequently anticipate that intelligent deployment of ICT solutions²¹ could deliver emissions reductions totalling around 7.8 billion t CO₂e worldwide in the year 2020. This amounts to around 15% of the global emissions expected in 2020, which totals 51.9 billion t CO₂e (Climate Group 2008). Beside this potential climate benefit, ICT is also a source of emissions amounting to 830 million t CO₂e worldwide in 2007 (Climate Group 2008)²². These emissions are expected to rise to 1.4 billion tonnes CO₂e by 2020 (Climate Group 2008).

2.4 Environmental aspects of the EEE sector

EEE manufacturing is 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 are detailed shortly in this section. Figure 2.15 and Table 2.3 show the main flows of materials and waste in the various life cycle phases of EEE products, from the EEE manufacturers' perspective²³.

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. Also, the impact of the EEE, relevant at the **end-of-life phase** when products turn into waste, is also integrated into EU legislation.

The relevant environmental aspects (i.e. manufacturers' activities that have / can have an impact on the environment) and the associated environmental pressures for the **EEE manufacturing processes** are illustrated in Table 2.3. They refer to both direct²⁴ and indirect²⁵ environmental aspects, such as component manufacturing and supply chain management respectively.

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.

²¹ 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)

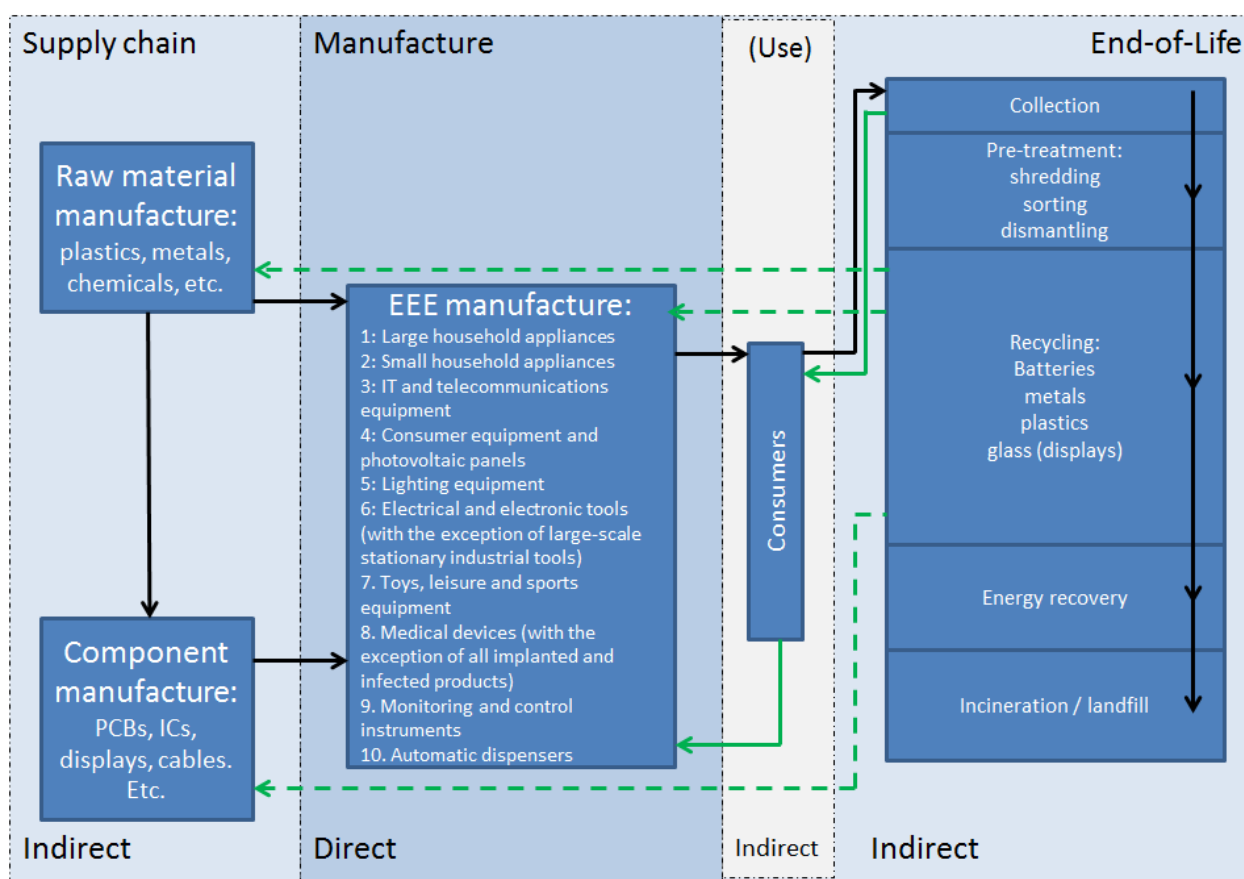
²² In the present study, ICT comprises computers, telecommunication networks and devices, printers and computer centres. Other studies estimate the global emissions attributable to the electricity consumption alone of ICT equipment and infrastructures in their use phase as amounting to around 2.1 billion t (Climate Group 2008).

²³ The use phase is not detailed as it is not in the scope of this study (consult chapter 3).

²⁴ Direct environmental aspects refer to environmental aspects associated with activities, products and services of the EEE manufacturer itself over which it has direct management control (according to REGULATION (EC) No 1221/2009).

²⁵ Indirect environmental aspects 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 (according to REGULATION (EC) No 1221/2009).

Figure 2.15. Overview of Input and Output Flows of Sector Activities (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

Table 2.3. Environmental Aspects and Associated Environmental Pressures (Manufacturers' Perspective)

Most relevant environmental aspects	Related main environmental pressures
Component manufacturing and assembly	Resource efficiency Water Waste Emissions to air Energy and climate change Hazardous substances
Final product assembly	Energy and climate change
Plant utilities	Resource efficiency Water Waste Emissions to air Energy and climate change Biodiversity
Site management	Water Waste Emissions to air Energy and climate change Biodiversity
Sourcing of materials and components	Resource efficiency Biodiversity
Supply chain management	Resource efficiency Energy and climate change

Most relevant environmental aspects	Related main environmental pressures
	Hazardous substances
Product design / Development of business model	Resource efficiency Water Waste Emissions to air Energy and climate change Hazardous substances
End-of-life	Resource efficiency Waste

The following sections (2.4.1-2.4.7) detail some of the main **environmental pressures** tied to the identified environmental aspects in the EEE manufacturing sector. To clarify the key areas of impact of the EEE manufacturing 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.

2.4.1 Resource efficiency

Resource efficiency in EEE manufacturing 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“*.²⁶ 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%. Despite the fact that efficiencies are improving, they are still an important focus of further development efforts.

2.4.2 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. The

²⁶ 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/>.

reduced consumption results in costs savings, including other costs, which are associated with energy use 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 mixed 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 „waste“ that need further treatment of the former and the costs of raw materials of the latter.

2.4.3 Waste

When EEE products reach the end-of-life phase and turn into waste, the following stages take place:

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

These stages are relevant for the Waste from Electrical and Electronic Equipment (WEEE), but the focus in this report concerns mainly the production and management of waste within manufacturing facilities, as well as measures to prevent, reuse and better recycling of waste at the end-of-life of EEE products.

Within manufacturing facilities, the treatment of different waste fractions incurring from the manufacturing activities 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 waste 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). Therefore, 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.

Moreover, this report also focuses on the efforts of the EEE manufacturers in the design of the products that influence directly the waste processing stage. Their efforts focus particularly on:

- Preferring the use of materials that can be recycled more easily or with fewer negative environmental impacts (energy and resource consumption, emissions), e.g. enabling and increasing the content of recycled plastics in EEE products.
- Shifting towards the use of fewer kinds of materials in the end-products, mainly in household appliances.
- Taking into account repair, refurbishment, reuse and recycling options in the design of new products e.g. enabling easier dismantling of product components and materials.

In 2009, the European Commission²⁷ estimated the annual amount of 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

²⁷ European Commission (2009), Report on Implementation of the Community Waste Legislation, pp. 8 and 11, available online at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0633:FIN:EN:PDF>

quantities and the often hazardous nature of this waste stream, but also in its potential as a source for valuable resources. Additionally, 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. 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. UNU (2008)²⁸ presented the collection rates of WEEE in the EU25 Member States for the year 2005. It concluded that at that 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 (Table 2.4):

Table 2.4. 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)

2.4.4 Emissions to air

Emissions to air relevant for the EEE manufacturing activities can be divided into the following groups:

The first group refers to emissions of Greenhouse Gases (GHG). Where these are more relevant to the production of electricity or heat for manufacturing purposes, 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). Reporting companies often refer to absolute emissions along with emissions normalised to production volumes.

²⁸ UNU (2008); Review of Directive 2002/96 on Waste Electrical and Electronic Equipment – Study No. 07010401/2006/ 442493/ETU/G4, page iii; available online at http://ec.europa.eu/environment/waste/weee/pdf/final_rep_unu.pdf

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.

The third group concerns dust from various processes or from the storage of raw materials. In the semiconductor sector such emissions are of additional concern, as many processes are very sensitive, performed in cleanrooms 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.

2.4.5 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 reduce energy costs and thus 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.

2.4.6 Biodiversity

For the manufacturing industry, currently 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, but also, with the selection of suppliers who are also concerned about biodiversity at their facilities. The Environmental Impact Assessments (EIA) and the statements prepared for new manufacturing activities address to some degree concerns on biodiversity onsite. 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.

2.4.7 Hazardous substances

An impact assessment prepared in 2008²⁹ 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

²⁹ 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 online at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2008:2930:FIN:EN:PDF>

chain stretching around the world. A study by Arcadis³⁰ 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. 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, the European Commission has outlined rules on the restriction of the use of certain hazardous substances (e.g. Lead, Mercury, Dibutyl phthalate)³¹.

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 those restrictions for additional substances are likely to continue. This is part of the motivation of some companies to voluntarily look into substitution of some additional hazardous substances. Sustainability reports and other 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.

2.5 Implementation of environmental management systems

2.5.1 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 authorities³².

According to the EMAS registration data base,³³ in February 2014, 134 companies were registered under the NACE codes relevant for the EEE (NACE codes 26 through 28).³⁴ 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

³⁰ 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).

³¹ European Commission (2015); Commission Delegated Directive EU 2015/863 amending Annex II to Directive 2011/65/EU of the European Parliament and of the Council as regards the list of restricted substances, L 137/10, official Journal of the European Union (4/6/2016), available online at: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L0863&from=EN>

³² See EU EMAS website: http://ec.europa.eu/environment/emas/index_en.htm

³³ See EMAS Register: <http://ec.europa.eu/environment/emas/register/>

³⁴ Compiled from data collected from the EU EMAS registry; available online at: <http://ec.europa.eu/environment/emas/register/search/search.do>, March 2014

- 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);
- 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.

2.5.2 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 auditing³⁵.

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.

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3 Scope of the document

The target group of the report is clearly the EEE manufacturers and specifically the companies that belong to the following NACE codes:

- **NACE code 26** Manufacture of computer, electronic and optical products
- **NACE code 27** Manufacture of electrical equipment
- NACE code 28 limited to:
 - 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**)

This report focuses on the reduction of environmental impacts of the entire EEE value chain 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.

Focus has given to those activities with the highest environmental relevance and/or highest improvement potential. These were identified according to the three filters below.

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 BEMPs tied to manufacturing processes. 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 sector 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.

Integrated circuits (IC) are practically used in all EEE products, and thus special attention is given. An 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 facilities³⁶.

³⁶ 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

The high complexity and chemicals consuming print and etch processes, the content of hazardous substances, and aspects of recyclability, make **printed circuit boards (PCB)** a 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).

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

A further distinction is between products and components that are manufactured, at least to some degree, in the EU28, and those produced outside the EU, for which available information on production processes may be limited. However, in some cases, production takes place both within and outside the EU, e.g. regarding integrated circuits and circuit boards.

Addressing these aspects is considered a geographical filter. In order to further enhance the relevance of various processes and technologies for review, attention is given to the 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. The geographical filter allows also investigating if production facilities are evenly distributed throughout the EU or more concentrated in countries in which specific characteristics or conditions apply.

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 BEMPs. BEMPs that are relevant for being applied across industry 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 products. 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 are covered.

Given the analysis above, this report includes BEMPs for the three following areas:

- BEMPs for manufacturing: This section covers the activities related to core electrical and electronic equipment manufacturing operations
- BEMPs for supply chain management: This section deals with the management of the supply chain by electrical and electronic equipment manufacturers. It focuses on the operations that companies of the sector can put in place to sustainably source materials, substitute hazardous substances and reduce the biodiversity impacts of their supply chain.
- BEMPs fostering circular economy: This section deals with management and strategic practices that electrical and electronic equipment manufacturers can implement to foster circular economy, such as changing design practices, remanufacturing products, or developing more sustainable business models.

4 BEMPs for manufacturing processes

4.1 Techniques portfolio

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 BEMP 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 chapter 3 were set for this purpose. When taking these considerations into account, the following fundamental conclusions are 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 manufacturing 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 EU28. 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 BEMPs sufficiently address all relevant environmental aspects that are associated with EEE production (see section 2.4 for more details). Within this context, an extensive review of existing environmental reports and declarations of EEE manufacturing 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.³⁷ 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 manufacturing 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 manufacturing sector. The production of compressed air can be very inefficient and thus most expensive of all energy carriers in the manufacturing site. For example, compressed air needs approximately ten times of the provided final energy during its production, accounting for 10% of total electricity consumption of EEE production sites; savings in the range of 50% are possible. Therefore, the large potential for improvement is detailed in the corresponding BEMP. While demand for compressed air is rather stagnant, cooling systems are becoming increasingly important in the EEE manufacturing 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.

³⁷ Cf. <http://seshaonline.org/proceedings00/naughtonphilip.pdf>

One of the core manufacturing processes of the EEE manufacturing sector is the **soldering**. This process causes 70% of the energy demand within the production process of surface-mounted devices, and can also cause emissions to air. In this report, the reflow soldering systems are presented, which are characterised by at least 20% lower electricity consumption due to the lower operating temperature profile ranges; 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 **perfluorocompounds (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, PFC 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.

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 manufacturing 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, 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 copper recycling 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.

Finally, **waste management within the manufacturing facilities** is a relevant environmental pressure, which is dealt with this report by presenting a series of measures on how to best sort and treat the waste generated within the EEE companies and develop industrial synergies with other adjacent companies/organisations.

The following table summarises the developed BEMPs 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

	BEMP	Environmental pressures addressed						
		Resource efficiency	Water	Waste	Emissions to air	Energy & climate change	Bio-diversity	Hazardous substances
	MANUFACTURING							
4.2.1	Energy-efficient cleanroom technology	X				X		
4.2.2	Energy-efficient cooling technology	X				X		
4.2.3	Energy-efficient reflow soldering	X			X	X		
4.2.4	On-site copper recycling in process chemicals	X	X	X				
4.2.5	Cascade rinsing systems and water use optimisation		X	X				
4.2.6	Minimising perfluorocompound emissions				X	X		X
4.2.7	Rational and efficient use of compressed air	X				X		
4.2.8	Protecting and enhancing biodiversity						X	
4.2.9	Use of renewable energy	X				X		
4.2.10	Optimised waste management within manufacturing facilities			X				

4.2 Description of best environmental management practice

4.2.1 Energy-efficient cleanroom technology

SUMMARY OVERVIEW:

BEMP is to minimise the energy use of the cleanrooms. This can be achieved by implementing the following measures:

- Defining correctly the capacity of the cleanroom facility and sizing its equipment accordingly. Downsizing to the minimum required is the target for all equipment, except cooling towers and passive components (pipes and ducts) which can be upsized to save energy. Their upsizing improves the chiller performance and allows the use of smaller fans and pumps.
- Reducing pressure difference between the cleanroom and its surroundings and adapting the air volume to the demand in order to reduce the electricity use of the fans.
- Allowing wider operating ranges for the cleanroom space temperature and relative humidity. Wider operating ranges lead to less energy use for cooling, preheating and dehumidification of the supply airflow.
- Setting a lower face velocity³⁸ by combining larger air handler units with smaller fans that allow the air circulation to be maintained at lower velocity.
- Determining the lowest possible Air Change Rate (ACR) by reducing the heat load and the actual particle generation within the cleanroom.
- Exploiting all opportunities to reduce the heat load generated within the cleanroom and recover the waste heat from process equipment. The recovered waste heat can be used, for instance, in the reheat of supply air.
- Use of high efficient components, such as Variable-Frequency Drives (VFD) fan motors, pumps and chillers to allow better response to the varying load of the cleanroom.
- Avoid over purification of the water required for the cleanroom operations by respecting the specifications of the required cleanroom classification, without too large safety margins.

Relevant lifecycle stages						
Manufacturing		Supply chain			End-of-life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">Energy use in the cleanroom for printed circuit board manufacturing (kWh/m² of processed printed circuit board)Energy use in the cleanroom for semiconductors and integrated circuits manufacturing (kWh/cm² of silicon wafers)Air Change Rate (number/hour)<ul style="list-style-type: none">COP (Coefficient of Performance) of the cooling equipment installed: kWh cooling energy provided / kWh energy usedWater conductivity (µS/cm)Avoidance of excessive pressurization of the cleanroom (Y/N);Installation of VFD components, for new built or retrofitted cleanrooms (Y/N)						
Applicability		<p>The BEMP is broadly applicable to all EEE manufacturers that operate cleanrooms.</p> <p>For new built cleanroom facilities, ACR can be lower than recommended ACR range according to its classification, but requires efforts to ensure and adjust the quality requirements of the cleanroom. For existing cleanroom facilities, particle count-based control and continuous monitoring can be applied to reduce ACR values.</p>				
Benchmarks of excellence		N/A				

³⁸ Face velocity is the speed at which air passes over the filters or heating/cooling coils in an air handler unit.

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). Within the EEE manufacturing sector, ultra-clean production conditions are essential for the quality of many electronic components and devices. This is especially valid 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).

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" classification and the "ISO standard" (ISO 14644-1). Table 4.2 gives an overview of the correlation between these two cleanroom classifications:

Table 4.2. Cleanroom classifications

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

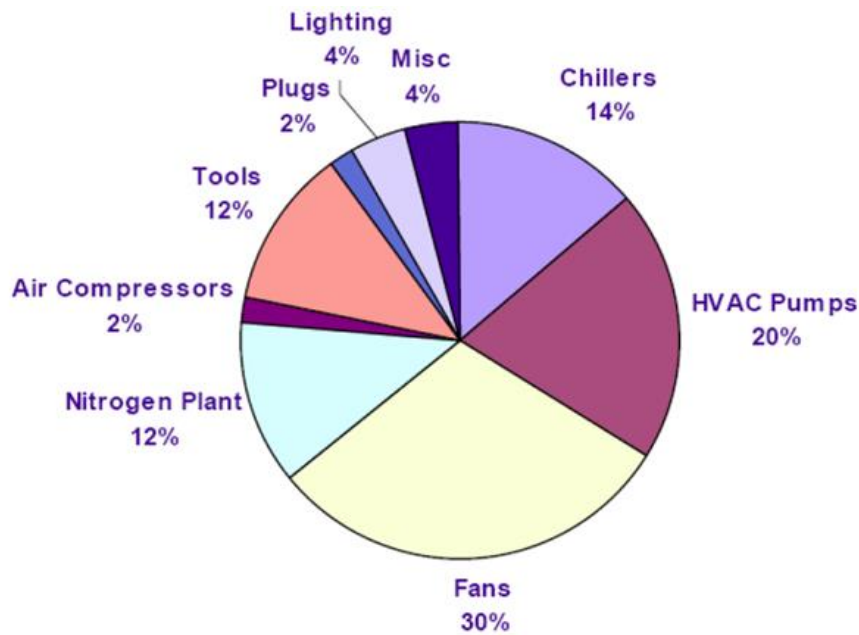
Source: Own table according to data from Rumsey (2010)

A "Class 1"/"ISO Class 3" cleanroom is defined as a cleanroom contaminated by no more than one particle larger than 0.5 micrometre per cubic foot³⁹ of air, whereas a "Class 10"/"ISO Class 4" cleanroom will contain up to 10 particles per cubic foot of air, and so on (Rumsey 2010).

Cleanroom facilities encompass various energy demanding processes, such as Heating, Ventilation and Air Conditioning (HVAC) systems, tools operation (e.g. fans, lighting). An illustration of the total energy use of a typical cleanroom is given in Figure 4.1 (City of Boulder, 2007). It shows that HVAC systems and fans are the most energy consuming processes and they account jointly for approximately 50% of the total energy use.

Figure 4.1. Cleanroom energy use

³⁹ 1 cubic foot equals 28.3 litres.



Source: City of Boulder (2007)

Cleanroom energy intensity depends heavily on the system design, the cleanliness level to be achieved, specific cleanroom functions (e.g. airflow type), and critical parameters such as temperature, room pressure, humidity, etc. (Xu 2003; Mathew et al. 2010). Fan motors and air conditioning, as the most important single consumers of electricity, bear a significant optimisation potential in terms of energy savings and reduced life cycle costs, but this potential can only be realised with an appropriate design of the cleanroom facilities.

Hence, a strategic approach for best environmental management practice in the field of energy efficient cleanroom considers both technology-related and design-oriented measures and encompasses the following elements:

1. Careful sizing and design of the cleanroom (very relevant for new built cleanroom facilities)
2. Reducing heat load and recovery of the waste heat where feasible
3. Use of high efficient components, such as premium efficiency fan motors and variable-frequency drives chillers
4. Apply efficient water purification techniques

Below, these three elements are further described.

Careful sizing and design of the cleanroom

The sizing of a cleanroom is an essential element regarding its energy consumption and overall environmental performance. Initially, the production capacity and the projected loads in the cleanroom of the EEE manufacturing plant have to be carefully studied, especially for new built cleanroom facilities. The next step is the correct sizing of the equipment of the cleanroom facility. The general goal is downsizing to the minimum required although in some cases upsizing can improve the overall environmental performance of the facility. In particular, when the cooling towers are upsized, the energy efficiency is improved because of the improvement of the chiller performance. Additionally, the upsizing practice is also applied on passive components, such as pipes and ducts, due to the fact that their upsizing allows the use of smaller fans and pumps.

Especially for new built cleanroom facilities, the implementation of energy modelling analysis at the facility and process level is feasible and important. The analysis of all the energy fluxes allows the downsizing of the facility systems and utilities.

Furthermore, during the design stage, investigating the possibility of free cooling, especially for new built cleanroom facilities, can offer significant energy savings and reduce the need for electric chillers at least during the lowest load periods of the year. When electric chillers are needed, the designer should ensure that cooling towers operate efficiently.

A key element in the design of cleanrooms is the Air Change Rate (ACR) parameter. The determination of this element depends upon two factors, the reduction of the heat load and the actual particle generation within the cleanroom. In particular, 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 far lower than recommended practice have proven to be feasible without affecting the cleanliness of production.

Another important approach is reducing 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 use of cleanroom fans. Additionally, parameters such as space temperature and relative humidity, if properly adjusted, allow wider operating ranges in order to lead to a reduction of the energy use.

In terms of optimised 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. Also, the duct networks and the air paths should be carefully designed and sized.

Moreover, energy savings in the context of optimised systems can also be achieved by taking into account the option of selective cleanroom environment. This means establishing a local protection / encapsulation of equipment or plants where a higher cleanliness class is maintained in a limited area and as required by a specific process.

Reducing heat load and recovery of the waste heat where feasible

In order to maintain the desired conditions within the cleanroom, heat load needs to be removed. Higher heat loads results in an increased ACR and thus in additional electricity consumption at the level of the ventilator and HVAC unit. In particular, the heat load from processes consuming electricity has a major influence, since most electricity used by these processes is converted directly into heat to be removed by the HVAC unit. Therefore, it is best practice to exploit all opportunities to reduce the heat load generated within the cleanroom.

Heat recovery measures can be also implemented when applicable (as it was previously mentioned, cleanrooms are cooling dominated). Appropriate heat exchangers can be installed around coils to recover heat. This heat can be used in the reheat of supply air after dehumidification of the incoming air.

Use of high efficient components such as premium efficiency fan motors and variable-frequency drives chillers

The use of high efficiency components, such as Variable Frequency Drives (VFD) fan motors, pumps and chillers, is another key element to improve cleanroom energy efficiency. For instance, when the fans and the pumps are equipped with a VFD system and the supply air units are installed in a parallel configuration that allow all of the air handlers or scrubbers to run at lower speed during normal operation, then significant energy savings can be achieved. Additionally, chillers with VFDs operate more efficiently and respond better to the varying loads of the cleanroom operation.

Apply efficient water purification techniques

De-ionized water is used in the cleanrooms for the wafers cleaning. The de-ionized water is classified into three categories, according to the level of its ionic impurities: ultra-pure water, pure water and purified water. For each category, a specified range of resistivity and conductivity is given ([Table 4.3](#)).

Table 4.3. Conductivity and resistivity of the de-ionized water

Quality	Ultra-pure water	Pure water	Purified water
Typical resistivity	10-18 MΩ cm	1-10 MΩ cm	1-0.02 MΩ cm
Conductivity	0.1-0.0555 μS/cm	1.0-0.1 μS/cm	1-50 μS/cm

Source: Pro-analitika (2002)

De-ionized water is rinsed between the different stages of the cleaning process of the wafers. Water contains elements such as, dissolved minerals, particulates, organics and dissolved gases, which make it inappropriate for use in a cleanroom. Therefore, these elements must be carefully removed before this water is used in the cleanroom. It is more efficient to produce the de-ionized water on site in order to achieve the specific quality and purity levels required by the production manufacturing facility. It is reported that for the production of 1,000 gallons of de-ionized water, 1,400-1,600 gallons of fresh water are required and approximately 6,000 gallons of de-ionized water are required for each 6" complementary metal oxide semiconductor (CMOS) wafer (Anonymous 2008). The de-ionized water must be continuously recirculated in order to maintain the achieved levels of quality and purity (Darling 2000; PPRC 2000).

The amount of the required de-ionized water for the cleanroom operations must be carefully calculated by the cleanroom managers according to the production capacity. Additionally, cleanroom managers should avoid the over-purification of water for the cleanroom operations by matching its cleanliness requirements to the actual cleanroom classification. Therefore, the de-ionization⁴⁰ of extra unnecessary amount of water or even over passing the cleanliness requirements of the cleanroom, results in higher energy use and thus extra costs.

Additionally, it is important to apply methods that reduce the amount of fresh water used at the manufacturing phase. In fact, water use can be reduced when recycling, reuse and/or use of reclaimed water⁴¹ methods are installed in the manufacturing facility (PPRC 2000).

All the technological measures mentioned above can be applied either separately or jointly. However, best results are achieved through an integrated approach implementing all or most of these measures.

4.2.1.2 Achieved environmental benefits

The operation of a cleanroom is a very energy intensive process associated with substantial electricity use.

It is estimated that a significant reduction in electricity use can be achieved through improved integrated design, commissioning, and operations (Lowell et al. 1999). Since the electricity use is a main driver for global warming effect, also the correspondent CO₂ emissions would be reduced significantly, if the measures described in this BEMP are implemented.

For example, it is reported that a 50% reduction in ACR⁴² can reduce the fan 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).

It has been reported that a reduction of 10% of the de-ionized water use in a cleanroom that uses 3 million gallons of purified water daily, it can result in savings of 5 million kWh annually (PPRC 2000).

⁴⁰ An effective practice for the de-ionization of the water is the combination of Reverse Osmosis (RO) and Electrodeionization (EDI) techniques, which results in relatively low levels of ions and total organic carbon (TOC).

⁴¹ The most common reclaimed water methods consider the use of membrane technologies such as microfiltration, ultrafiltration, reverse osmosis and electrodialysis techniques.

⁴² For more details concerning the definition of the air change rate and corresponding optimisation potentials, see the "appropriate environmental performance indicators" and "operational data" sections respectively.

4.2.1.3 Appropriate environmental performance indicators

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

- for semiconductor / IC facilities, this indicator is expressed as kWh/cm², i.e. energy use of the cleanroom (in kilowatt hours) per square centimetre of processed silicon wafers; this indicator is measurable only if the semiconductor manufacturing facility can measure the share of the electricity use of the cleanroom;
- for PCB production, this indicator is expressed as kWh/m², i.e. energy use of the cleanroom (in kilowatt hours) per square metre of PCB.
- Additionally, other qualitative and quantitative indicators can be introduced, such as:
 - avoidance of excessive pressurization of the cleanroom (Y/N);
 - installation of VFD components (Y/N), for new built or retrofitted cleanrooms;
 - COP (Coefficient of Performance) of the cooling equipment installed: kWh cooling energy produced / kWh energy used;
 - ACR can serve as a first step in order to identify efficiency potentials; the ACR is a measure of how many times the air within a defined cleanroom space needs to be replaced in order to reduce the heat load of the cleanroom. This metric is usually indicated as a number per hour.
 - Water conductivity, is expressed as µS/cm; conductivity is always referenced to 25°C to allow different samples to be comparable⁴³.

The electricity consumption of the cleanroom itself it is a useful indicator and can be expressed as electricity consumption of the cleanroom per surface of the cleanroom (kWh/m²). However, this indicator is not always meaningful or realistic as it is greatly impacted by the performed processes and the installed equipment. Therefore, this indicator does not allow the comparison of the energy use between different cleanroom facilities.

4.2.1.4 Cross-media effects

Cross-media effects are considered to be irrelevant for most of the approaches mentioned in this BEMP. 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 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, the extraction of rare earths such as neodymium is associated with a heavy burden on the local environment and high technical complexity. 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 are taken (Schüler et al. 2011).

4.2.1.5 Operational data

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

Careful sizing and design of the cleanroom

⁴³ Changes in the temperature may change water conductivity by around 2% for each degree Celsius.

Due to normative documents (such as ISO 14644) and their poor interpretation, over-specification and over-design of cleanroom facilities is quite common. One of the causes is that the normative documents cover mostly general aspects and do not sufficiently address the specific features of cleanrooms. Guidance in terms of optimisation 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 ACR, the current recommendations concerning ACR are not based on scientific findings (Mathew et al., 2010). For example, for ISO Class 5 (US cleanroom class 100) cleanrooms, ACR 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; Xu 2003). Therefore, the reduction of the ACR can yield substantial energy savings.

Concerning pressure difference, due to safety reasons, ISO 14644 recommends pressure differences (between a cleanroom and its surroundings) in the range of 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 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 (Cleanroomtechnology 2014; Rumsey 2010).

Additionally, especially for a semiconductor manufacturing plant (fab) cleanroom design, it is very helpful to perform a detailed energy modelling analysis during the design stage. In particular, by mapping out all the energy flows within a cleanroom, including all facility systems as well as the process tools, an energy modelling analysis allows optimising the energy use of the facility by selecting and implementing the most appropriate energy saving strategies. Moreover, a downsizing of the facility during the design process might be possible leading to the corresponding energy and cost savings.

Reducing heat load and heat recovery

Within the context of optimising 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 in the "Achieved environmental benefits" section.

Use of high efficiency components

Since the continuous duty fan motors consume a large share 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 are especially interesting for retrofits (see also economic perspective in the "Economics" section).

Using VFDs can be an interesting option 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.

Case study: Western Digital Cleanroom facility

This case study refers to a renovation of an existing cleanroom facility of the Western Digital manufacturing company. [Table 4.4](#) outlines the results of this renovation and the energy savings achieved.

Table 4.4. Achieved savings of the renovation of the Western Digital cleanroom facility

	Before	After
Total surface of the facility	7,432 m ²	8,361 m ²
Cleanroom facility type	Semiconductor facility	Hard disk manufacturing plant
Cleanliness requirements	Class 10,000	Class 10
Peak energy demand	1,350 kW 181 W/m ²	850 kW 102 W/m ²

Source: City of Boulder (2007)

The objective of the renovation was to switch from the manufacturing of semiconductors to hard disks, which led to the increase of its surface and its cleanliness requirements, from Class 10,000 to Class 10 (i.e. from ISO Class 7 to ISO Class 4). However, thanks to the changes implemented (listed below), the retrofit resulted in energy savings of approximately 56% (City of Boulder 2007):

- Employ of VFD components such as fans, pumps that respond better to the production demand during the year; parallel operation that allowed operation at slower speeds
- Installation of new more efficient cooling towers
- Optimised design of the duct network and the filters to minimise the pressure drop

Case study: Motorola

In a cleanroom at Motorola, energy savings were obtained by improving the management of the cleanroom and reducing the cleanliness requirements from class 10,000 to class 100,000 (i.e. from ISO Class 7 and ISO Class 8 respectively). The savings were achieved thanks to the better control of the temperature and humidity in the cleanroom. In particular, the unnecessary dehumidification of the incoming air when the outside air was already below the cleanroom humidity set point was avoided (City of Boulder 2007).

Case study: Hine design

In a cleanroom at Hine design (manufacturing of robotics), new VFDs components were installed setting properly the speed according to the load of the cleanroom. Energy savings of 82% in fan power have been reported (City of Boulder 2007).

4.2.1.6 Applicability

The approaches for improving the energy efficiency of cleanroom facilities can be applied by all manufacturing companies that are planning significant cleanroom investment, i.e. for new cleanroom space to be built, as well as cleanroom retrofits.

However, it has to be noted that downsizing the ACR might require efforts regarding ensuring and adjusting the quality requirements of the cleanroom. As already mentioned, the cleanliness level is not necessarily affected in a negative way by a reduced ACR. In fact, for new built cleanroom facilities, ACR can be lower than the recommended ACR⁴⁴ range. For existing cleanroom facilities, particle count-based control and continuous monitoring, can be applied in order to further reduce ACR. This is because turning down the fan speed (as a prerequisite for a lower ACR) may actually improve cleanliness by reducing turbulence in the room (Mathew et al., 2010).

When recycling (e.g. collection of rainwater), reuse and/or use of reclaimed water methods are implemented on site, then only the cleanest water streams can be used at the production phase.

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, the improvement of energy efficiency can yield significant cost savings.

Concerning the installation of premium-efficiency fan motors, these components consume their capital equipment cost value in electricity roughly every month. Hence, efficiency improvements make most retro-fit solutions cost-effective. VFD chillers are characterised by payback times of about one year⁴⁵ (Rumsey et al. 2004).

It has been reported that in a semiconductor manufacturer in Plymouth, UK, savings of over £30,000 a year in energy costs are achieved after the installation of six variable frequency drives HVAC fans (37 kW capacity) on its three cooling towers. The investment cost was £15,000 while the payback was six months.

Implementation of water recycling methods on site creates extra costs and thus a feasibility analysis beforehand is required.

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, costs are considered to be the most important driver for the implementation of the best management practices described.

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

4.2.1.9 Reference organisations⁴⁶

Western digital

Hine design

Motorola

4.2.1.10 Reference literature

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⁴⁴ The recommended ACR range comes from the cleanliness requirements of the cleanroom.

⁴⁵ 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.

⁴⁶ The current list of the reference organisations is not exhaustive and other companies from the sector operating cleanrooms could also exist.

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4.2.2 Energy-efficient cooling

SUMMARY OVERVIEW:						
<p>BEMP is to reduce the need for cooling and improve the energy efficiency of the cooling systems used in production processes and production halls. This can be achieved by applying the following measures:</p> <ul style="list-style-type: none">– Assessing and optimising the required temperature level for each of the processes and rooms/spaces with cooling demand;– Using cooling cascades by splitting the existing cooling circuit into two or more temperature levels;– Implementing free cooling techniques. Different relevant technological options include direct cooling with flow-through colder outside air, free dry cooling where a water cycle is cooled with outside air and free wet cooling (cooling tower);– Use of an heat recovery ventilation system to cool and dehumidify the incoming ambient air.– Use of absorption cooling technology as an alternative to compression chillers. Recovered waste heat can be used to provide the thermal compression of the refrigerant.						
Relevant lifecycle stages						
Manufacturing		Supply chain			End-of-life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">• Coefficient of Performance (COP) (kWh provided cooling power / kWh power used) for individual cooling equipment• Coefficient of System Performance (COSP) (kW provided cooling power / kW power used) including the energy required to run the supplementary equipment of the cooling system (e.g. pumps)• Use of cooling cascades (y/n)• Use of free cooling (y/n)• Use of heat recovery ventilators (y/n)• Use of absorption chillers (y/n)• Energy use of the cooling system per unit of turnover (kWh/€)						
Applicability		<p>Measures to improve the energy efficiency of cooling are broadly applicable to EEE manufacturing companies.</p> <p>To be able to implement free cooling, the temperature level of the return flow of the cooling system must be above the outdoor temperature and enough space must be available on the outdoor area of the production site.</p> <p>Absorption cooling is applicable where a source of waste heat or renewable heat is continuously available at the production site or in its surroundings.</p> <p>The economic feasibility of the proposed measures depends substantially on the existence of a year-round cooling load.</p>				
Benchmarks of excellence		N/A				

4.2.2.1 Description

Cooling systems are becoming increasingly important in the electrical and electronic equipment (EEE) manufacturing 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 (IC) and of Printed Circuit Boards (PCB), increasingly requires the use of cooling technology. In a typical semiconductor fabrication plant, the energy consumption for cooling purposes accounts for approximately 24% of the whole energy consumption in the plant (Öchsner 2014).

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 IC or PCB, but also electronic assemblies in general (Edelbluth 2014a). Additionally, some manufacturing processes require a very stable and steady-temperature environment. Typical examples are the etching and lithography processes where the allowed temperature range is limited to $\pm 0.1\text{K}$ and $\pm 0.001\text{K}$ respectively.

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.

The reference document on the Best Available Techniques (BAT) related to industrial cooling systems published by the European Commission in 2001 (European Commission 2001) focuses mainly on cooling energy demand at higher temperature levels (i.e. above 20°C). Therefore, its applicability to EEE production processes is rather limited. Also, recent technological developments in the field of the industrial cooling (e.g. absorption cooling technology) are not covered in this reference document.

Against this background, the main elements for a strategic approach within the context of best environmental management practice in the field of energy-efficient cooling in the EEE manufacturing sector are listed below:

- Assessment and optimisation of the required room temperatures;
- Use of cooling cascades;
- Use of free cooling;
- Use of heat recovery ventilators;
- Use of absorption cooling technology.

The assessment and optimisation 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.

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 achieved.

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 utilise the existing potentials for free cooling, the following three main options exist:

- 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 feasible technological option is the heat recovery ventilation. In principle, this option operates only with fresh air and does not recycle air, since it aims at cooling and dehumidifying the incoming ambient air. In order to effectively operate a heat recovery ventilation system, the amount of heat that the building/facility gains in is considered. The amount of air provided by the installed ventilation system is set in order to meet the desired temperature (REHVA, 2011; ENTR Lot 6, 2012).

Absorption cooling technology can be seen as an alternative technology to compression chillers. Basically, instead of electricity, this technology uses a heat source (preferably waste heat) in order to provide the thermal compression of the refrigerant.

The presented elements can be applied either separately or jointly. However, best results are achieved through an integrated approach implementing all the relevant measures.

4.2.2.2 Achieved environmental benefits

Cooling systems are becoming increasingly important in the electrical and electronic equipment (EEE) manufacturing 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 (IC) and of Printed Circuit Boards (PCB), increasingly requires the use of cooling technology. In a typical semiconductor fabrication plant, the energy consumption for cooling purposes accounts for approximately 24% of the whole energy consumption in the plant (Öchsner 2014).

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 IC or PCB, but also electronic assemblies in general (Edelbluth 2014a). Additionally, some manufacturing processes require a very stable and steady-temperature environment. Typical examples are the etching and lithography processes where the allowed temperature range is limited to $\pm 0.1\text{K}$ and $\pm 0.001\text{K}$ respectively.

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4.2.2.3 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 most common indicator that is used to this aim is the coefficient of performance (COP) for the cooling equipment itself, which represents the ratio of cooling provided to work required. The higher COP values result in higher efficiency of the operation of the equipment and thus lower operating costs. The relevant metrics are $\text{kW (cooling power provided)} / \text{kW (power required)}$. It should be noted that the COP measures the energy efficiency of the cooling equipment itself and not the overall energy use in the manufacturing facility for cooling purposes. In order to calculate the overall energy efficiency of the cooling equipment in the manufacturing facility (COSP – Coefficient of System Performance), the power use of the supplementary equipment (e.g. pumps) is also needed to be added in the calculations (specifically in the denominator of the proposed metrics).

Another useful indicator is the energy use of the cooling system (kWh) divided by the production in terms of unit of turnover (€).

Also, the cooling efficiency indicator can prove useful. It is expressed as the ideal cooling demand of the space/process divided by the actual energy use for cooling purposes (%).

For plants where the energy for cooling is not measured, indicators on a qualitative basis can be introduced. Such indicators can be:

- Implementation of the elements of a strategic approach for energy efficient cooling:
 - Assessment and optimisation of the required room temperatures (Y/N)
 - Use of cooling cascades (Y/N)

- Use of free cooling (Y/N)
- Use of heat recovery ventilators (Y/N)
- Use of absorption cooling technology (Y/N)
- And more specifically for free cooling:
 - 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? (Y/N)
 - Have all possibilities of free dry cooling been examined? (Y/N)
 - Have all possibilities of free wet cooling been examined? (Y/N)

Was it possible to completely substitute conventional compression chiller units after all measures concerning free cooling were implemented? (Y/N)

4.2.2.4 Cross-media effects

When opting for free cooling with wet cooling units, a substantial water use is induced. For example, a hybrid cooling tower is characterised by a water use of about 0.5 m³/h/MWth (European Commission 2001).

Fogging on the cooling towers caused by the evaporation of water can also be an environmental issue (not purely an 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).

4.2.2.5 Operational data

This section outlines details for implementation and operational data for each of the approaches introduced in the "Description" section.

Assessment and optimisation of the required temperature level

As a rule of thumb, 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. In other words: if permitted by the requirements of the processes, each degree Celsius of higher temperature enables direct annual savings of 50 kWh of electricity for cooling purposes (Edelbluth 2014b).

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 PCB 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 obtained with free cooling techniques. 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 shows significant potential for the application of this technique (Table 4.5). 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%

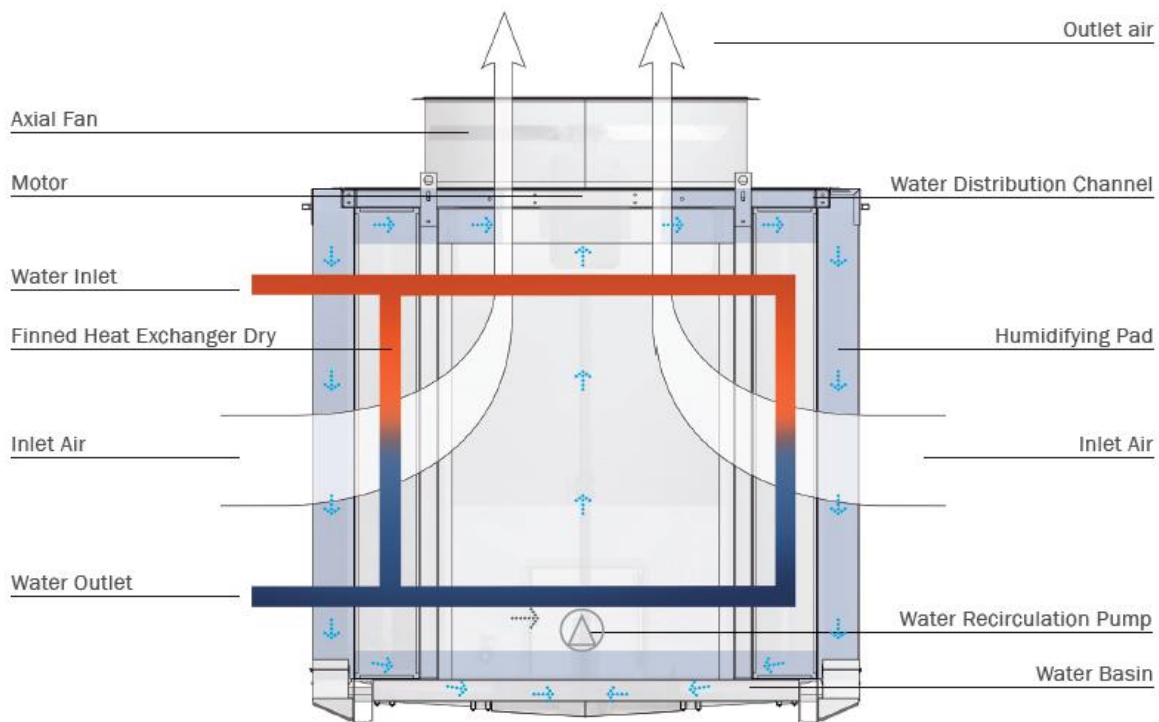
Source: Own table according to data from Stulz (2014)

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 (Figure 4.2). Compared with wet coolers, however, these systems are characterised by much lower capital and operating costs (see the "Economics" section) (Edelbluth 2014b).

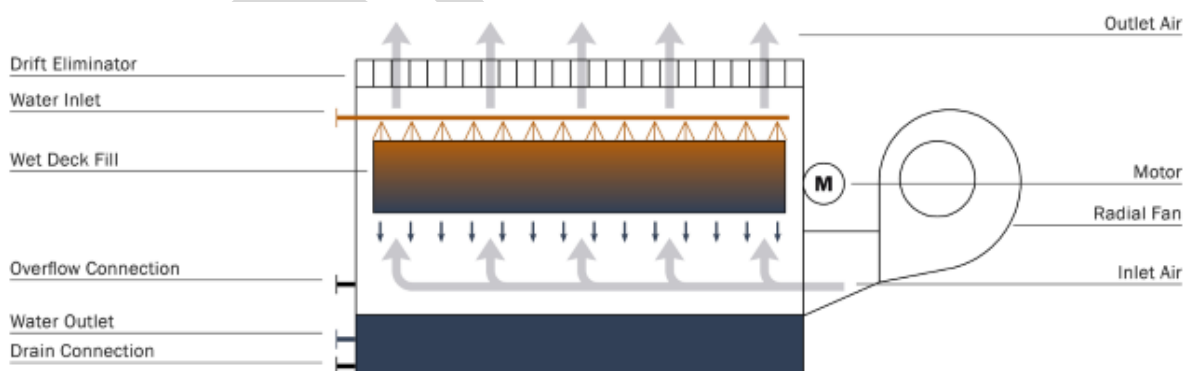
Figure 4.2. Free dry cooling



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 based on 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 ([Figure 4.3](#)). With wet cooling, even very large temperature differences can be handled.

Figure 4.3. Free wet cooling



Source: Gohl (2015)

Use of heat recovery ventilation technology

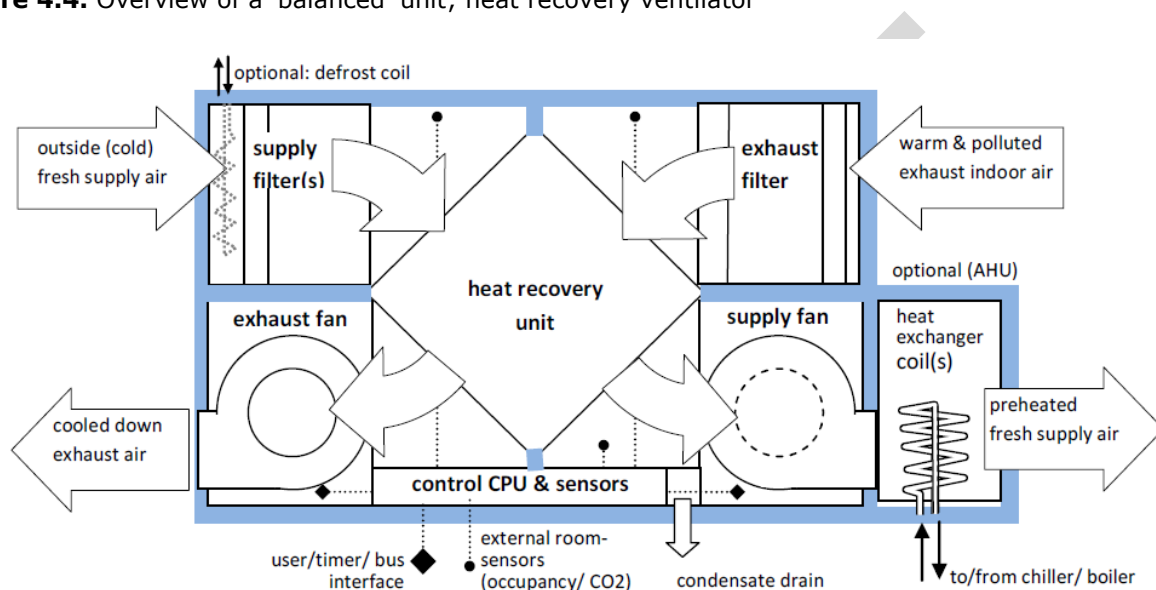
A typical heat recovery ventilation system (a 'balanced' unit as it is usually called) is illustrated in Figure 4-8 and provides both the air exhaust and air supply mechanically. The system consists of air-to-air heat exchangers that have separate air duct systems, which bring and distribute fresh air inside the facility (room/office, building etc.), while discharging the stale

air. This system is usually installed on the top of the roof of the building (REHVA, 2011; ENTR Lot 6, 2012).

Basically the system is subdivided into two major components: the central heat recovery unit (a counterflow heat exchanger at the central of [Figure 4.4](#)) and the Air Handling Unit (AHU), which is an optional component (bottom right of [Figure 4.4](#)). The efficiency of the central heat recovery unit ranges from 80 to 90%.

The AHU is composed of two fans; the first one takes out the stale air whereas the second one brings in fresh air. The AHU (whenever exists) can be combined with cooling and/or heating functions. Its capacity ranges from 1,000 to 100,000 m³/hr at external pressure 200-1,000 Pa whereas the efficiency of the heat exchanger coil(s) is approximately 50% in case of a cross flow exchanger and ranges from 60 to 70% in case of a rotary wheel exchanger (REHVA, 2011).

Figure 4.4. Overview of a 'balanced' unit; heat recovery ventilator

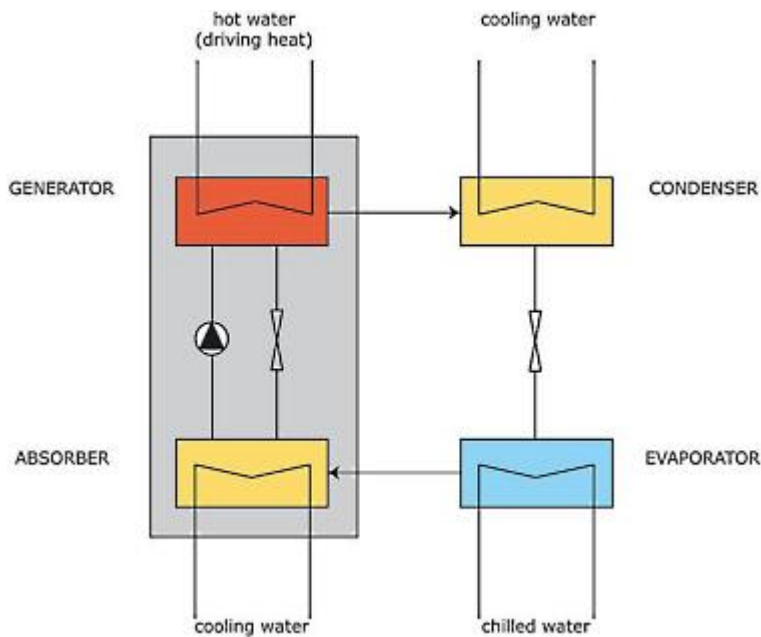


Source: REHVA (2011)

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 ([Figure 4.5](#)). 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 4.5. Scheme of absorption cooling technology



Source: Solair (2009)

Case study: IBM - Vermont

The installed capacity of the cooling system at this IBM's plant in Vermont is 26 MW. The cooling is achieved via electrical chillers that use water and pumps to remove heat from the building loop and send it directly to the condenser and cooling towers that dissipate the heat through the secondary water loop. Wet free cooling concept is also available. In particular, chillers shut down when the ambient temperatures are suitable for cooling. The wet free cooling operates 4 full months and 2 partial months per year.

4.2.2.6 Applicability

The approaches for reducing the need for cooling and improving the energy efficiency of cooling systems described in this BEMP are broadly applicable by companies of the sector.

The assessment and optimisation of the required room temperatures is a fundamental step prior to the installation of any cooling equipment and should be performed by all companies.

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). Additionally, it should be mentioned that when a free cooling system is installed in a semiconductor fabrication plant, the processes may be designed with a process water temperature higher compared to a plant with a non-free cooling system, in order to increase the duration of the free cooling operation (Öchsner, 2014).

In terms of direct cooling, the possibility of having a flow of cooling air through the building is required (Edelbluth 2014b).

In the case of 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 in its surroundings.

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

4.2.2.7 Economics

Already when implementing rather simple measures like the optimisation 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/kWh⁴⁷, 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 optimising 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 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) together 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).

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 in [Table 4.6](#):

Table 4.6. Cost data and payback times for selected measures

⁴⁷ This price represents an exemplary, typical value for electricity for industrial customers in Germany.

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)

4.2.2.8 Driving force for implementation

Cost savings are considered 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.

4.2.2.9 Reference organisations

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4.2.3 Energy-efficient reflow soldering

SUMMARY OVERVIEW

BEMP is to improve the energy efficiency of reflow soldering operations.

For existing soldering equipment, BEMP is to:

- Maximise throughput of the existing reflow soldering equipment in order to reduce the specific electricity demand per square meter of the manufactured printed circuit boards. This is achieved through the optimisation of the speed of the conveyor of the soldering line while maintaining an acceptable process window⁴⁸.
- Install retrofit insulation to the soldering equipment.

For new soldering equipment, BEMP is to:

- Select equipment with i. improved power management system (e.g. available stand by or dormant state), ii. a flexible cooling system which allows switching between an internal and external cooling units and enables waste heat recovery⁴⁹ and iii. improved consumption monitoring and control system for liquid nitrogen.
- Use of direct-current (DC) fan motors instead of alternating-current (AC) in order to regulate separately the speed of the different motors.

For both existing systems and new soldering equipment, BEMP is to:

- Avoid the use of liquid nitrogen for less delicate applications, such as low complexity assemblies.

Relevant life cycle stages

Manufacturing

Supply chain

End of life

Main environmental benefits

Resource efficiency

Water

Waste

Emissions to air

Energy and climate change

Biodiversity

Hazardous substances

Environmental performance indicators

- Total energy demand per unit of surface of the processed printed circuit board (kWh of electricity / m² of PCB)
- Nitrogen consumption per unit of surface of the processed printed circuit board (kg of nitrogen / m² of PCB)

Applicability

This BEMP is applicable to EEE manufacturers with reflow soldering operations, and especially relevant for the production of printed circuit boards.

The measures for new soldering equipment are applicable when the overall decision to install a new reflow soldering line is taken. The return of investment depends considerably on increased yield, performance, maintenance requirements rather than energy savings.

Benchmarks of excellence

N/A

⁴⁸ Process window defines the operating temperature range of the soldering process that ensures the quality of the manufactured EEE products. In particular, the lower limit is determined from the thermal energy that is required by the solder joints whereas the heat resistance of the components define the upper limit of the soldering process.

⁴⁹ This option enables using waste heat of the internal cooling unit during heating periods, whereas during times with high outside temperatures, the reflow soldering system can be switched to the external cooling.

4.2.3.1 Description

Within EEE manufacturing, 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 (PCB), soldering is most relevant in order to connect the electronic components to the circuits on the board⁵⁰. Most applications are reflow soldered⁵¹ and/or wave soldered⁵². 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 optimisation potential. For example, reflow soldering equipment is responsible for 70% of energy demand within the SMD production process (Bell et al. 2013). Therefore, this BEMP focus on the reflow soldering technique.

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 maximising the throughput of the soldering line as well as of avoiding the use of nitrogen have to be mentioned.

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

1. Maximise 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, optimised 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 maximisation 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

⁵⁰ This BEMP is mainly focused on the manufacture of the PCBs.

⁵¹ 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.

⁵² 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 devices and surface mounted devices.

issue is to optimise 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;
- optimised use of liquid nitrogen.

Further details can be found in the "Operational data" section.

The main reason for using nitrogen during the soldering process is obviously to reduce defects. The use of Nitrogen in soldering 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

4.2.3.2 Achieved 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 characterised 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 CO₂ emissions of up to 12 tons⁵³ per year (Bell et al. 2013; Kurtz 2010).

In addition to energy savings, also 20% less nitrogen demand can be achieved (Friedrich 2012b, Friedrich 2014). This opens up additional cuts in CO₂ emissions since nitrogen has to be produced through cryogenic air separation representing an energy-intensive process.

4.2.3.3 Appropriate environmental performance indicators

The environmental performance of reflow soldering can be assessed 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). The unit for this indicator is usually: *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.

The reflow soldering process requires an inert process area, or oxygen-free area, within the reflow oven. The oxygen-free area prevents the oxidation of the surfaces of the components that are going to be soldered and of the molten solder. The gas is usually used in this process is nitrogen and its consumption is monitored with the metrics: kg of nitrogen used in the reflow oven per the surface of the processed PCB (*kg of Nitrogen / m² of the processed PCB*).

⁵³ The mentioned reductions of CO₂ emissions are dependent on the specific emission factors for electricity production and refer to German conditions.

4.2.3.4 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. Neodymium is regarded as "critical raw material" in the EU; furthermore, its extraction is associated with heavy burden on the local environment (EU 2014; Schöler et al. 2011).

On the other hand, energy-efficient soldering equipment shows beneficial impacts also with regard to other environmental aspects. 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).

4.2.3.5 Operational data

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

Maximise throughput of existing reflow soldering equipment

When maximising 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 characterised 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 downstream 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 unit. 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 optimised 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. Achieved environmental benefits section). By means of several measuring points, optimisation 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

Table 4.7 gives a summary of conditions / applications that can be optimised 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 optimised 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: 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.

4.2.3.6 Applicability

Basically, the approaches for improving the energy efficiency of reflow soldering facilities can be applied by all companies, which do not belong necessarily to EEE manufacturing sector, but they use such equipment⁵⁴. Although for many EEE products mass production of electronic

⁵⁴ The energy efficient soldering is a technique that also highly affects the automotive industry; in particular the automotive industry is one of the major consumer/user of such electronic components/equipment.

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 4.2.3.9) 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 as well (Petermann 2014c).

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

In contrast to this, approaches like improved power management systems, optimised 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.

4.2.3.7 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 is important aspect for the economical assessment (Friedrich 2012b).

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

In terms of the savings potential, 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 the 'Achieved environmental benefits' section) result in further cost savings. When assuming nitrogen consumption for one reflow soldering line of approximately 15 m³/h, 20% savings can account for more than 2,000 EUR⁵⁵ per year (SMT n.y.).

Furthermore, 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 approximately 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).

The resulting payback time of new reflow soldering equipment is highly dependent on the individual circumstances of the different companies, especially concerning the savings that can be realised because of increased yield. Thus, general information on payback times is not provided.

4.2.3.8 Driving force for implementation

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

4.2.3.9 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

⁵⁵ This cost saving potential has been calculated on the basis of a two shift operation (4160 hours p.a.) and of nitrogen costs of 0.15 €/m³.

tumble dryers as well as the manufacturing of electronic components for all Miele products is located (Petermann 2014a):

- 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 ([Figure 4.6](#)):

Figure 4.6. 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).

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4.2.4 On-site copper recycling in process chemicals

SUMMARY OVERVIEW						
BEMP is to recover copper from the etching process agents used in printed circuit boards manufacturing by electrolysis. This allows recovering high quality copper, reducing the amount of etching agent used and re-using water.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">On-site copper recycling system in place (Y/N)Amount of copper recycled from etching process agents (t/year)						
Applicability		The BEMP is applicable to printed circuit board production facilities. However, the economic feasibility depends considerably on the production levels, and thus on the amount of high quality copper that can be recovered (e.g. over 60 t of copper per year). A further limitation is the space needed for the on-site recycling system, which ranges between 50 and 80 m² depending on the arrangement of the installation and the volume of the buffer tanks. However, this does not necessarily need to be right next to the etching process.				
Benchmarks of excellence		N/A				

4.2.4.1 Description

In the EEE production, wet processes are the most chemically intensive production processes. They also offer good opportunities for the on-site recycling of process chemicals.

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 very cost-effective. However, electrolytic recovery can also be used for other metals, such as copper or nickel, when cost-effective too. 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 (EC 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 (EC 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, allowing a direct in-house re-use. Besides, the recovered metals can be sold in the scrap metal trade (EC 2006).

In particular, in the case of Printed Circuit Board (PCB) production, large quantities of copper are contained in the basic etching solution and in the rinsing water.

This copper can be recycled either off-site or on-site. In the first case, the copper is concentrated in a solution or in sludge in order to transport it to a specialist recycler. This is feasible also for companies using low amounts of copper. This BEMP describes instead the on-site copper recycling from etching process agents in PCB production, which is feasible for production facilities using large amounts of copper (e.g. with the potential to recover over 60 t of copper per year). The process is also described in the Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics (EC 2006) 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.

When the feasibility of on-site recycling is ensured by the amount of copper that can be recovered, this solution is preferable to off-site recycling since similar efficiencies can be achieved and the transport of dangerous substances can be avoided. Moreover on-site recycling also replaces the need to refine the copper that is purchased.

4.2.4.2 Achieved environmental benefits

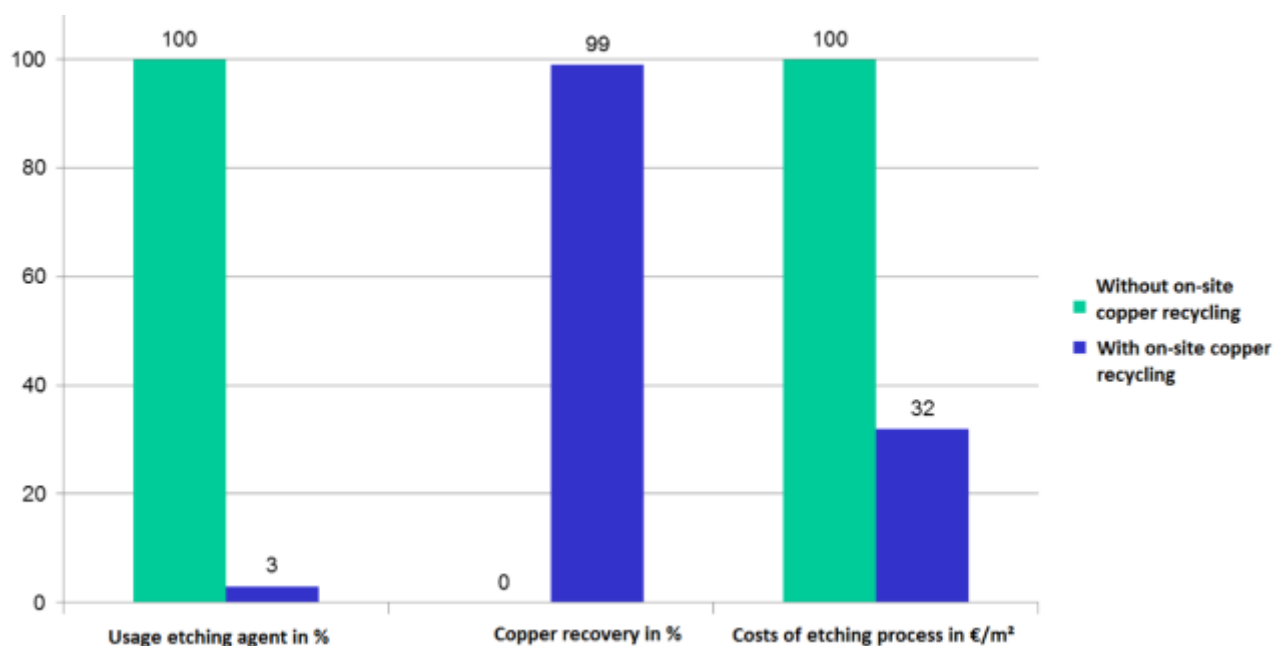
On-site copper recycling from PCB etching processes results in various environmental benefits. So far, the use of etching agents has been limited to the maximum amount of copper in the etching agent. If the value of 150 g/l copper is exceeded, a new etching agent (replenisher) needs to be added. The on-site recycling of copper allows for an extended use of the etching agent by removing the copper. Thereby, the amount of the etching agent used is reduced by more than 95% ([Figure 4.7](#)).

As rinsing water also undergoes a copper extraction, the water can be reused too, and the generation 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.

In the absence of on-site copper recycling, the etching agent used can be transported to an external recycler. However, as the etching agent used is classified as a dangerous substance, it has to be transferred by transport of dangerous goods by road. The reduced amount of dangerous goods and its transport by road is a qualitative environmental benefit (reduced risk for environmental contamination). In addition, the overall reduced transport of material can be calculated in reduced CO₂ emissions, whose relevance depends on the distance between the manufacturing facility and the external recycler.

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

Figure 4.7. Advantages of on-site copper recycling from the PCB etching solution



Source: Wolfer (2014)

4.2.4.3 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 copper could be a suitable indicator, it depends on the production and throughput. Besides, also original copper foil which was not used in the PCB production is often accounted together with the recycled copper.

Thus, the installation of a copper recycling system can be a simpler but more effective indicator for implementation. It is a proxy for the various environmental benefits (reduction of etching agent; reduction of transport of hazardous goods, reduced risk of environmental contamination etc.) independently from the the current production levels.

Summarising, the proposed environmental performance indicators for this BEMP are:

- On-site copper recycling system in place (Y/N)
- Amount of copper recycled from etching process agents (t/year); this indicator is not comparable among similar companies or for a same company over time in case the production capacity or the throughput has changed.

4.2.4.4 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.

4.2.4.5 Operational data

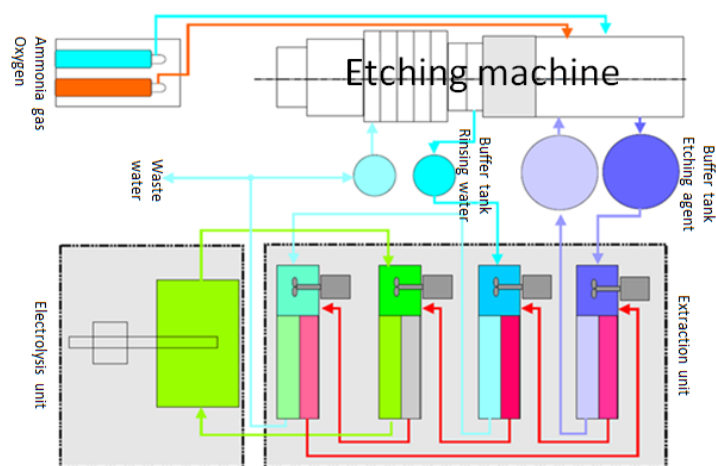
Copper recycling from the etching solutions in PCB production can be performed in a separate system that does not necessarily need to be installed next to the etching process (Sigma Gruppen, 2015a).

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 ([Figure 4.8](#)) (Sigma Gruppen 2015b).

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 4.8. Model of the alkaline etchant and copper recycling installation next to the etching line



Source: Wolfer (2014)

4.2.4.6 Applicability

On-site copper recycling is applicable to printed circuit board manufacturing facilities. However, the economic feasibility depends considerably on the production levels, and thus on the amount of high quality copper that can be recovered (e.g. over 60 t of copper per year – see also the 'Economics' section below). A further limitation is the space needed for the on-site recycling system, which ranges between 50 and 80 m² depending on the arrangement of the installation and the volume of the buffer tanks. However, this does not necessarily need to be right next to the etching process.

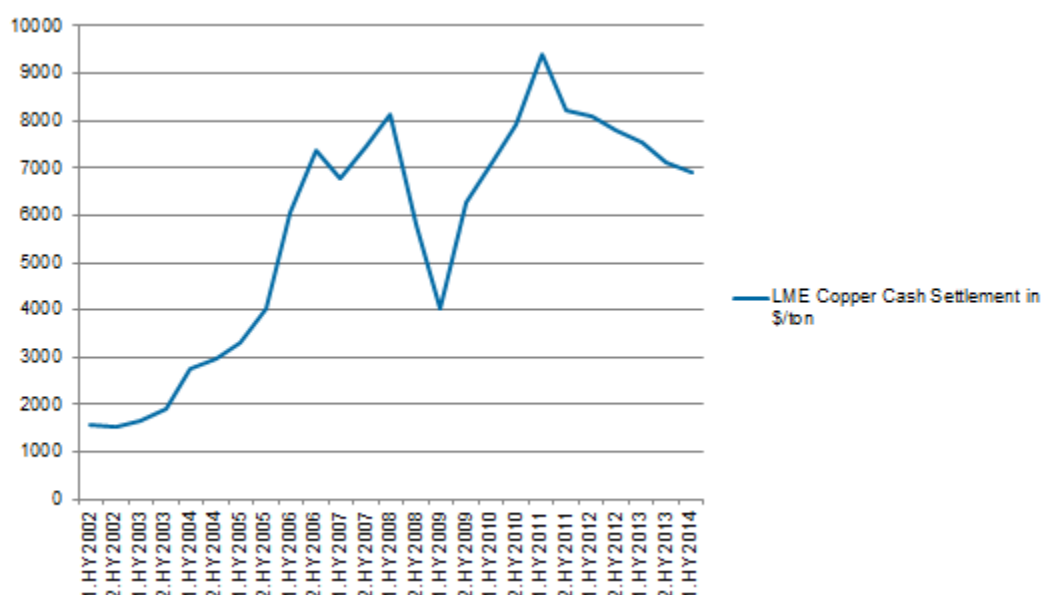
4.2.4.7 Economics

It is reported that the pay-back period of the investment usually ranges between 6 and 18 months because of the reduced operational costs for replenisher, rinse water and chemicals for water treatment, as well as because of the revenue from the recovered copper (Sigma Gruppen 2015b). Altogether, the overall costs of the etching process can be reduced by almost up to 70%. As for the recovered copper, in case this is sold, due to its high quality (99.99% purity), a price of 92% of the copper quotation can be reached (Wolfer 2014) and it can be sold to different customers, e.g. to the scrap metal trade or to a copper company.

However, the return on investment strongly depends on the amount of sold high quality copper and precious metals. For instance, the pay-back period in the case of 90 tonnes of recycled copper per year is estimated to be in the order of 14 months, extending to 18 months in case of 60 tonnes of recycled copper per year. For smaller quantities, the return on investment tend to be considerably longer (e.g. 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 ([Figure 4.9](#)) (ECI 2012; LME 2016). Thus the pay-back period of more than three years with a recovery of about 600 kg of high quality copper per month indicated in the Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics (EC 2006) has significantly shorten.

Figure 4.9. 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

4.2.4.8 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.

The drivers for the price increase has been the increasing global demand, which resulted in ore production for copper almost doubling between 1985 and 2005 (Table 4.8).

Table 4.8. Ore production of copper in million t/a in 1985, 1995 and 2005

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

Source: Oeko-Institut (2007)

Against a background of a real threat of physical scarcity, copper requirements are increasingly being met by recycling (Glöser et al. 2013).

This development in the copper segment is running in parallel with a general increasing global demand for natural resources and the sharply increasing raw material prices (Oeko-Institut 2007).

4.2.4.9 Reference organisations

- AT&S operates a copper recycling system at one production site in Fehring and recycles 100 tonnes copper per year (Rossmann 2014)
- Würth Elektronik: The company operates a copper recycling system (for more details see section "Operational data").
- Other European PCB producing companies equipped with copper recycling systems: Intectiv in Slovenia, Piciesse in Italy, Richter Elektronik in Germany, Luznar in Slovenia, Laskar in Poland, Teltex AB in Sweden, Ei PCB Factory in Serbia and CYNER substrates in the Netherlands (Sigma Gruppen, 2015c)
- EU-funded FP7 project ECOWAMA (Eco-efficient management of water in the manufacturing industry) proposes an eco-efficient closed cycle management model for the treatment of effluents of the metal and plastic surface processing industry.

4.2.4.10 Reference literature

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4.2.5 Cascade rinsing systems and water use optimisation

SUMMARY OVERVIEW						
BEMP is to minimise water use in the manufacture of Printed Circuit Boards by installing multiple cascade rinsing systems with four or more stages.						
In addition, BEMP is optimising the water use by e.g. setting the water intake in rinsing baths according to process specific quality requirement and re-use of rinsing bath water for different working steps.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climatic change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">• Total water consumption in the fabrication plant (l/m2 of PCB manufactured)• Share of cascade rinsing systems with four or five stages out of the total number of rinsing systems (%)• Water consumption in cascade rinsing systems with four or five stages compared with the water consumption in three-stage cascade rinsing systems (%)• Five-stage cascade rinsing system in place (Y/N)						
Applicability		<p>The BEMP is broadly applicable to printed circuit boards manufacturing companies. The optimisation measures and the installation of multiple cascade rinsing systems with at least four stages are applicable both in existing facilities and in new-build. In the case of cascade rinsing systems with four or more stages, the available space needed may pose some limitations.</p> <p>More specifically, five-stage cascade rinsing system are mostly applicable for systems with high machine throughput or highly concentrated electrolytes and the following additional limiting factors need to be considered:</p> <ul style="list-style-type: none">– Highly concentrated rinse water leads to a larger use of chemicals and longer time needed for sedimentation in deionisation for waste water treatment.– Heating of the rinsing bath water due to increased numbers of pumps, which increases pressure by germ contamination.– Germ contamination needs to be mitigated by implementing proper water disinfection techniques.				
Benchmarks of excellence		<ul style="list-style-type: none">• At least 50% of the rinsing facilities are equipped with a cascade rinsing system with four or more stages				

4.2.5.1 Description

The management and protection of water resources is "one of the cornerstones of environmental protection" (EC no date) and limiting water use to reduce the risks of water scarcity and drought is becoming a widespread relevant issue in Europe.

There is no comprehensive overview on the amounts of water used for manufacturing of EEE, since this is generally considered together with all manufacturing industry (BIO IS 2009; Ecologic-Institute 2007). However, wet processes for metal surface treatment that are relevant for the manufacturing of EEE, 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 (BAT) are also summarised in the BAT Reference document (BREF) on the Surface Treatment of Metals and Plastics (EC 2006): a reduction of rinsing water consumption is closely related to the reduction of drag-out that can be achieved by different means such as 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 (EC 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 share of the water consumed (EC 2006).

Technologically, the different processes in PCB manufacturing are implemented in individual baths/tanks 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 and they are comprised of two or more rinse tanks. Water flows from the top of one tank into the surface of the water in the following tank. 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.

Frontrunner PCB producing companies implement water saving measures by implementing multiple cascade rinsing systems. Since a three-stage cascade rinsing system is considered today state-of-the-art technology (e.g. see relevant German legal framework⁵⁶), the implementation of **cascade rinsing systems with at least four stages** in PCB production can be considered best environmental management practice.

In addition, other measures for optimising the processes and equipment can be implemented. Two examples are: setting the water intake in rinsing bathes according to process specific quality requirement and re-use of rinsing bath water for different working steps.

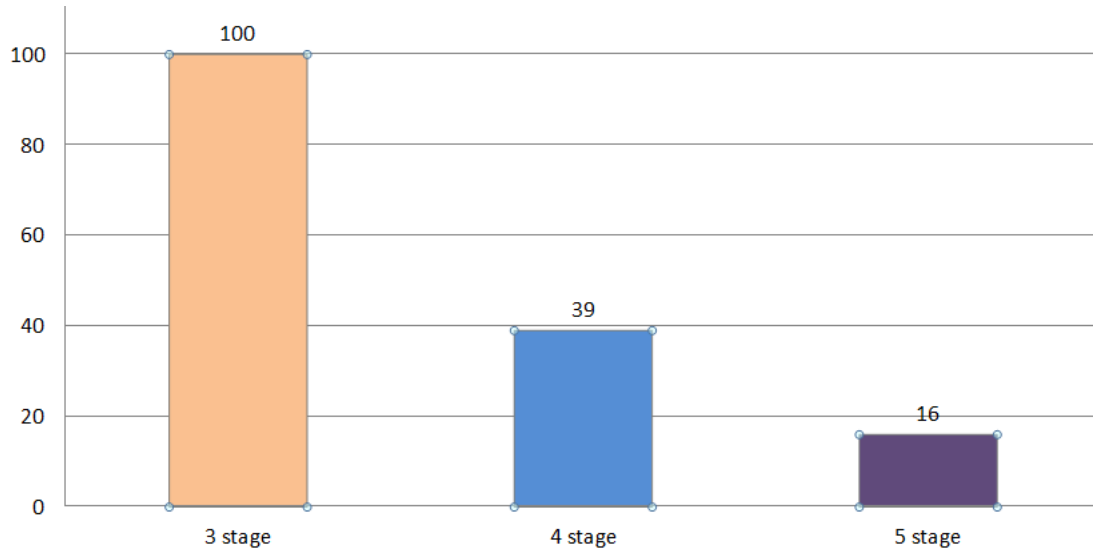
4.2.5.2 Achieved environmental benefits

The cascade rinsing systems contribute to environmental benefits by conserving drinking water. Nevertheless, it is difficult to estimate/quantify the water savings in a cascade rinsing system, since the number of the installed stages and the number and intensity of the carried out industrial process play an important role.

⁵⁶ 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&isLegisum=true>

Figure 4.10 shows that a significant reduction of rinsing water demand can be achieved. Compared to a system with three stages, the implementation of a four-stage cascade rinsing system yields a reduction of more than 60%. 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 4.10. Comparison of water consumption in cascade rinsing systems comprising 3, 4 and 5 rinsing tanks



Source: Wolfer (2014)

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. Additionally, water loss occurs by evaporation while additional water re-use might be installed between the lines.

4.2.5.3 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 document (EC, 2006), water consumption ranges between 170 and 600 l/m² in PCB manufacturing. However, it is unclear whether water for washing and cleaning equipment is also accounted in those values.

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

- Double-sided PCB (54 process steps, including 36 wet processes): 130 – 160 litres rinsing water per m² PCB
- Multilayer PCB, 10 layers (114 process steps, including 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 by means of internal optimisation, 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 "Operational data" to account for more than 50% of the water consumed (Wolfer 2014).
- Water savings 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).

Against the background of the large differences between the specific rinsing water demand for different types of PCB and the varying product portfolios processed at the different plants, it is not reasonable to use this first indicator to compare different production lines, plants or companies.

A more practical indicator can be the share of cascade rinsing systems with four or five stages out of the total number of cascade rinsing systems. This can be accompanied by information on the water consumption achieved in the cascade rinsing systems with four or five stages compared to the water consumption in the systems with three stages (as shown in [Figure 4.10](#)).

These indicators consider best practice both systems with four and systems with five stages, taking into account the currently limited technological and economic feasibility of five-stage cascade rinsing systems (see sections "Operational data" and "Economics").

Concluding, the proposed environmental performance indicators for this BEMP are:

- Total water consumption in the fabrication plant (l/m² of PCB manufactured)
- Share of cascade rinsing systems with four or five stages out of the total number of cascade rinsing facilities (%)
- Water consumption in cascade rinsing systems with five (or four) stages compared with the water consumption in three-stage cascade rinsing systems (%)
- Five-stage cascade rinsing system in place (Y/N)

4.2.5.4 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. 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).

4.2.5.5 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. Specifically 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 optimised as well (Rossmann 2014), the number of cascades is the most important determinant for water saving. In new installations, 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 ([Figure 4.10](#)). 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 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 to UV lamps, other techniques that can be used for the disinfection of the water are ozone treatment and chlorination.

In addition, the optimisation of processes and equipment also allows substantial water savings. It needs to start with a thorough monitoring: the manufacturer's information on the rinse water flow must be checked carefully, and can be adapted to the specific process conditions. Examples of measures applied by different manufacturers in existing plants include (Rossmann 2014, Wolfer 2014):

- Setting the water intake in rinsing baths according to process specific quality requirement: a computer-based application monitors the water quality (conductance value) in the second last cascades and triggers a defined water inflow regulated by a magnetic valve / electronic volume metre. The last rinse bath is also monitored periodically in order to detect changes in the carry-over.
- Re-use (double use) of rinsing bath water for different working steps: thanks to separate collection, the rinsing water can be transferred for re-use between processes where the working steps need the same chemical composition (e.g. rinsing before and after post dip).

4.2.5.6 Applicability

The optimisation measures described can be applied by any companies using cascade rinsing systems.

As for the implementation of five-stage cascade rinsing systems, the germ contamination factor (addressed in the "Operational data" section) can be a limiting factor that needs to be mitigated by the implementation of appropriate water disinfection techniques (Wolfer 2014).

For new installations or for switching to a cascade rinsing system with more stages, the available space in the facility may also be a limiting factor and needs to be taken into account both during planning of the measures and in terms of economic feasibility.

4.2.5.7 Economics

Although a significant reduction of operational costs by water savings are reported by companies, it is difficult to quantify these in a general way, as water pricing and water tariffs vary considerably in the EU. Moreover, the savings in operational costs derive also from a reduced amount of waste water and depend on the local charges for municipal waste water treatment or the costs for on-site waste water treatment. However, information on pay-back periods reported by companies can still provide a useful indication and incentive for other companies to apply similar measures.

Würth Elektronik indicated the following pay-back periods for the measures described in section "Operational data". They are based on a pricing of 4 € per m³ for water and waste water, which does not include internal waste water treatment costs; taking internal waste water treatment costs into account, water prices reach 12 to 18 € per m³. For companies with higher specific charges for water supply and treatment, economic break-even can be achieved within a shorter period ([Table 4.9](#)).

Table 4.9. Water saving measures in cascade rinsing systems and their pay-back periods in a specific company

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
Water savings measures in existing installations if implementation (development of software tool, plant modifications) can be done in-house	< 1
Water savings measures in existing installations if implementation (development of software tool, plant modifications) <u>cannot</u> be done in-house	~ 2

4.2.5.8 Driving force for implementation

Two streams of driving forces were reported by EEE manufacturing companies:

- The first one is corporate responsibility and the commitment of the companies to protect resources. This goes hand in hand with an EMAS registration or 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.

4.2.5.9 Reference organisations

- AT&S: In the production site in Fehring (Austria), 40% of all cascade systems comprise 4- to 6-stage cascades; other measures are also 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 "Operational data" for more details).

4.2.5.10 Reference literature

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

4.2.6 Minimising perfluorocompounds emissions

SUMMARY OVERVIEW

BEMP is to minimise the emissions of perfluorocompounds (PFC) in semiconductor fabrication facilities by:

- Substituting PFC gases with a high specific global warming potential by others with a lower global warming potential, e.g. replacement of C_2F_6 by C_3F_8 for Chemical Vapour Deposition (CVD) chamber cleaning.
- Optimising the CVD chamber cleaning process to increase the conversion factor of the PFC gases used, in order to avoid that unused PFC gases are emitted after the chamber cleaning process. This requires monitoring emissions and adjusting operational parameters, such as chamber pressure and temperature, plasma power cleaning gas flow rates and gas ratios in case PFC gas mixtures are used.
- Operating remote plasma cleaning technology that replaces the use of PFC gases in situ (e.g. C_2F_6 and CF_4) with remote NF_3 . In this process, NF_3 is dissociated by the plasma before entering the process chamber and is thus more efficiently used with very little NF_3 being emitted from the process chamber after cleaning.
- Installing point-of-use abatement techniques, such as: a burner-scrubber, installed after the vacuum pump, or a small plasma source, installed before the vacuum pump, used to abate PFC emissions from plasma etching.

Relevant life cycle stages

Manufacturing

Supply chain

End of life

Main environmental benefits

Resource efficiency

Water

Waste

Emissions to air

Energy and climatic change

Biodiversity

Hazardous substances

Environmental performance indicators

- Normalised Emission Rate (NER), i.e. global warming potential caused by the PFC emissions of a production site in relation to the surface of the produced wafers ($kgCO_2e/cm^2$)

Applicability

The BEMP is broadly applicable to semiconductor fabrication facilities using PFC gases. The specific measures that can be implemented in a facility need to be assessed on a case by case basis.

Process optimisation is broadly applicable and can be effective measure both in existing facilities and in new-build CVD chambers. It is the only measure which also saves costs, since it can allow lower gas consumption and better throughput.

Substitution of PFC gases is often technically unfeasible, especially for plasma etching.

Remote plasma cleaning technology using NF_3 and point-of-use plasma etching abatement are broadly applicable. They are especially relevant for new semiconductor fabrication facilities or in facilities where equipment is being renewed on a larger scale. However, these are associated with high investment costs.

Burner/scrubber systems are broadly applicable although space, existing infrastructure and investment costs may be limiting factors.

Benchmarks of excellence

- The Normalised Emission Rate for PFC emissions is lower than $0.22 kgCO_2eq/cm^2$.

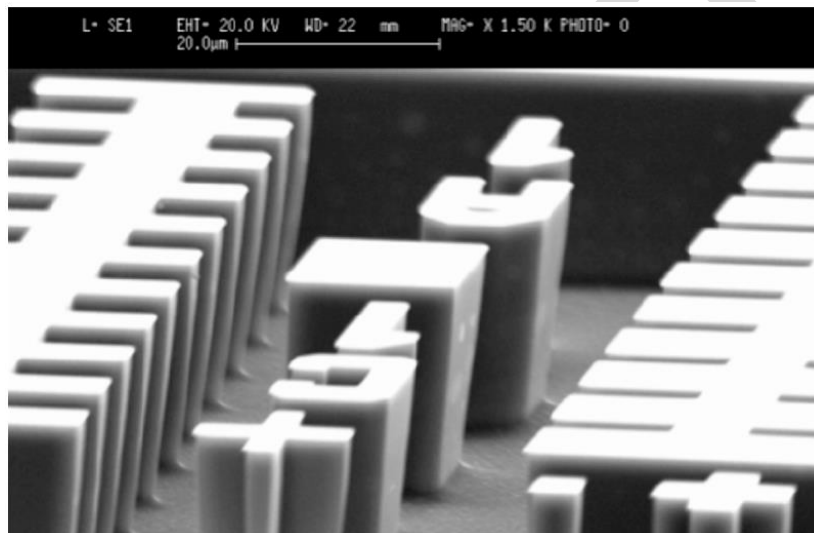
4.2.6.1 Description

During the production of semiconductor devices, various gaseous perfluorocompounds (PFC) are required. The most relevant PFCs that are used in the EEE manufacturing 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 (Figure 4.11).

Figure 4.11. Submicron patterns of integrated circuits



Source: www.iht.tu-bs.de, reproduced in ZVEI (2011), p. 14

Regarding the cleaning of CVD chambers (Figure 4.12), 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 4.2.6.2).

Figure 4.12. CVD chamber



Source: 3D:it – 3D Infotainment Technologies UG, reproduced in 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 optimisation 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 PFC emissions (EPA 2006).

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

- Process optimisation (focused on CVD chamber cleaning);
- Substitution of PFC gases (e.g. replacement of C_2F_6 by C_3F_8 , focused on chamber cleaning);
- Remote plasma cleaning technology (Remote NF_3 instead of in situ NF_3 or in situ C_2F_6 and CF_4);
- Point-of-Use (POU) abatement techniques (such as burner-scrubber installed after the vacuum pump or small plasma source installed before the vacuum pump).

Substantial reductions of PFC emissions can be achieved through process optimisation, which is primarily focused on CVD chamber cleaning and consists of monitoring emissions and providing clean end point times. The main goal of process optimisation 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.

When substituting PFC gases with a high specific global warming potential by substances with a lower potential, a substantial reduction of the environmental impact of the use of PFC 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-situ⁵⁷ C_2F_6 and CF_4 and in-situ NF_3 chamber cleaning. Its main characteristic is that NF_3 is dissociated by a plasma before entering the process chamber and is thus more efficiently used with very little NF_3 being emitted from the process chamber after cleaning.

Concerning abatement, the emission reduction is highly dependent on the type of installed abatement devices and the carried out process (WSC, 2012). There are a number of different POU abatement device types, such as burner /scrubber POU abatement (installed after the vacuum pump) that rely on thermal destruction and a subsequent scrubber, or plasma based abatements installed before the vacuum pump used to abate PFC from plasma etching.

⁵⁷ In-situ refers to a cleaning process that takes place inside the CVD chamber.

4.2.6.2 Achieved environmental benefits

In general, PFC gases are characterised 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 characterisation factor; the following table gives an overview of relevant⁵⁸ PFC gases with regards to this metric.

Table 4.10. Global warming potential (GWP) of relevant PFC gases; values are based on the IPPC 5th Assessment Report

PFC gas	Chemical Formula	GWP characterisation factor 100-yr
Hexafluoroethane	C ₂ F ₆	11,100
Tetrafluoromethane	CF ₄	6,630
Trifluoromethane	CHF ₃	12,400
Octofluoropropane	C ₃ F ₈	8,900
Octofluorocyclobutane	c-C ₄ F ₈	9,540
Nitrogen Trifluoride	NF ₃	16,100
Sulphur Hexafluoride	SF ₆	23,500

Source: EPA (2014)

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. C₂F₆) can be replaced by a substitute with a lower value (e.g. C₃F₈). 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 4.2.6.5).

4.2.6.3 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 CO₂ equivalents – CO₂e) caused by the PFC emissions of a production site should be set in relation to the surface area of the produced wafers. This is expressed as *kg CO₂e /cm²*.

This metric has 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 4.2.6.8).

Other qualitative indicators that can be used for monitoring the environmental performance of this BEMP are listed:

- Minimisation of the PFC emissions by:
 - Applying process optimisation focused on CVD chamber cleaning (Y/N)
 - Substituting of PFC gases (Y/N)
 - Installing remote plasma cleaning technology (Y/N)
 - Using POU abatement techniques (Y/N)

4.2.6.4 Cross-media effects

Cross-media effects associated with the different approaches listed in the Description section 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 4.2.6.5). Due to water recycling, however, this aspect can be mitigated and made negligible.

⁵⁸ Relevant in terms of the voluntary agreement mentioned in the Driving force for implementation section.

The same applies to the additional energy, which is usually fuel like natural gas and rarely electricity, of the identified abatement techniques, since the CO₂ emissions caused by electricity supply will be clearly overcompensated by the substantial reduction of global warming potential due to the PFC emissions savings.

4.2.6.5 Operational data

This section provides further details and operational data for each of the four approaches mentioned in the Description section.

Process optimisation

Within the context of process optimisation, 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. According to Bühler (2007) and Koch (2008), these measures could enable a reduction in emissions of up to 73% compared with the status quo. ESIA (2011) also reports that process optimisation can yield considerable emission reduction (in the order of 10-56%) when compared with non-optimised processes. However, the process has to be (partly) re-assessed, which requires significant engineering resources.

Substitution of PFC gases

A typical example for the substitution of PFC gases is the replacement of C₂F₆ by C₃F₈ (see differences in global warming potential characterization factors in the Achieved environmental benefits section). 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 NF₃ also represents a very powerful greenhouse gas (Table 4-7) the replacement of C₂F₆ and CF₄ by NF₃ in remote plasma cleaning technology is associated with significant environmental relief. Within this process, NF₃ 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 (SiF₄). Since a conversion factor for NF₃ 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 techniques

There are several technological proven options concerning POU abatement (EPA 2005; WSC 2012):

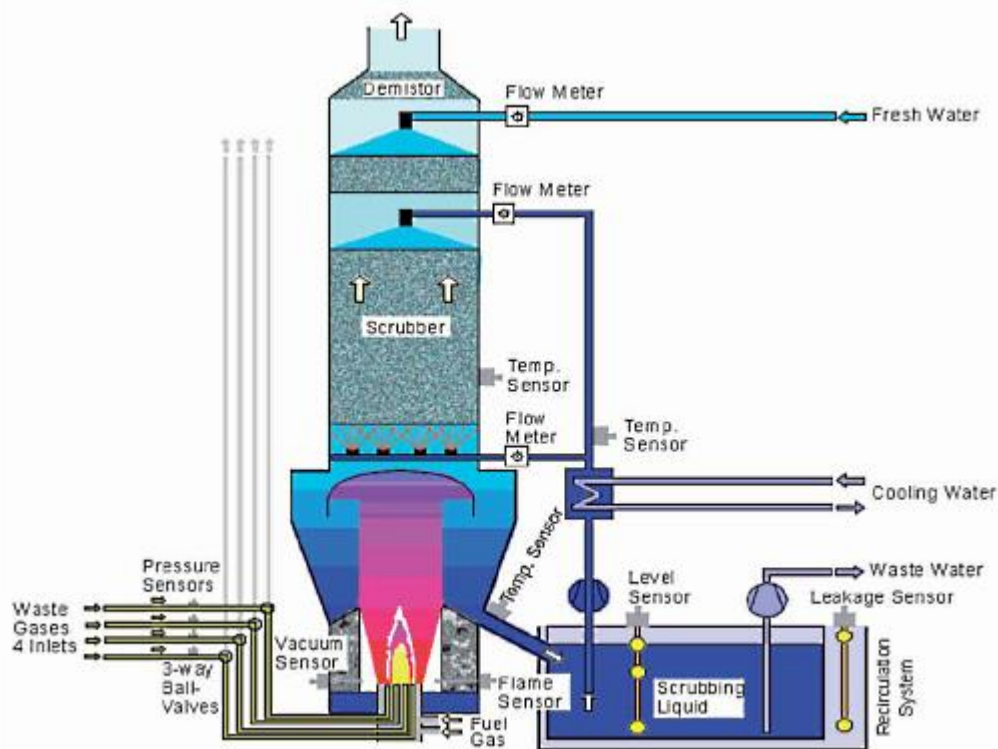
- POU fuelled combustion scrubber;
- POU absorption scrubber;
- POU plasma/plasma scrubber;
- POU electrically heated thermal scrubber;
- Collecting system refining and recycling system.

Two examples are the installation of a burner-scrubber installed after the vacuum pump and/or a small plasma source between the plasma etching chamber and the vacuum pump and.

In the first example, a burner-scrubber system can be used to decompose PFC emissions remaining after the implementation of the above-mentioned measures achieving an efficiency of up to 99%. Such a system is schematically presented in [Figure 4.13](#).

In the second example, a small plasma source effectively dissociates the PFC molecules reacting with fragments of the additive gas (such as H₂, O₂, H₂O, or CH₄). As a result, low-molecular-weight substances like HF with little or no GWP are created. They can, anyway, be removed by wet scrubbers (Rhiemeier & Harnisch 2009). Point-of-use plasma abatement for PFC emissions from plasma etching is estimated at 95% (EPA 2006).

Figure 4.13. Schematic figure of an exhaust air purification facility (burner / scrubber system)



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

4.2.6.6 Applicability

Process optimisation 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 often technically unfeasible, especially for plasma etching with its increasingly stringent requirements, calling both for fluorine to etch and the right carbon/fluorine ratio (ESIA 2011; ZVEI 2011).

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). However, their implementation requires investment in CVD manufacturing hardware (tools) as well as cooperation with companies down the supply chain. 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.

As for burner-scrubber systems, these are broadly applicable. Nevertheless, the main limitations are space, existing infrastructure and then costs.

4.2.6.7 Economics

Only process optimisation 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 described are associated with substantial costs. For instance, according to US EPA (2006), the installation of a remote CVD cleaning system requires purchase and installation capital costs of approx. 50,000 € per chamber, plus net annual costs of approx. 12,000 € per chamber, while plasma abatement technology need approx. 30,000 € investment per etching chamber, which covers the purchase and installation of the system, plus operational expenses of about 800 € per etch chamber.

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 retrofitting in an existing facility. Indeed, new production sites can be designed and built in accordance with the latest know-how and are not subject to the existing infrastructure and space limitations of existing facilities (ESIA 2011).

4.2.6.8 Driving force for implementation

Both the political relevance of PFC emission reduction as well as the resulting establishment of various voluntary agreements within this context are 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 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 for a 41% 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).

In 2011, the WSC announced a new voluntary PFC agreement for the next 10 years. The industry expects that the implementation of best practices will result in a Normalized Emission Rate (NER) in 2020 of 0.22 kgCO₂e/cm², equivalent to a 30% NER reduction from the 2010 aggregated baseline. Best practices will be continuously reviewed and updated by the WSC (May 2014 Taipei -WSC 18th meeting).

4.2.6.9 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 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 implemented 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 (Hermanns 2012).

Micronas: Micronas produces sensors and embedded controllers for smart actuators, such as drivetrains, chassis frames, engine management and convenience functions for automotive and industrial business. Within its wafer production, Micronas has optimised the C₂F₆ 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 C₂F₆ consumption. Even further reductions were achieved through the use of new exhaust PFC gas abatement units (Micronas 2008).

World Semiconductor Council (WSC): WSC promotes cooperative semiconductor industry activities, expands international cooperation in the semiconductor sector in order to facilitate the healthy growth of the industry from a long-term, global perspective.

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4.2.7 Rational and efficient use of compressed air

SUMMARY OVERVIEW

BEMP is for electrical and electronic equipment manufacturers to reduce their energy use associated with the use of compressed air in the manufacturing processes by:

1. Mapping and assessing the use of compressed air. When part of the compressed air is used in inefficient applications or in an inappropriate manner, other technological solutions can be better fit for purpose or more efficient. In case a switch from pneumatic tools to electricity-driven tools for a certain application is considered, a proper assessment, considering not just energy consumption but all environmental aspects as well as the specific needs of the application, need to be carried out;
2. Optimising the compressed air system by:
 - identifying and eliminating leaks, using suitable control technology, such as ultrasound measuring instruments for air leaks that are hidden or difficult to access;
 - better matching supply and demand of compressed air within the manufacturing facility, i.e. matching the air pressure, volume and quality to the needs of the various end use devices and, when appropriate, producing the compressed air closer to the consumption centres by choosing decentralised units rather than a large centralised compressor catering for all uses;
 - designing the compressed air system based on the annual load duration curve, in order to ensure supply with the minimum energy use over base, peak and minimal loads;
 - producing the compressed air at lower pressure by decreasing the pressure losses in the distribution network and, when needed, adding pressure boosters only for devices that require higher pressure than most applications;
 - selecting highly efficient components of the compressed air system, such as highly efficient compressors, variable frequency drives and air dryers with integrated cold storage;
 - once all of the above is optimised, recovering the waste heat from the compressor(s) through the installation of a plate heat exchanger within the oil circuit of the compressors.

Relevant life cycle stages

Manufacturing	Supply chain	End of life
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Main environmental benefits

Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
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Environmental performance indicators

<ul style="list-style-type: none"> • Electricity use per standard cubic meter of compressed air delivered at the point of end-use (kWh/m³) at a stated pressure level • Air Leakages Index, calculated, when all air consumers are switched off, as the sum for each of the compressors of the time it runs multiplied by the capacity of that compressor ($Air\ Leakages\ Index = \sum_i t_{i(cr)} \times C_{i(cr)}$) 	
Applicability	<p>The measures described in this BEMP are broadly applicable to all EEE companies that use compressed air.</p> <p>Regarding the recovery of waste heat, a continuous demand for process heat is necessary in order to realise the corresponding energy and cost savings.</p>
Benchmarks of excellence	<ul style="list-style-type: none"> – The electricity use of the compressed air system is lower than 0.11 kWh/m³ of delivered compressed air, for large installations working at 6.5 bar effective,

	<p>with volume flow normalised on 1013 mbar and 20°C, and pressure deviations not exceeding 0.2 bar effective.</p> <ul style="list-style-type: none"> – After all air consumers are switched off, the network pressure remains stable and the compressors (in stand-by) do not switch to load condition.
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4.2.7.1 Description

Compressed air is a widely applied technology. It can be used both as an energy carrier (e.g. "energy air" used to power pneumatic tools) and as a process enabler (e.g. "dynamic air" to transport materials or "process air" to provide oxygen to an industrial process).

Compressed air is highly useful for electrical and electronic equipment manufacturers and nearly all companies make use of it, mostly as energy carrier. The advantages of compressed air lie in the inherent safety of this energy source, as well as the speed, precision, durability, low weight and small size of air tools.

It is estimated that the generation of compressed air accounts for up to 10% of the total electricity consumption of an EEE manufacturing site (Radgen & Blaustein, 2001). It is thus very relevant for EEE manufacturers to make efforts to reduce this energy consumption.

The first step is mapping where and how the compressed air is used. If part of the compressed air is used in inefficient applications or in an inappropriate manner (e.g. using blowguns to remove waste materials), other solutions are better fit for purpose (e.g. removing waste using a vacuum device). Some EEE manufacturers also decide switching, for certain applications, from pneumatic tools to electricity-driven tools. This allows reducing the overall energy use provided that the efficiency of the electrical tool is higher than the combined efficiency of the compressed air system (generation + distribution) and of the pneumatic tool, which is usually the case (Niermeier 2013).

However, companies need to carry out a proper assessment on a case-by-case basis, considering not just energy consumption but all environmental aspects as well as the specific needs of the application being considered, taking into account the advantages of pneumatic tools. Some of these are:

- durability - in general, compressed air tools have a longer life compared to electrically driven tools;
- compact size - pneumatic tools are usually smaller and can make possible to drill holes or tighten fasteners in places which cannot be accessed by bulkier electric tools;
- Suitability for high loading and clamping operations: compressed air tools do not generate heat under load and can thus have lower rated power to perform the same task;
- safety in ATEX⁵⁹ environments - Electrically driven tools cannot be used in a number of environments, where sparks or heat cannot be produced (e.g. explosive atmosphere).
- Power-to-weight size ratio: compressed air tools have a higher power-to-weight size ratio compared to electric tools, thus less efforts is needed for operators to carry out their job.
- WEEE generation - once reached their end-of-life, electrically driven tools become WEEE and, if battery-powered, the disposal of batteries is one of the main issues, while compressed air tools are much easier to recycle;
- use of critical raw materials - electrically driven tools use some critical raw materials (in motors and batteries), which is not the case for pneumatic tools.

When the use of compressed air is considered appropriate based on the mapping and assessment of its use, it is then best practice to optimise the compressed air system and minimise the related energy consumption by:

- 1) Identifying and eliminating leaks using appropriate control technologies;

⁵⁹ ATEX refers to potentially explosive atmospheres (European Commission 2016)

- 2) better matching supply and demand of compressed air within the manufacturing facility;
- 3) designing the compressed air system based on the annual load duration curve;
- 4) producing the compressed air at lower pressure by decreasing the pressure losses in the distribution network and, when needed, adding pressure boosters only for devices that require higher pressure than most applications;
- 5) selecting highly efficient components of the compressed air system;
 - Implementing waste heat recovery.

The single most important measure, as well as the easiest, is the identification and elimination of air leaks. Air leaks can cause substantial losses in terms of both energy and costs, even with very small diameters (e.g. 1 mm). 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.

Another relevant measure is the better matching of supply and demand of compressed air within the manufacturing facility. This is usually achieved by matching the air pressure, volume and quality to the needs of the various end use devices and, when appropriate, by producing the compressed air closer to the consumption centres by choosing decentralised units rather than a large centralised compressor catering for all uses. Additionally, because of the relevance of the design of the compressed air system on its energy efficiency, it is important to ensure supply of compressed air with the minimum energy use over base, peak and minimal loads. This can be achieved by designing the compressed air system based on the annual load duration curve.

In terms of reducing the pressure level of the compressed air system, when feasible, it allows a substantial increase of the overall energy efficiency of the system. Indeed, 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). As already mentioned, optimization of the system design is very important prior to the installation of technical solutions.

In terms of analysing the overall energy efficiency of the compressed air system, it can be useful referring to relevant ISO standards: the general energy management standard (ISO 50001) and the standard specific to compressed air systems (ISO 11011). In particular, ISO 11011 sets requirements for conducting and reporting the results of a compressed air system assessment that considers the entire system, from energy input to the work performed as a result of this input. It deals with:

- the analysis of the data from the assessment,
- the reporting and documentation of assessment findings, and
- the identification of an estimate of energy savings resulting from the assessment process.

The ISO 11011 standard also identifies the roles and responsibilities of those involved in the assessment activity.

Concerning the selection and installation of energy-efficient components, especially compressors need to be taken into account, since they represent the most important as well as most energy-consuming components. In the selection of compressors, the highest possible efficiency needs to be sought. In this respect, the installation of drives with variable speed is often beneficial. Besides compressors, also dryers, which 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) allows increasing the overall energy efficiency of a compressed air system, once all the above measures have been adopted. When installing appropriate components (e.g. plate heat exchanger), large amounts of heat dissipated by the compressor can be made accessible for other EEE manufacturing processes.

The different elements mentioned in this BEMP can be applied separately or jointly. However, best results will be achieved through an integrated approach implementing all or most of the measures.

4.2.7.2 Achieved environmental benefits

When implementing the measures presented in the description section (4.2.7.1), and especially heat recovery, savings in the range of 50% are possible (Radgen & Blaustein 2001). Other assessments show savings potentials of up to 66% (VDMA 2005).

Also the correspondent CO₂ emissions can be cut by half. For example, a compressed air system with best available management practice can save approx. 0.05 kg CO₂e per cubic meter of compressed air⁶⁰.

When compressed air operated tools are substituted by motor-driven tools, up to 90% energy savings can be achieved (Niermeier 2013b). However, important circumstances for the realisation of these savings are the costs that are associated with the investment of the motor-driven tools (see 4.2.7.7 section for more details) and the drawbacks of this technology (see 4.2.7.1 section)

4.2.7.3 Appropriate environmental performance indicators

The most appropriate environmental performance indicator for this BEMP is the energy performance of the compressed air system⁶¹. A correct assessment of the energy performance of a compressed air installation needs to refer to the entire compressed air system and take into account the energy input compared to the useful output, at the useful pressure and at the useful air quality⁶².

A simple metrics that can be employed to monitor the energy performance of the compressed air system is the electricity use per standard cubic meter (calculated on the basis of standard conditions: at a pressure of 1.01325 bars and at a temperature of 20°C) of compressed air delivered (kWh/m³), stating the pressure level of the compressed air system. As mentioned, 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 pumps for the operation of heat recovery. It is therefore not enough to assess the key figures of the manufacturer and test values.

Besides assessing the energy performance of the compressed air system, also the energy demand of important individual components (especially compressor and dryers) needs to be analysed. It can support decisions at the component level. Within this context, besides the performance at full load, special consideration should be given to the energy efficiency at partial load (e.g. 33%, 50%, 75%).

Concerning air leaks in the compressed air network, how significant they are can be calculated by adding, each time a compressor switches on when all air consumers are switched off, the product between the interval during which the compressor(s) run and the capacity of the compressor(s) running:

$$\text{Air Leakage Index} = \sum_i t_{i(cr)} \times C_{i(cr)}$$

Where:

- $t_{i(cr)}$ is each time period (min) during which at least one compressor run when all air consumers are switched off (stand-by of the compressed air system);
- $C_{i(cr)}$ is the capacity (Nm³/min) of each compressor that switches on for the time $t_{i(cr)}$, while all air consumers are switched off (stand-by of the compressed air system).

⁶⁰ Own calculations based on data from EcoInvent (2014) for a compressed air system operating with a capacity above 30 kW and at 6 bar gauge.

⁶¹ As presented in the description section of this BEMP, standards ISO 50001 and ISO 11011 deal in detail with the energy efficiency of compressed air systems and how it can be calculated.

⁶² Useful output: look into the demand profile over a reference period and identify the lowest point, by default, as waste, unless it can be attributed to useful processes at that moment.
Useful pressure: during peak demands, a poorly designed distribution net can create such a pressure drop that the pressure at the compressor room is substantially higher than what is needed at the point of use.
Useful quality: in some cases, when compressed air is dried to a deep dew point for applications that do not require it, this constitutes a waste of energy.

In fact, after all air consumers are switched off the network pressure should remain stable (if there are no leaks), and the compressors in stand-by should not switch to load condition. If there are leaks, instead, the network pressure will decrease, and when the minimum pressure is reached at least one compressor switches to load and delivers compressed air to bring the network back to the pressure set. This can happen several times over the period of stand-by.

4.2.7.4 Cross-media effects

Improving the efficiency of compressed air systems and the potential substitution of compressed air tools requires additional equipment and consequently generates environmental cross-media effects (e.g. from the use of natural resources, energy for manufacturing). However, these cross-media effects are considered to be not relevant for most of the approaches mentioned in 4.2.7.1 section. In fact, 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.

However, more caution is needed in the case of the installation of energy-efficient compressors or the substitution of compressed air tools with electrically driven devices. Here it has to be taken into account that electric motors usually require the use of critical metals in their magnets, especially neodymium. Neodymium is regarded as “critical raw material” in the EU; furthermore, its extraction is associated with heavy burden on the local environment (European Commission 2014; Schöler et al. 2011).

Additionally, the adoption of electrically driven devices instead of compressed air tools causes the generation of WEEE when the tools and batteries reach their end of life, while compressed air tools are typically easier to handle and recycle at their end of life.

4.2.7.5 Operational data

This section provides details for implementation and operational data for the different approaches presented in section 4.2.7.1.

Map and assess the use of compressed air

By analysing where and how compressed air is used, companies can:

- create an inventory of the needs in terms of air pressure, volume and quantity of the various end use devices;
- identify inappropriate use of compressed air (e.g. using blowguns to remove waste materials);
- assess the potential energy savings by comparing the use of pneumatic tools with electric tools for specific applications.

Concerning the latter, however, before eventually deciding to switch for certain end-uses from pneumatic tools to electric tools, EEE manufacturers need to carefully consider all environmental aspects as well as the specific advantages of pneumatic tools (e.g. durability, compact size, suitability for high loading, safety).

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 leaks. For example, a 10 mm air leak in a network operating at 6 bars causes power losses⁶³ of more than 30 kW (or more than 18,000 EUR per year). However, also relatively small leakages of only 1 mm in diameter should not be neglected.

Table 4.11. Air and power losses, with related costs, caused by air leaks

⁶³ Power losses represent the additional compressor power which would be needed to compensate the loss due to the air leak in order to keep delivering compressed air at the same flowrate and pressure.

Diameter of air leak (mm)	Air losses (l/s)		Power 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 ([Figure 4.14](#)). 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 4.14. Ultrasonic testing device with rod and parabolic microphone



Source: Miele

Desing and operate an energy efficient compressed air system

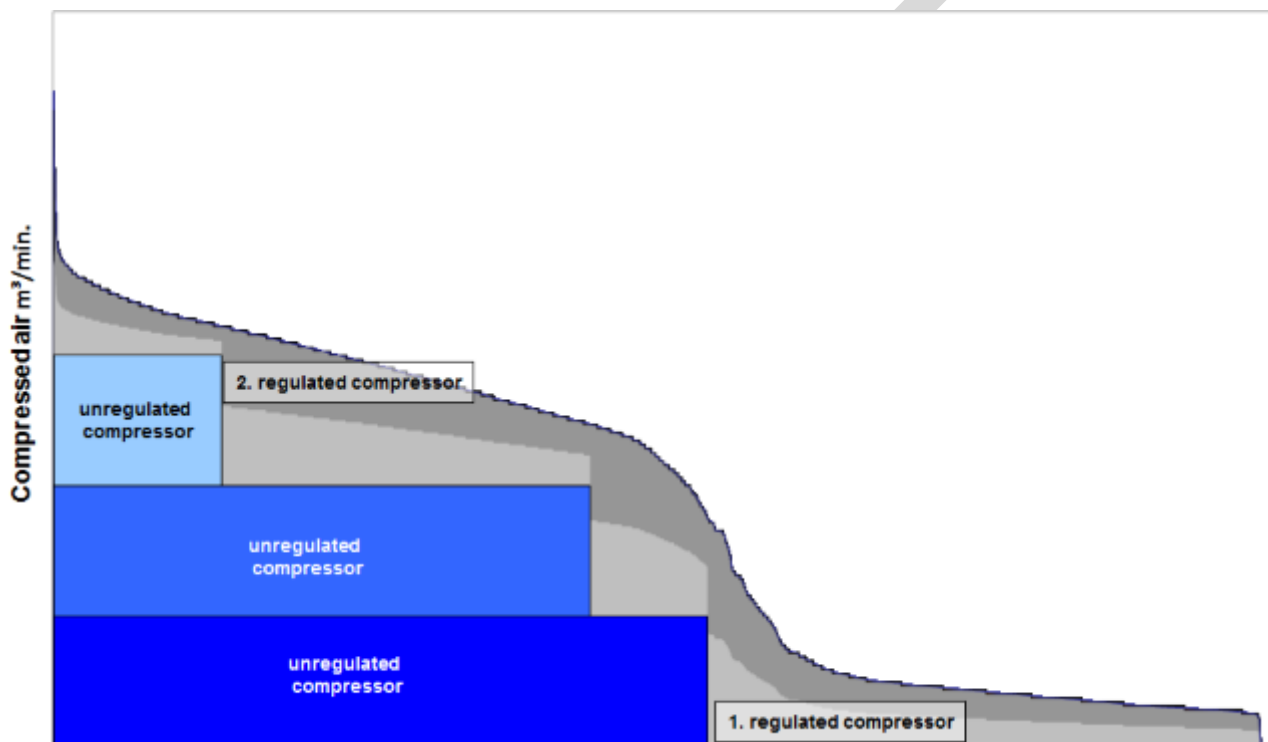
It is recommended to check the existing compressed air system in terms of possible improvements concerning overall energy efficiency, especially if the following reasons for pressure losses exist (Diemer & Feihl 2011):

- Too small hose 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 consumption 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 figure, 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 4.15. System design according to annual load duration curve



Source: Miele

Selection of highly efficient components for the compressed air system

In terms of compressor technology, the first step is an analysis of the technical requirements (e.g. pressure and volume needs) and the specific characteristics of the site. On these bases, the most suitable compressor technology can be selected, implementing a tailor made configuration. Particular attention needs to be given to the supply of compressed air at partial load.

Currently, the market of compressors 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, after a careful assessment of user needs and the specificities of the site, 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).

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 runs only when the compressor is operating. No continuous operation of

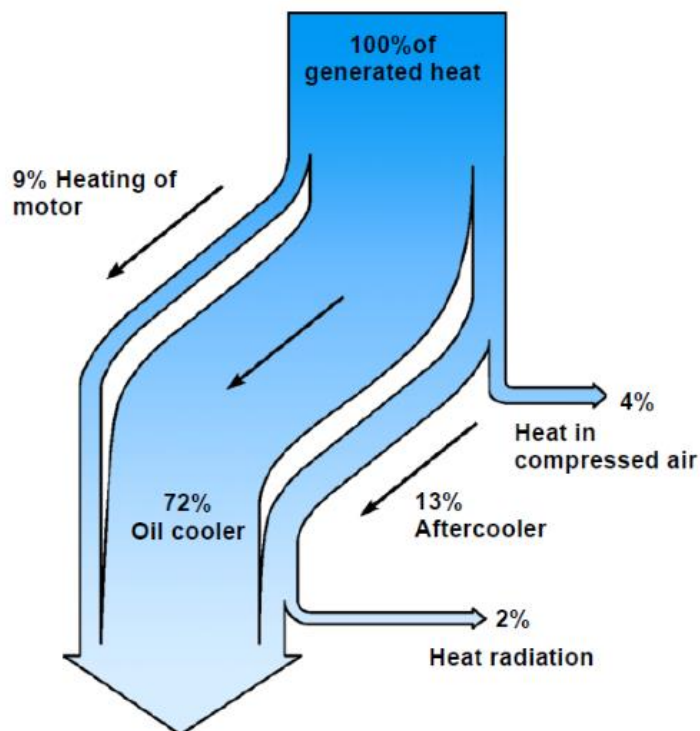
the dryer is necessary, because the cold storage provides cooling until the dryer has reached the operating point (Hermelingmeier 2014a).

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 power consumption can be exploited for heat recovery ([Figure 4.16](#)).

Figure 4.16. Potentials for waste heat recovery

Heat recovery



Source: BOGE (2008)

Before implementing any heat recovery solution, improving the energy efficiency of the compressed air system, by eliminating leaks and better matching supply and demand, is key in order to reduce the overall generation of waste heat. Once the waste heat generation from compressors has been minimised, waste heat recovery ensures a further improvement of the energy efficiency of the system. Demand of waste heat can have seasonal fluctuation which should be taken into account when calculating the payback times of the solutions planned and, additionally, reliability and efficiency of compressors should not be negatively affected by the heat recovery system.

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). It can be used for the drying of products, for regenerating the desiccant dryer and other similar purposes, or for space heating.

Another very interesting use of the waste heat from compressed air systems is the operation of an absorption chiller for air conditioning (see 4.2.2 BEMP on energy efficient cooling).

4.2.7.6 Applicability

The approaches described in this BEMP for reducing the energy consumption related to the use of compressed air systems are broadly applicable.

The guidance on optimization of system design is especially relevant for systems that have “grown” over decades (with implementation of extensions that were not originally planned) and that need revision. It is estimated that this approach is applicable for at least 50% of all compressed air systems (Radgen & Blaustein 2001).

Regarding the recovery of waste heat, a continuous demand for process heat is necessary in order to realise the corresponding energy and cost savings.

4.2.7.7 Economics

A German study of 59 firms detected potential energy and cost savings from improving their use of compressed air of, on average, 34%, with payback times between two and four years, depending on the individual age, size and state of the system (VDMA, 2005).

The following table shows typical payback times⁶⁴ for selected measures applicable for the European scope:

Table 4.12. 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

4.2.7.8 Driving force for implementation

The main driving force behind the approaches described in this BEMP is the corresponding economic savings. These can become very visible, also at management level, if companies account separately for the costs of compressed air, which also allows monitoring the success of the measures implemented. Moreover, the adoption of an energy management system according to ISO 50001, with its audits, is regarded to be another important driver for raising awareness about the importance of improving the energy efficiency of compressed air systems.

4.2.7.9 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 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.

⁶⁴ The typical payback times shown in the table are from a study published in 2001. Financial conditions may have changed since then.

4.2.7.10 Reference literature

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4.2.8 Protecting and enhancing biodiversity on-site

SUMMARY OVERVIEW						
<p>BEMP is to devise, implement and periodically review an action plan for protecting and enhancing biodiversity at the production facilities and in nearby areas. Examples of actions that can be included in the action plan are:</p> <ul style="list-style-type: none">- planting trees or reintroducing native species into a degraded natural environment;- surveying flora and fauna, with the aim of documenting and monitoring the state of biodiversity at a specific site;- allowing open land within a facility to “revert to nature”;- developing biotopes to create new habitats;- involving staff, their relatives and local communities in biodiversity projects.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">• Implementation of a site biodiversity action plan in all production facilities (y/n)• Land use – area (m2) of land within the production site and its assessed natural value (e.g. brown fields, areas adjacent to protected areas, areas of high biodiversity value)<ul style="list-style-type: none">– Area of protected or restored natural habitats within the production site, or outside but managed or protected by the manufacturer (m2)						
Applicability		The BEMP is broadly applicable to all electrical and electronic equipment manufacturers.				
Benchmarks of excellence		<ul style="list-style-type: none">– A biodiversity action plan is implemented in all production facilities to protect and enhance the state of biodiversity (flora and fauna) at the specific site				

4.2.8.1 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 "Achieved environmental benefits").

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.

Nonetheless, 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. It is therefore best practice for EEE manufacturers to protect and enhance biodiversity on-site and in nearby areas by formulating, implementing and reviewing an action plan which lists measures to be adopted and targets to be achieved.

Measures included in the action plan can involve concrete initiatives 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 eco-systems. 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 (this is further elaborated in a self-standing BEMP in section 5.2.5). 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 in the action plan 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, e.g. where employees can spend their lunch break.

On regular basis (e.g. every three years), the action plan for protecting and enhancing biodiversity on-site and nearby needs to be reviewed in light of the targets set (e.g. number of trees planted, areas reverted to nature, number of people involved in biodiversity projects). Following the revision, new actions and targets can be set with the aim of strengthening and improving biodiversity on site and nearby.

4.2.8.2 Achieved 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 creating better conditions for an plants and wildlife abundance. 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 on biodiversity of employees and nearby communities, 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).

4.2.8.3 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 "Operational data").

Measuring directly the protection and enhancement of biodiversity is not easy while a number of indicators can be used as proxy:

- Land use – area of land within the production site and its assessed natural value e.g. brown fields, areas adjacent to protected areas, areas of high biodiversity value (m²);
- Share of green/natural spaces in manufacturing facilities compared to the total land used (%);
- Area of protected or restored natural habitats within the production site, or outside but managed or protected by the manufacturer (m²);
- Implementation of a site biodiversity action plan in all production facilities (Y/N)

Front runners tend to monitor their efforts based on a checklist encompassing a number of actions along several dimensions, including e.g.:

- Land use - monitor the land used in production sites and assess its natural value (e.g. brown fields, adjacent to protected areas and areas of high biodiversity value outside protected areas);
- 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;
 - Develop green spaces and protect and restore natural habitats on manufacturing sites and, where relevant, create natural corridors for adjacent natural green spaces;

- Develop a strategy, analyse and define actions for reducing the impact of manufacturing activities on biodiversity;
- Implementation of greening efforts adjacent to factory premises, including species survey (e.g. number of IUCN Red List species and national conservation list species with habitats in areas affected by operations, by level of extinction risk) and effort to preserve and enhance biodiversity of ecosystems;
- Include protection of biodiversity in Research and Development (R&D) activities for new products, including also ex-situ aspects;
- 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.

4.2.8.4 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 assessable later.

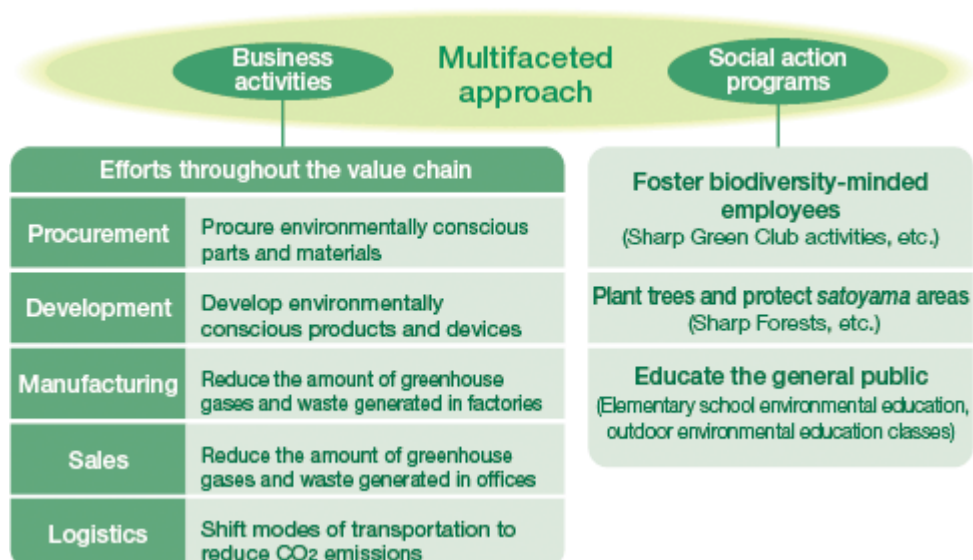
It is worth mentioning in this regard that SMF works with local organisations on the development of biodiversity-motivated action, and that this may have had a positive impact in light of the expertise and previous experience that personnel of such organisations bring with them. SMF emphasize that biodiversity 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).

4.2.8.5 Operational data

Possible initiatives to protect and enhance biodiversity at an enterprise's site 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.

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-faceted approach ([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-faceted 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 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 precautionary 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 (further elaborated in section 5.2.5).

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,⁶⁵ 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

⁶⁵ 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.

acorn seedlings. For FY 2012, employees planted Japanese irises, the official flower of Kameyama City (Sharp 2013).

Sharp details 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);
- 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;

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 makes an effort to reduce the adverse impact of business activities on biodiversity, as well as to promote forest ecosystem conservation with employees' volunteer activities.⁶⁶

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.

⁶⁶ For further details see <http://www.ricoh.com/environment/biodiversity/outline.html>

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 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 m² 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.

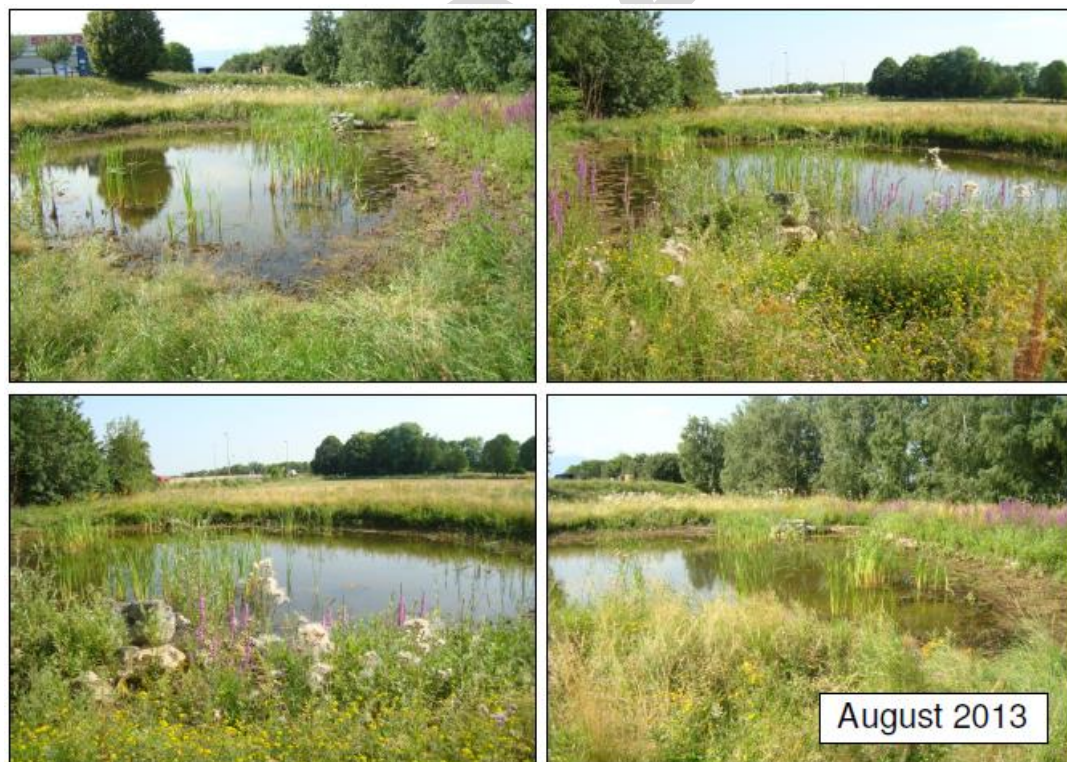
In some cases, such on-site monitoring may be as simple as photographic documentation for the purpose of comparing stages of progress, such as in the documentation prepared on the development of a biotope-pond on the SMF facility grounds, which is presented in [Figure 4.18](#) (SMF 2014).

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.

4.2.8.6 Applicability

From a review of sustainability reports, it is observed that most EEE enterprises have only started to become proactive in the implementation of practices for enriching and conserving biodiversity within or 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 the section "Operational data".

From communication with SMF, it is understood that smaller projects can be implemented at manufacturing facilities with relatively low financing (see section "Economics" below), through cooperation 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 at 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, this practice is not only relevant for 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 "Operational data", 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.

4.2.8.7 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.

4.2.8.8 Driving force for implementation

A major driving force for protecting and enhancing biodiversity can be seen in legislation or local plans that already exist in some countries and regions and prescribe activities for maintaining or preserving the natural environment. For instance, the biosphere reserve

concept⁶⁷ 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 Targets⁶⁸ 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.

4.2.8.9 Reference organisations

All these companies have implemented measures to protect and enhance biodiversity in their production facilities:

- Ricoh⁶⁹
- Philips⁷⁰
- Sharp
- Lexmark⁷¹

4.2.8.10 Reference literature

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⁶⁷ For detail please see <http://www.nrdc.org/land/wilderness/fbios.asp>

⁶⁸ 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>

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

⁷⁰ For further details see <http://www.philips.com/about/sustainability/ourenvironmentalapproach/biodiversity/index.page>

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4.2.9 Use of renewable energy

SUMMARY OVERVIEW						
BEMP is for electrical and electronic equipment manufacturing companies to use renewable energy for their processes thanks to:						
<div><div></div><div><ul style="list-style-type: none">- purchase of verified-additional renewable electricity or own generation of electricity from renewable energy sources;- own production of heat from renewable energy sources.</div></div>						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<div><div></div><div><ul style="list-style-type: none">• Share of electricity from renewable sources (own generated or purchased with verified additionality) out of the total electricity use (%)• Share of heat from renewable sources out of the total use of heat (%)</div></div>						
Applicability		<div><div></div><div><p>This BEMP is broadly applicable to all companies of the sector.</p><p>Use of renewable electricity (own generated or purchased) is generally possible in all cases.</p><p>Integration of heat from renewable sources in EEE manufacturing processes, instead, is more difficult due to their complexity, the need of high temperatures, and, in some cases, incompatibility between heat demand and seasonality of renewable heat offer.</p></div></div>				
Benchmarks of excellence		N/A				

4.2.9.1 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 – 4.2.33), this BEMP is focused 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 verified green electricity or own production of electricity from renewable energy sources;
- Own production of heat from renewable energy sources.

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 an environmentally friendly option if this green electricity creates an additional environmental benefit.

To begin with, this includes verifying 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 own produced or purchased green electricity, the installation of heat technologies provides 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, 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.

4.2.9.2 Achieved 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 that the electricity fuel mix corresponds 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 CO₂-eq/MWh, whereas in Austria only 0.26-0.29 t CO₂-eq/MWh can be saved ([Table 4.13](#)).

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 CO₂-eq/MWh
Photovoltaic	0.020-0.050
Wind power	0.007
Hydropower	0.024
National mission factors for consumed electricity	
Country	t CO₂-eq/MWh
Austria	0.310
Belgium	0.402
Germany	0.706
Denmark	0.760
Spain	0.639
Finland	0.418
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 Covenant 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 CO₂ 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)

4.2.9.3 Appropriate environmental performance indicators

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 (own generated or purchased with verified additionality) out of the total electricity use (%);
- Greenhouse gas emissions (in CO₂-equivalents) of the company-specific electricity mix.

In analogy to electricity, the use of heat from renewable energy sources should be monitored by the following metrics:

- Share of heat from renewable sources out of the total use of heat (%);
- Greenhouse gas emissions (in CO₂-equivalents) of the company-specific heat energy mix.

4.2.9.4 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). [Table 4.14](#) 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.

4.2.9.5 Operational data

According to the different approaches mentioned in the section "Description", 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 section "Description"), the following options for green electricity have been distinguished by Rüdener 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 match approximately 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-CHP⁷², 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 eligibility⁷³ or additionality⁷⁴. Requirements on these criteria might refer directly to the supplying power plants or to a fund⁷⁵ fed by the green product.

Green version 3: 100% RES-E, including accessory requirements. Again, the accessory requirements refer to either eligibility or additionality, whereas requirements on these criteria might refer directly to the supplying power plants or to a fund 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/m², 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

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 the temperatures of 100°C, especially in Southern European climates. (Schweiger et al. n.y.)

⁷² As reference values for calculation of efficiency highly efficient combined heat and power generation (HE-CHP) plants according to the CHP Directive (Article 4).

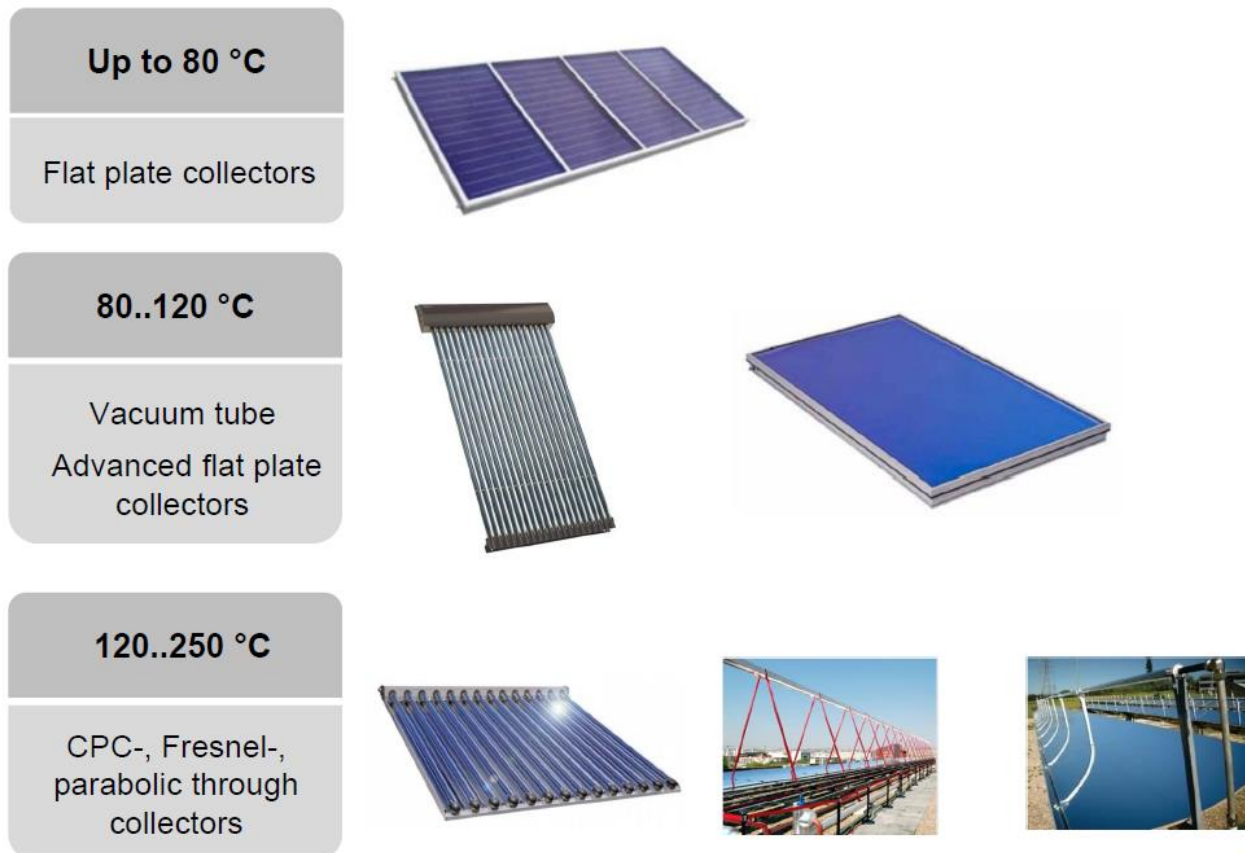
⁷³ Eligibility comprises requirements in order to reduce the environmental impact of specific renewable energy sources (such as hydropower or biomass) or technologies and usually refers to nature conservation.

⁷⁴ 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.

⁷⁵ 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.ecotopen.de/download_forschungsberichte.php)

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 manufacturing sector⁷⁶).

⁷⁶ More information at: <http://susproc.jrc.ec.europa.eu/activities/emas/documents/FoodBeverageBEMP.pdf>

4.2.9.6 Applicability

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

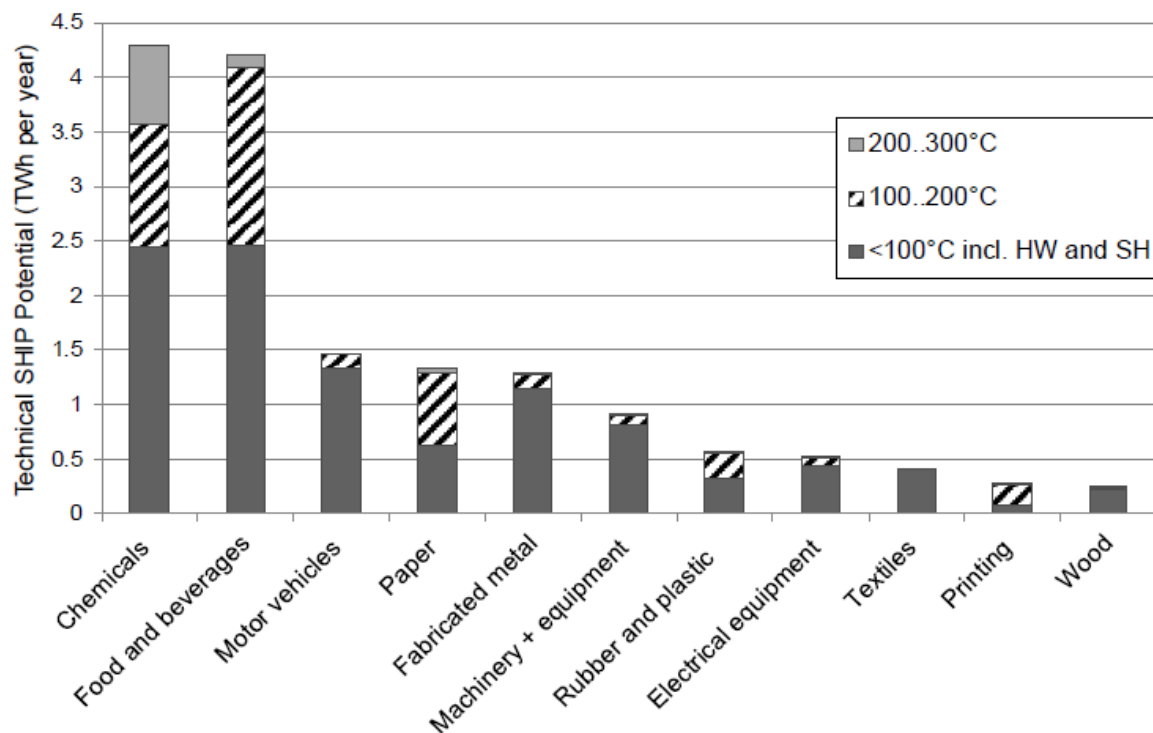
- Sweden, for example, already has a high share of hydropower. Thus, fossil CHP, being part of green version 2, is not perceived as a green option at all. Similar, additionality criteria aiming at further extension of RES-E production capacities are not requested by consumers. The focus of green electricity 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, the focus is on decreasing CO₂ 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 CO₂ emissions compared to the coal-dominated national electricity mix.
- The same considerations presented for Germany 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.

Consumption of own generated renewable energy is accounted differently in various Member States, however, this is not a barrier to the adoption of on-site renewable energy generation. In fact, how the use and generation of energy is accounted affects the company only in the calculation of the energy bill and the available feed-in tariffs.

In terms of renewable heat, a number of challenges limit its applicability in the EEE manufacturing sector. Besides economic aspects (see section "Economics" for more details), integration of heat from renewable sources in EEE manufacturing processes is more difficult due to their complexity, the need of high temperatures, and, in some cases incompatibility between heat demand and seasonality of renewable heat offer (Carbontrust 2014).

In contrast to other sectors (like e.g. food and beverages manufacturing), 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 CHP plants that have been recently installed at a number of EEE production sites (see also section "Economics"). 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 "Operational data"). As a result and illustrated by [Figure 4.20](#), 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

4.2.9.7 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. [Table 4.15](#) 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 "Operational data"):

Table 4.15. Additional Charges for the Three Green versions (GV) Relative to 'Grey' Electricity

Member State	Baseline price [€/MWh]		Additional charge [€/MWh]		Remark
	'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 additionality (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)

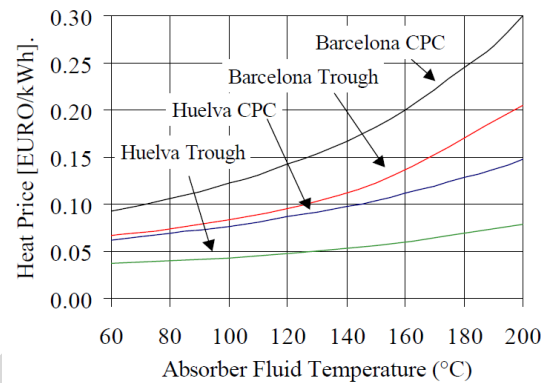
According to this assessment, the additional charges for the three green product versions, relative to the baseline price for grey electricity, account for 0-18% of the baseline price,

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 100°C heat costs are in the range of 0.04-0.12 EUR/kWh (Schweiger et al. n.y.). [Figure 4.21](#) indicates the heat prices from CPC (Compound Parabolic Collector) devices a function of mean collector fluid temperature for different locations in Spain.

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.).

Figure 4.21. Heat prices as a function of mean collector fluid temperature

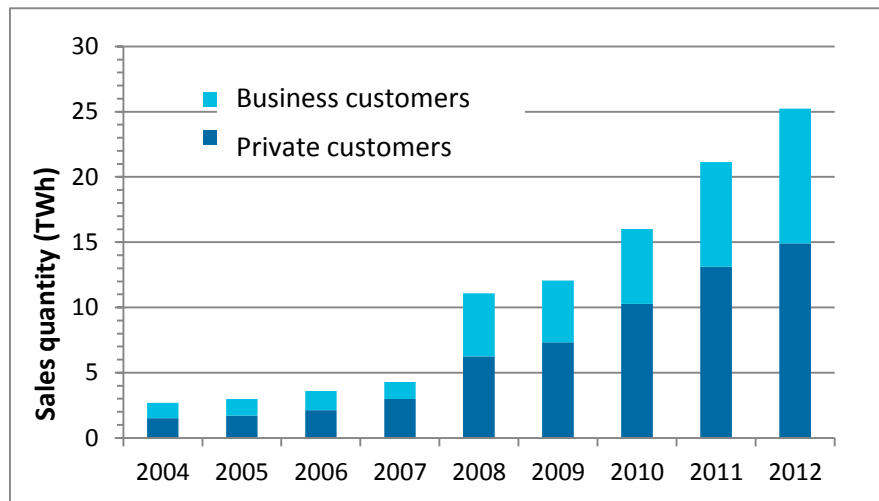


Source: Schweiger et al. n.y.

4.2.9.8 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). 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 "Achieved environmental benefits") are "Grüner Strom Label" and "ok-power" (EnergieVision & Grüner Strom Label 2000).

Figure 4.22. Sales Quantity of Green Electricity in Germany



Source: Moeller M. et al., 2015

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. 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 CO₂ 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 CO₂ 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 organisations 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 it is thus still in its infancy.

In order to overcome the barriers concerning the use of renewable heat mentioned in section "Applicability", 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).

4.2.9.9 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 has 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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4.2.10 Optimised waste management within manufacturing facilities

SUMMARY OVERVIEW						
BEMP is for electrical and electronic equipment manufacturers to develop and implement a waste management strategy that prioritises other treatment options than disposal for all the waste generated at the manufacturing facilities and follows the waste hierarchy ⁷⁷ . This strategy needs to encompass both non-hazardous and hazardous waste fractions, set ambitious targets for improvement and monitor them, and also explore possibilities to implement the approach of industrial symbiosis.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">• Development and implementation of an effective waste management strategy (yes / no)• Share of sites with a waste management strategy in place (%)• Landfill diversion rate = $\frac{\text{weight of waste sent for recycling}}{\text{total waste generation}}$ (%)• For a specific product or product range, waste generation per metric ton of product or other suitable functional unit (kg/t)						
Applicability		This BEMP is broadly applicable to all EEE manufacturing companies. Limiting factors for the effective implementation of industrial symbiosis are the need for communication and coordination among different companies, i.e. lack of knowledge and insight in other companies' activities and thus potential valorisation routes for waste and by-products.				
Benchmarks of excellence		<ul style="list-style-type: none">• The company has a waste management strategy in place in all sites• The company achieves a landfill diversion rate of 93% on average across all manufacturing plants				

4.2.10.1 Description

Waste from the manufacturing of EEE can be roughly differentiated into two major fractions:

A fraction similar to municipal solid waste (MSW) contains waste from packaging, paper, glass, wood, organics etc., but also metal scrap and construction waste at times of site development and expansion.

The other fraction consists of hazardous waste generated from the various processes as well as sludge and filter dust resulting from the treatment of other emissions (water, air).

Concerning volume, usually about half of the waste is hazardous, the disposal of which is specially regulated, whereas the other half is non-hazardous (Infineon 2016; Intel 2016).

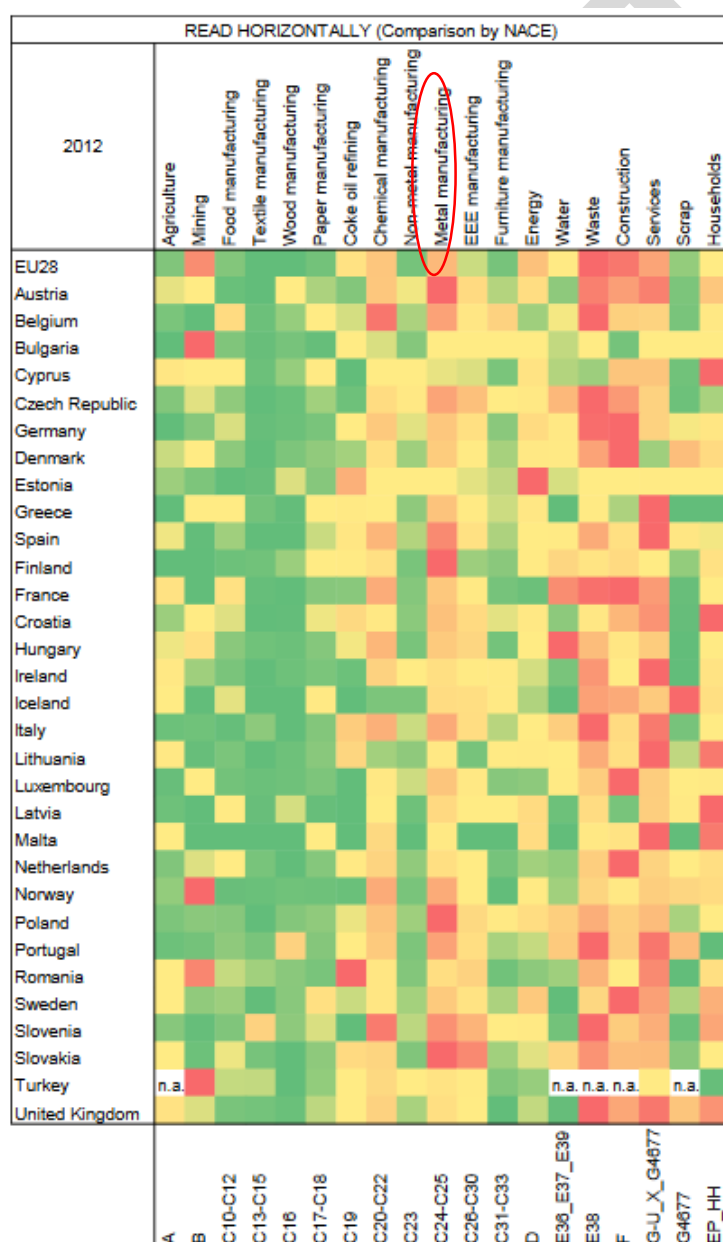
⁷⁷ The Waste Framework Directive (Directive 2008/98/EC) introduces an order of preference for action to reduce and manage waste. This is known as the waste hierarchy. It set the highest priority on waste prevention, followed by waste re-use, then recycling and then (energy) recovery of waste fractions that cannot be prevented, re-used or recycled. Finally, waste disposal is only to be considered when none of the previous routes are possible.

For non-hazardous waste, several management options exist, but in some EU countries (e.g. Bulgaria, Czech Republic, Ireland, Spain and UK) landfilling still plays an important role.

As for hazardous waste, landfilling is still the dominant management route in Europe (with 48% of the treated amount in 2012), followed by recovery (so-called 'backfilling' without energy recovery, encompassing 28% of the treated amount) and incineration (with and without energy recovery, each accounting for approx. 5% of the treated amount) (EEA 2015).

When comparing the generated amount of hazardous waste of the EEE sector with other branches of the economy (**Mapping of hazardous waste generation in EU-28 member countries, IS, NO and TR** Figure 4.23), significant levels can be observed in countries like the Czech Republic, Slovenia and Slovakia, many of which are characterised by a waste management system where landfilling predominates (see above). For example, only in the Czech Republic approx. 147.000 tonnes of hazardous waste are generated by EEE companies per year (EEA 2015).

Figure 4.23. Mapping of hazardous waste generation in EU-28 member countries, IS, NO and TR



Note: Red cell indicates the highest level of hazardous waste generated and the green the lowest. "n.a." represents missing data.

Source: EEA 2015

Against this background, it is considered to be best environmental management practice to put in place a company-specific **waste management strategy** that prioritises other treatment options than disposal for waste generated at EEE manufacturing facilities. This strategy needs to encompass both the non-hazardous and hazardous fractions and can be structured as a 5-step approach: (i) Starting with a waste audit, it should include (ii) the calculation of the key performance indicators as introduced in section 4.2.10.3 as well as the (iii) implementation of an action plan; it should also address (iv) the selection of competent waste management companies and (v) the communication of the strategy to both internal and external stakeholders. Finally, a periodic revision of the strategy in light of the achieved results needs also to be planned.

In general, the waste management strategy needs to set clear priorities concerning treatment options for the different waste fractions, thus enabling the highest possible environmental benefit. Within this context, the Waste Framework Directive (Directive 2008/98/EC) introduces an order of preference for action to reduce and manage waste. This is known as the waste hierarchy (Figure 4.24).

Figure 4.24. Hierarchy of waste management options according to Directive 2008/98/EC



Source: EU 2008

According to the waste hierarchy, the waste management strategy developed and implemented by EEE manufacturers should set the highest priority on waste prevention and re-use, followed by recycling and, then, (energy) recovery of waste fractions that cannot be prevented, re-used or recycled.

The waste management strategy needs to set ambitious targets for improvements and monitor them. Moreover, it should consider innovative waste management approaches such as industrial symbiosis (i.e. local, regional or virtual networks for the use of the by-products generated from the production processes). A meaningful implementation of industrial symbiosis in the EEE manufacturing sector can be achieved by providing other companies with by-products that they can use as input materials, or, respectively, by using by-products from other companies. The partner company does not necessarily need to belong to the EEE sector. Suitable materials include re-used / refurbished components from other EEE, but also materials (like metal sections, wood, etc.) from other sources that can be used, for instance, for the casing of electric or electronic appliances.

4.2.10.2 Achieved environmental benefits

Implementing an effective waste management strategy yields several environmental benefits.

First of all, each waste prevention measure is an active contribution to increasing resource efficiency. If waste from EEE manufacturing is prevented or re-used in other business operations, fewer resources are required from an overall perspective. Some of those resources would be difficult to recycle: for instance, the metal waste fraction of EEE manufacturing

processes often contains critical metals (e.g. palladium, platinum, silver) or rare earths (e.g. iridium, dysprosium, indium) that can be – if at all – only partly recycled and would be subject to dissipation if landfilled.

Reducing the amount of the disposed waste also decreases the impacts from waste handling and treatment (especially transports, waste incineration and disposal), resulting in lower emissions to air, water and soil. Especially in case of disposal of waste in landfills, and if no control measures (e.g. gas control system, leachate collection and removal system) exist or these are not fully effective, the environmental benefits of avoiding disposal are very significant.

4.2.10.3 *Appropriate environmental performance indicators*

Environmental performance indicators need to cover the implementation of a waste management strategy in the first place:

Metrics	Description
yes/no	Development and implementation of an effective waste management strategy
%	Sites with a waste management strategy in place

In order to monitor the effectiveness of the strategy, the indicators need to cover also the results in terms of minimisation of disposal. Within this context, the landfill diversion rate is one of the key parameters. It represents the amount of waste that is diverted from landfill and sent for recycling. It is calculated by dividing the amount of material sent for recycling by the total amount of waste generated:

Metrics	Description
%	landfill diversion rate = $\frac{\text{weight of waste sent for recycling}}{\text{total waste generation}}$

This metric is often also referred to as recycling rate; it should be differentiated according to the two major waste fractions (hazardous and non-hazardous waste) and / or the most important materials of the waste stream, e.g.:

- Metal scrap (from machinery and products);
- Polymers (from products and packaging);
- Chemicals (from production processes);
- Wood (from transport and packaging) and
- Construction waste (from site development and expansion).

It is also useful to define a metric that helps to quantify and monitor the improvements on the product level, whereby the issue of waste prevention is addressed. This indicator is the specific waste generation:

Metrics	Description
$\frac{kg}{t}$ or $\frac{kg}{f.u.}$	For a specific product or product range, waste generation per metric ton of product or other suitable functional unit (f.u.), e.g. cm ² of wafer surface or m ² of printed circuit board surface

4.2.10.4 *Cross-media effects*

When implementing measures according to the waste hierarchy, such as re-use and recycling, the corresponding processes often require significant amounts of energy. This is particularly relevant for processes like collection, dismantling, conditioning, refurbishing, smelting of metals or re-granulating of polymers.

However, when assessing the overall input-output balance, the required amounts of energy are generally overcompensated by the energy (as well as resource and other) savings that are created by the re-used products and secondary resources.

A good example is the recycling of polymers. A recent study that investigated the life cycle environmental impacts associated with the production of post-consumer recycling plastics from the mixed plastics-rich WEEE comes to the conclusion that the recycling of plastics results in a global warming potential and a fossil depletion potential that is five to six times lower than that of the virgin plastics production. Also the other LCA impact categories (like acidification, eutrophication, human toxicity and eco-toxicity, etc.) are significantly lower (Wäger & Hirsch 2015).

4.2.10.5 Operational data

This section provides further details and operational data on the two measures introduced in the 'Description' section.

Development of a waste management strategy

The development of a waste management strategy can be structured as a 5-step approach (see also CIPS 2007):

- Starting from a **review of the specific legislation** for the waste produced in the manufacturing processes and an analysis of the role that waste plays within the overall environmental issues, it is recommended to perform a **waste audit**. Such an investigation forms the initial step and aims to quantify and identify the different fractions (for both hazardous and non-hazardous waste) and origins of the waste. Parallel to the physical metrics (kg, m³) also the corresponding costs should be identified and quantified. In practical terms, all of the waste generated (both for disposal and for recycling) during a specified period of time (usually 24 hours) needs to be weighted.
- Taking into account the waste hierarchy (see 'description' section above), it needs to be identified in a second step what currently happens to the waste as soon as it arises. Part of this exercise is the **calculation and interpretation of the key performance indicators** as presented in section 4.2.10.3.
- Within a third step, an **action plan** for reducing the different waste fractions needs to be developed, including targets for improvements for the major waste streams. According to the waste hierarchy, a clear focus on measurements and targets should be set on waste prevention and re-use. A crucial point of this step is to get the commitment from the top management of the company for the envisaged targets and corresponding measures. Concerning printed circuit board manufacturing, for example, etching materials (such as hydrochloric acid or copper salts) can be treated and reused in other areas of the process system (see section 4.2.4); furthermore, recyclable metal-based solutions are reprocessed (Würth Elektronik 2016).
- The fourth step refers to the organisational implementation of the waste strategy. As part of this step, the different **waste management companies** need to be selected carefully. Moreover, the existing contracts need to be revised. For front-running companies like Miele, an important criterion within the selection process of a service provider is the ability to guarantee a consistent waste sorting, e.g. the clean separation of foil and plastic without any mixing or the improved separation of cardboard and paper (Miele 2015). Furthermore, it is important to monitor the achievements using currently updated key performance indicators.
- Last but not least, the achievements should be **communicated** to the staff and senior managers as well as outside of the organisation to interested stakeholders (CIPS 2007). This should not be perceived as the final step, but rather as a corollary process from the beginning and includes the communication about the goal and scope of the waste management strategy itself. Any feedback from **internal and external stakeholders** should be considered with a view to the continuous improvement of the strategy.

Industrial symbiosis

Industrial Symbiosis is a promising integrated concept for industrial cooperation (European Commission 2015). This concept represents a shift from the traditional industrial model in which waste is considered the norm, to a circular economy in which all streams are valorised. Within this approach, waste and by-products generated in various manufacturing processes are converted into value-added inputs for other industries or processes so as to ensure that overall no (or virtually no) waste is generated. This results in a synergistic exchange of waste, by-products, water and energy between individual companies in a locality, region or even in a virtual community (European Commission 2016a, European Commission 2016b).

The overall interest in this concept has grown steadily in recent years, and industrial symbiosis networks are now operational in several EU and non-EU countries (European Commission 2015). While in other sectors such as the ferrous and non-ferrous industry as well as in food processing, construction and demolition, wood processing, paper and pulp, and chemistry (European Commission 2016b), industrial symbiosis is growing, in EEE manufacturing it can be considered to constitute best environmental management practice as it is only observed in very few cases.

In general, a meaningful implementation of industrial symbiosis in the EEE manufacturing sector can be achieved by EEE manufacturers providing other companies with by-products that they can use as input materials or, respectively, by using by-products from other companies. The partner company need not necessarily belong to the EEE sector.

One example that refers to the user side of industrial symbiosis is the use of by-products and reused components for computer manufacturing. Over the past years, the Irish company MicroPro Computer Systems has developed a touchscreen computer and a laptop combining eco-design with an increased lifetime and reuse potential of the computer, in order to minimise waste throughout the lifecycle and across the supply chain. In the case of the 'D4R' laptop (based on the principles of design for Recycling, Re-use, Repair & Refurbishment), MicroPro made use of by-products from other companies along the supply chain, including reused components from existing computers recovered by social economy enterprises. The D4R laptop uses wood by-products from furniture companies and recycled industrial aluminium for the housing, and facilitates the use of reused parts and components, including the LED screen, the hard drive, the memory, the power supply etc. (European Commission 2016b).

4.2.10.6 *Applicability*

This BEMP, and especially the development and implementation of a waste management strategy, is applicable to all EEE manufacturing companies.

Due to existing differences regarding the regulatory framework and waste management practice in EU-28, the implemented measures should take into consideration the availability of local waste management and waste treatment infrastructures and the local waste regulation.

Innovative approaches such as industrial symbiosis might be hampered in member states or regions where the necessary networks or circumstances for this approach do not exist. This is relevant in cases of high transport costs, dispersed production structures and sub-optimal scale economies. If waste or by-products have to be transported over long distances, the economic feasibility of the whole approach declines, and thus the geographical range of influence for industrial symbiosis activities is rather limited. Transport costs have been reported as the restricting aspect for several waste materials (such as wood waste, construction waste and non-scrap metal waste) with a relatively high volume-to-value ratio (European Commission 2016a).

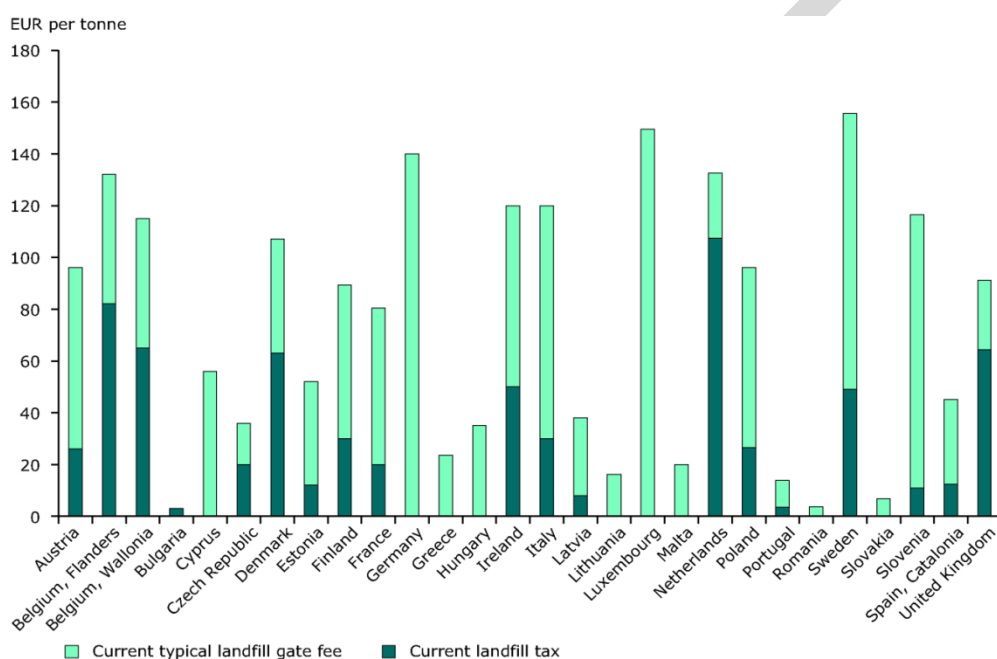
Another limiting factor for a wide-spread applicability of industrial symbiosis can be seen in coordination problems. This problem arises from the lack of knowledge and insight in potential valorisation routes for waste and by-products. Furthermore, it is often difficult to find sufficient information on where potential partners, clients, and marketable applications can be found. This phenomenon can be observed not only in SME-dominated markets. Besides company size, industry characteristics and the inter-sectoral character of waste valorisation are also important factors. For example, major valorisation routes are often located in other sectors, and looking beyond the borders of a specific sector often implies entering unknown realms (European Commission 2016a).

Beyond the above-mentioned complex obstacles on the inter-sectoral level, the applicability of a more stringent waste management with higher recycling rates might also be hampered by rather basic limitations on the company level. For example, if the workplaces of a company lack sufficient space for containers that are necessary for separate collection of waste, successful source separation that allows recycling may require much more efforts.

4.2.10.7 Economics

On a general level reducing, reusing, recycling and recovering waste cut waste management costs, and even generate revenues. Savings can arise especially from prevented costs for disposal / landfilling. Currently, the average landfill charge for EU-28 is approx. 80 EUR/tonne (CEWEP 2014). However, the spectrum ranges from few Euros per tonne in Bulgaria and Romania to approx. 150 euros per tonne in Sweden (see following figure).

Figure 4.25. Typical charge (gate fee and landfill tax) for legal landfilling of non-hazardous municipal waste in EU Member States and regions



Source: EEA 2013

Within this context, it is clear that the economic feasibility for implementing this BEMP is highly dependent on the location of the manufacturing plant where the waste arises.

Another factor contributing to this, is that the costs that are associated with the development and implementation of a waste management strategy are dominated by staff costs, thus dependent on local labour costs as well as on the level of management structures that already exist in the company concerning environmental issues.

Finally, the specific actions to be implemented are largely determined by the specific activities carried out in the plant, the input material that is used during manufacturing, and the waste operations carried out on-site. Due to their diversity from company to company and plant to plant, the costs and benefits need to be calculated and evaluated on a case-by-case basis.

4.2.10.8 Driving force for implementation

For many companies, the dominating rationale for the implementation of this BEMP, is rising costs / fees for waste treatment, and especially disposal / landfilling (see 'Economics' section).

Another economic driving force derives from the costs for resources: after some decline in recent years, they increased again to very high levels for many resources (e.g. gold and silver, being very relevant for the EEE manufacturing sector). Hence, efforts in improving circularity are driven by the fact that a company can often save money if it can save resources.

Besides the economic rationale, relevant driving forces for optimised waste management can be observed on the political level. In its communication titled 'Closing the loop - An EU action plan for the Circular Economy', the European Commission encourages practices aimed at transitioning "to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised" (European Commission 2016c).

Furthermore, better waste management can also be fostered by the 'sharing economy' approach and the establishment of a 'culture of collaboration': collaboration between companies and the synergistic possibilities offered by geographical proximity, such as industrial symbiosis, are key waste minimizing approaches. Existing networks dedicated to industrial symbiosis aim to provide support for companies by organising dedicated matchmaking events, developing resource databases, informing about valorisation opportunities, as well as creating trust and disseminating showcases to members. Examples of publicly supported initiatives include the Kalundborg region in Denmark, SMILE Resource Exchange in Ireland, the National Industrial Symbiosis Programme (NISP) in the UK as well as Borsa de subproductes de Catalunya in Spain (European Commission 2016b).

4.2.10.9 *Reference organisations*

The following examples of organisations that have successfully implemented this BEMP:

- AT&S: The Austrian manufacturer of printed circuit boards attaches great importance to waste separation (AT&S 2016).
- Infineon: Waste is collected separately wherever possible at the point where it is produced. During the 2015 fiscal year, a new waste collection centre went into operation at the Villach site in Austria with the aim of improving waste logistics. The centre covers a total area of 1,600 square meters. As a result, approx. 66% of the waste generated at all company sites is recycled. The specific waste generation is aimed to be kept below 27.5 grams / cm² of wafer manufactured. Compared to the sector average, Infineon sites generate 50% less waste (Infineon 2016).
- Intel: Since 2008, Intel has recycled more than 75% of the total waste generated in their operations. The objective of the company is to recycle 90% of the non-hazardous waste fraction, and to divert all hazardous waste from landfills by 2020. In order to achieve this goal, the company has implemented several programmes to reduce, reuse, and recycle non-hazardous waste, including donating materials to schools and non-profits. Several sites, e.g. including facilities in Ireland, have already achieved recycling rates above 90%. On the company level, 82% of the non-hazardous waste was recycled in 2015. In the same year, Intel sent less than 2% of the hazardous waste to landfill sites, and is thus on track to achieve its corresponding goal. To achieve zero hazardous waste to landfill by 2020, multiple groups across Intel are working to identify innovative ways to treat or eliminate waste streams, or even convert them into sources of revenue (Intel 2016).
- MicroPro Computer Systems: The Irish company has implemented the approach of industrial symbiosis at the level of the manufacture of a touchscreen computer ('D4R') and a laptop. By-products from other companies along the supply chain were used, including reused components from existing computers recovered by social economy enterprises. The D4R laptop uses wood by-products from furniture companies and recycled industrial aluminium for the housing, and facilitates the use of reused parts and components, including the LED screen, the hard drive, the memory, the power supply etc. (European Commission 2016b).
- Miele: In fiscal year 2013/2014, the average recycling rate for all plants was 93%, and thus almost reached the existing goal of 95%. The current specific waste generation accounts for approx. 157 kg/tonne of product (Miele 2015).
- Würth Elektronik: Waste is separated at the company's own recycling station and is recycled or disposed of by certified disposal companies. About 88% of the recycled solutions are returned to Würth Elektronik. All in all, 97% of all waste produced in the circuit board plants is recycled (Würth Elektronik 2016).

4.2.10.10 Reference literature

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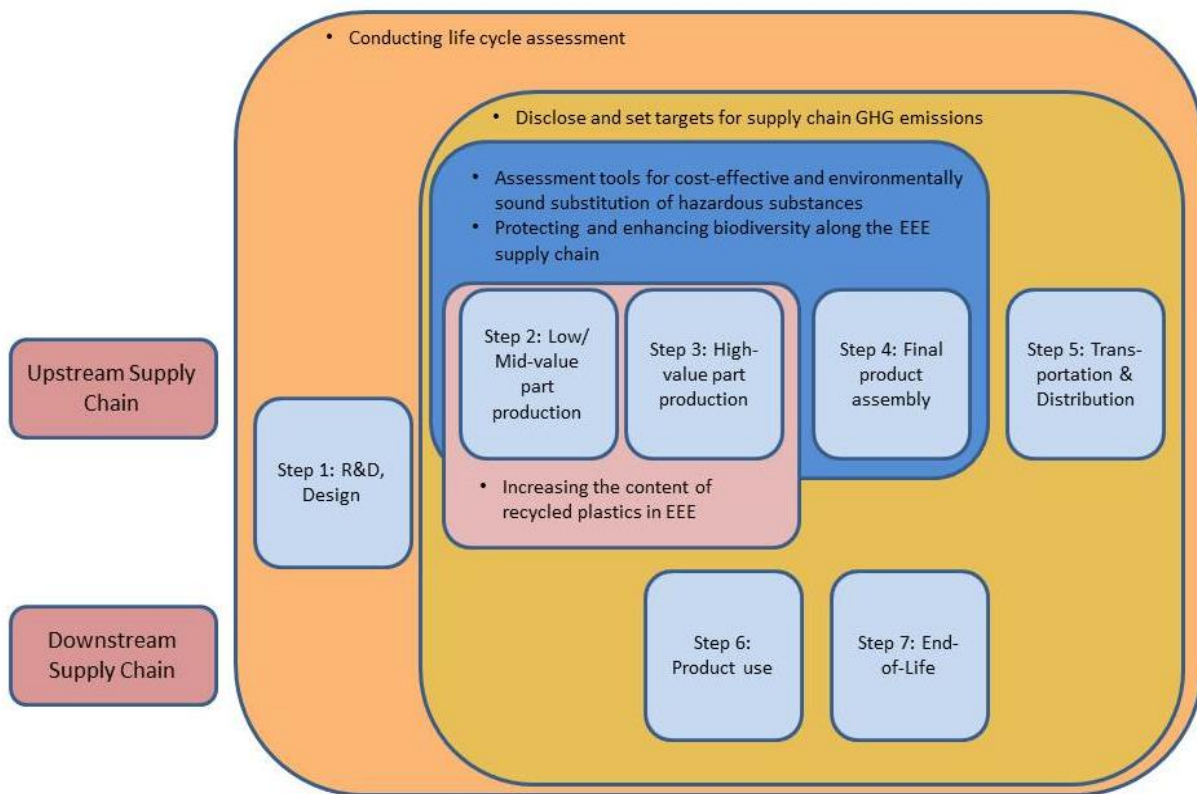
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5 BEMPs for supply chain management

5.1 Techniques portfolio

The scope of this chapter encompasses activities at various stages of the supply chain of EEE manufacturers. As supply chains of EEE are very complex networks with many different actors 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. [Figure 5.1](#) below gives a simplified illustration of the focus of each enclosed supply chain management BEMPs:

Figure 5.1. Schematic overview of the scope of the supply chain BEMPs



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 (see BEMP on “Disclose and set targets for supply chain GHG emissions” (section 5.2.2). Even today (end of 2016), 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 CO₂e, 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, 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. The brominated flame retardants TBAs often used as a reactive substance to form brominated epoxy resins for

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)⁷⁸. There are a number of assessment tools which allow sound substitution of hazardous substances and these are described in the specific BEMP.

Overall environmental impacts in the supply chain can also be reduced by reducing the use of virgin resources. The BEMP on increasing the content of recycled plastics in the EEE products shows the way to decrease the demand for virgin materials – in this case crude oil.

In addition, 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. Therefore, thanks to LCA, life-cycle based environmental impacts can be assessed and appropriate strategies/techniques that reduce them can be identified (see BEMP on "Conducting Life Cycle Assessment, BEMP 5.2.3).

Finally, the protection and enhancement of biodiversity in the supply chain is a key area of action for EEE manufacturers. As presented in the specific BEMP (section 5.2.5), there are a number of actions which can be implemented by EEE manufacturers in order to affect and improve the biodiversity at the suppliers' sites.

Against this background, [Table 5.1](#) gives an overview of the developed BEMPs for the supply chain management of EEE manufacturers and the addressed environmental pressures.

Table 5.1. Overview of the Developed BEMPs for EEE Supply Chain Management and the Addressed Environmental Pressures

No.	BEMP	Environmental pressures addressed						
		Resource efficiency	Water	Waste	Emissions to air	Energy & climate change	Biodiversity	Hazardous substances
5.2.1	Assessment tools for cost-effective and environmentally sound substitution of hazardous substances							X
5.2.2	Disclose and set targets for supply chain GHG emissions					X		
5.2.3	Conducting Life Cycle Assessment		X	X	X	X		
5.2.4	Increasing the content of recycled plastics in EEE	X				X		
5.2.5	Protecting and enhancing biodiversity along the EEE supply chain						X	

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

⁷⁸ 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

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. For instance, the supply chain of Hewlett-Packard (HP), 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](#)):

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.

5.2.1 Assessment tools for cost-effective and environmentally sound substitution of hazardous substances

SUMMARY OVERVIEW						
<p>BEMP is to use reference tools to identify hazardous substances in purchased materials in order to substitute them, focussing on three key steps:</p> <ul style="list-style-type: none">• <u>Clarification</u> of whether the substance under discussion is a substance of very high concern (based on the REACH Candidate List), in which case substitution has high priority.• <u>Classification</u> of the substance under discussion taken from the safety data sheet and confirmed by comparison with a database of hazardous substances.• Use of an <u>assessment tool</u> in addition to the above, for well-known problematic groups of substances, such as phthalates and halogenated flame retardants, to investigate best alternatives.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">• Share of suppliers that provide a full material declaration (% of supply chain expenditure)• Share of suppliers that issue a Supplier Declaration of Conformity for a company specific list of restrictions, complemented by a certification (preferably third-party) based on laboratory testing (% of supply chain expenditure)• Disclosure (e.g. on website and annual sustainability reports) of the two previous indicators (y/n)						
Applicability		This BEMP is in principle applicable to all companies of the sector. However, SMEs may lack the leverage to demand Full Material Declarations from many suppliers, in which case they can request Supplier Declarations of Conformity complemented by laboratory testing.				
Benchmark of excellence		<ul style="list-style-type: none">• Mandatory requirements for all major suppliers (in terms of percentage of supply chain expenditure) to provide a full material declaration are in place.				

5.2.1.1 Description

The electrical and electronics industry and its supply chain use material declarations to track and declare specific information about the material composition of its products. 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 (2016), or for compliance with company-specific substance restrictions.

Meanwhile, industry standards are gradually being agreed upon. For instance, to harmonize requirements across the supply chain and to improve economic efficiencies, standard IEC

62474 from the International Electrotechnical Commission provides an international standard for the exchange of material composition data and requirements for material declarations (IEC 2016). This standard establishes requirements for reporting of substances and materials, standardizing protocols, and facilitating transfer and processing of data. It is also complemented by a regularly updated database (IEC 62474 DB) which specifies to the electrical and electronics industry and its suppliers what substances, substance groups and material classes need to be included in material declarations; and to software developers, specifications on the data format for the exchange of material declaration data.

Nonetheless, there are currently 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:

Table 5.3. Parts production and assembly locations for smartphones

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) ⁷⁹	http://www.greenscreenchemicals.org/
Determination and work with code numbered products (MAL Code)	National Working Environment Authority, Denmark	http://arbejdstilsynet.dk/~media/48245F6E041C4FBBA99EFC6E1FA322A2.aspx
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	http://www.rijksoverheid.nl/documente

⁷⁹ 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)

Assessment/Substitution Tool	Elaborated by	Source
	Planning and Environment	n-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/lanquage/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):

- (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, but, however, they 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 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>).

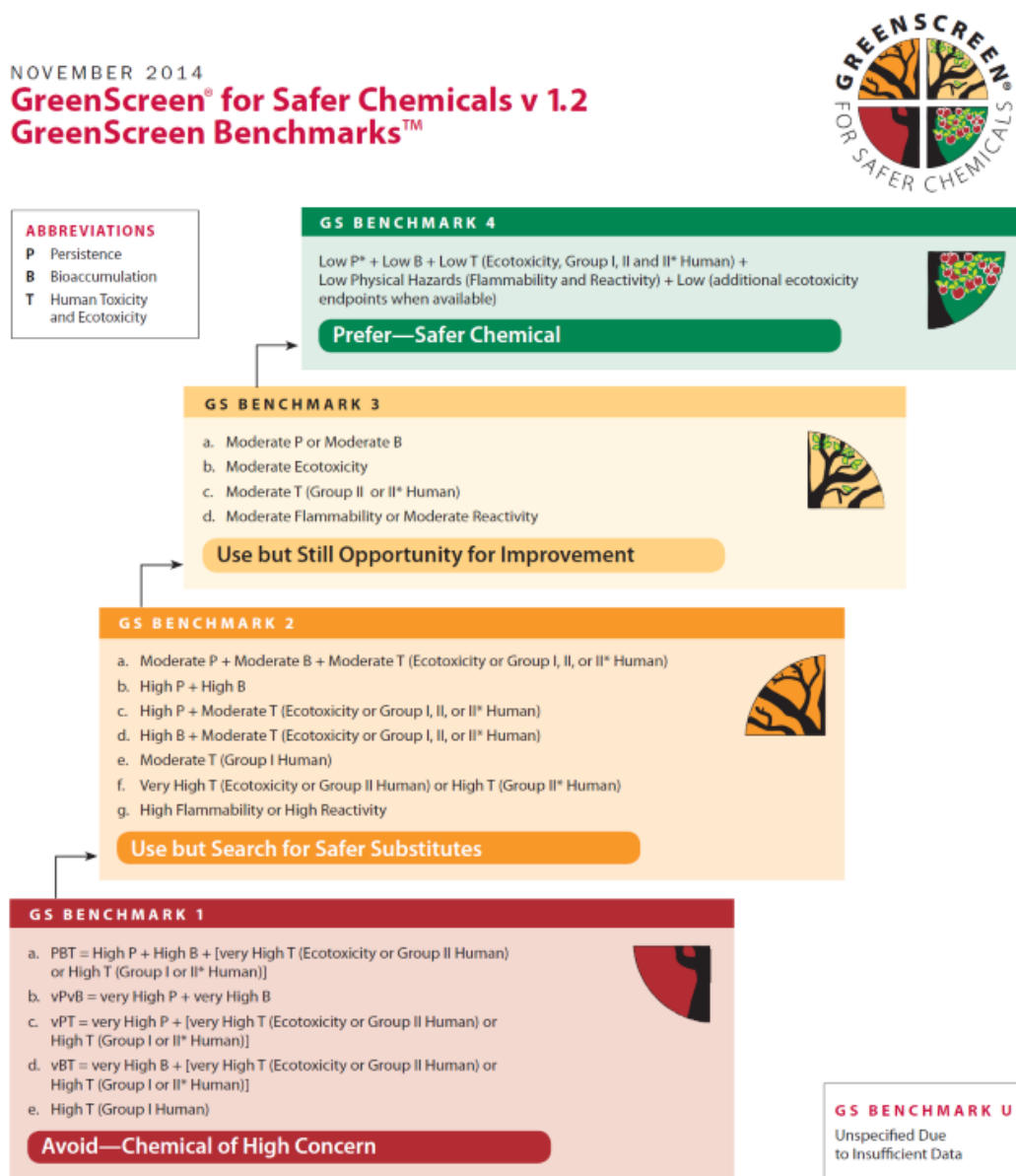
In summary, three steps are recommended for the sound substitution of hazardous chemicals.

- 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.

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



See Guidance (GreenScreen for Safer Chemicals Hazard Assessment Procedure) at www.greenscreenchemicals.org for instructions.

Group I Human includes Carcinogenicity, Mutagenicity/Genotoxicity, Reproductive Toxicity, Developmental Toxicity (incl. Developmental Neurotoxicity), and Endocrine Activity. **Group II Human** includes Acute Mammalian Toxicity, Systemic Toxicity/Organ Effects-Single Exposure, Neurotoxicity-Single Exposure, Eye Irritation and Skin Irritation. **Group II* Human** includes Systemic Toxicity/Organ Effects-Repeated Exposure, Neurotoxicity-Repeated Exposure, Respiratory Sensitization, and Skin Sensitization. Immune System Effects are included in Systemic Toxicity/Organ Effects. **Ecotoxicity** includes Acute Aquatic Toxicity and Chronic Aquatic Toxicity.

* For inorganic chemicals persistence alone will not be deemed problematic. See Guidance.

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— 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		Alternative 1		Alternative 2		Alternative 3		Value	
	Score	Certainty	Score	Certainty	Score	Certainty	Score	Certainty	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

The following environmental performance indicators can be used to monitor the implementation of this BEMP:

- Share of suppliers that provide a full material declaration (% of supply chain expenditure)

- Share of suppliers that issue a Supplier Declaration of Conformity for a company specific list of restrictions, complemented by a certification (preferably third-party) based on laboratory testing (% of supply chain expenditure)
- Disclosure (e.g. on website and annual sustainability reports) of the two previous indicators (y/n)

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.

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 available⁸⁰. 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 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 5.6 and Table 5.7 below list the plasticizers evaluated, the GreenScreen® benchmark scores and provide links to the full GreenScreen® assessments. Table 5.6 lists the verified assessments; Table 5.7 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)).

⁸⁰ 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)

Table 5.6. 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)

Table 5.7. 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	<i>4 Formulations</i> 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	<i>5 chemical ingredients</i> 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

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 5.5:

Figure 5.5. 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 5.8. 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> In IC2 database, 33 GreenScreen® assessments are publicly available (accessed: 18.06.2014).
- Techstreet: <http://www.techstreet.com/searches/3638231>
- 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

Example of substance substitution: phthalates (ortho-phthalates)

Phthalates are the most commonly used plasticisers (or softeners) in flexible polyvinyl chloride PVC. 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).

The phthalates DEHP, DBP, BBP, and DIBP are listed in REACH Annex XIV, meaning that since 21st February 2015 they cannot be manufactured or placed on the EU market in substance form. 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 yet affected by this ban. These substances have however been also listed in Annex II of RoHS, which will mean a gradual phase out by 2019.

Some manufacturers had anticipated this step and sought alternatives. DIDP and DINP, other phthalates, 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, since there are certain concerns relating to human health i.e. suspicions of endocrine disrupting (anti-androgenic) effects or negative effects on the liver. Thus, substitution by shifting within the group of phthalates also entails health risks (however, possibly at a lower level).

As these substitutes are therefore still not ideal, some frontrunner companies go beyond the ban of the above-mentioned four phthalates and the risks of their substitutes by going completely phthalate-free, e.g. Apple, while other manufacturers take a gradual phase-out approach.

5.2.1.6 Applicability

This BEMP is in principle applicable to all companies of the sector. However, SMEs might lack the leverage to demand Full Material Declarations from many suppliers, in which case they can request Supplier Declarations of Conformity complemented by laboratory testing.

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 modelling 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'), 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.

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.

- 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.

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5.2.2 Disclosing and setting targets for supply chain GHG emissions

SUMMARY OVERVIEW						
BEMP is to assess according to recognised standards and regularly disclose all the direct and the most relevant indirect GHG emissions (all scope 1 and scope 2 as well as the most relevant scope 3 emissions ⁸¹). Based on the assessment, BEMP is to set targets for the reduction of those direct and indirect GHG emissions as well as demonstrate and regularly publish actual absolute and/or relative GHG emission reductions.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">Periodical (e.g. annual) publication of GHG emissions calculated with a recognised standard method (y/n)Categories of scope 3 emissions included in the assessmentPeriodical (e.g. annual) disclosure of absolute or relative GHG emission reduction targets (y/n)Periodical (e.g. annual) disclosure of demonstrated actual absolute and/or relative GHG emission reductions (y/n)						
Applicability		This BEMP is applicable to all companies of the sector. However, there are some limitations in the calculation of scope 3 emissions, due to the complexity of the value chains of electrical and electronic equipment.				
Benchmarks of excellence		<ul style="list-style-type: none">GHG emissions (including scope 1, 2 and the most relevant scope 3) are calculated with a recognised standard method and periodically publishedAbsolute or relative GHG emission reduction targets are disclosed publiclyAbsolute and/or relative actual GHG emission reductions are demonstrated and periodically published				

5.2.2.1 Description

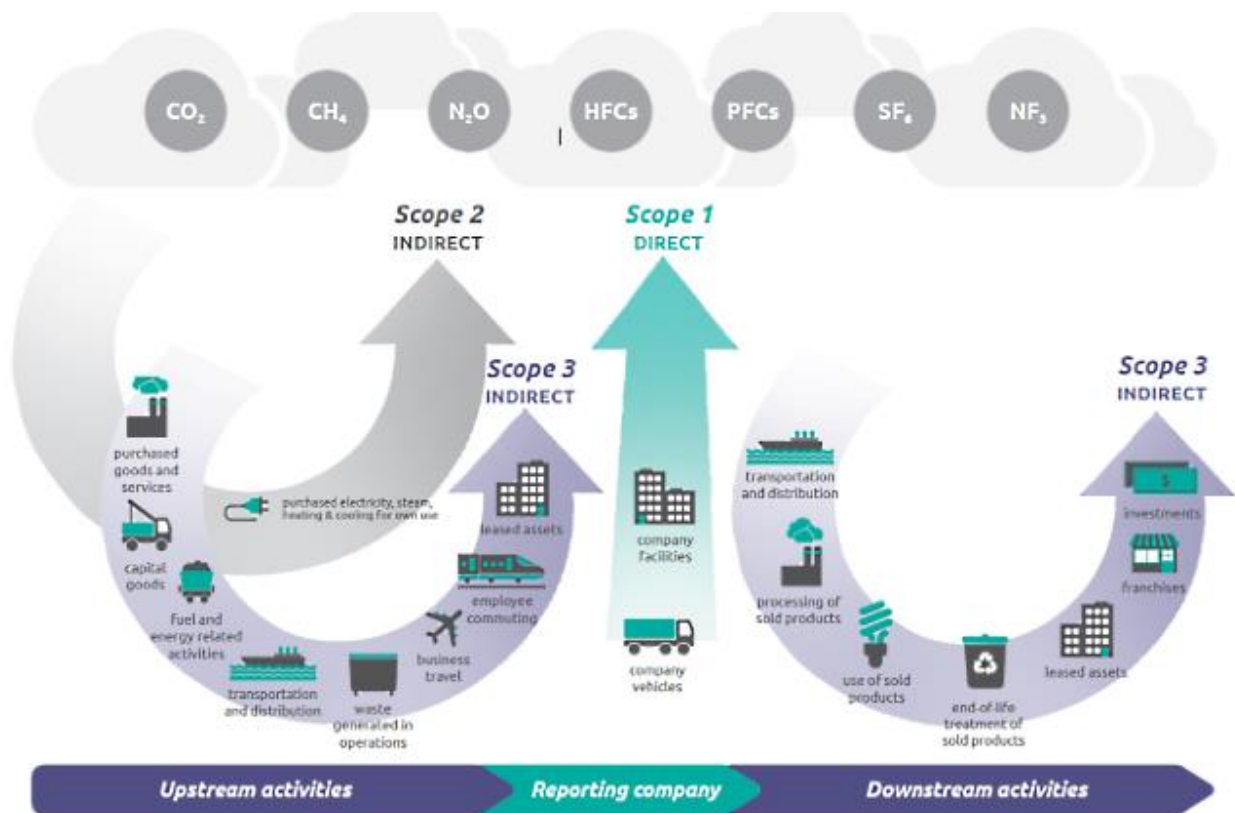
EEE manufacturers directly emit greenhouse gas (GHG) but are also part of complex supply chain networks, made up of many different companies, all contributing in some form to the goods and services an EEE manufacturer offers. Each of these companies itself, through purchasing and processing of materials and energy, directly or indirectly causes the release of 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 direct and indirect GHG emissions, through both:

⁸¹ According to the GHG Protocol, scope 1 emissions are all direct GHG emissions of a company, i.e. GHG emissions that are released in owned or controlled facilities or vehicles. Scope 2 emissions are indirect GHG emissions from consumption of purchased electricity, heat, cold or steam, i.e. emissions that were released elsewhere to produce the energy consumed within company boundaries. Scope 3 denotes all other indirect emissions from product (good or service) or material flows entering or leaving the company boundaries.

- publicly disclosing significant GHG emissions (including all the value-chain) according to recognised standard(s);
- setting and meeting (absolute and relative) targets for their reduction.

Indirect emissions (along the value chain) are commonly referred to as “Scope 3 emissions”. Scope 1 emissions are all direct GHG emissions taking place 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 5.6](#)).

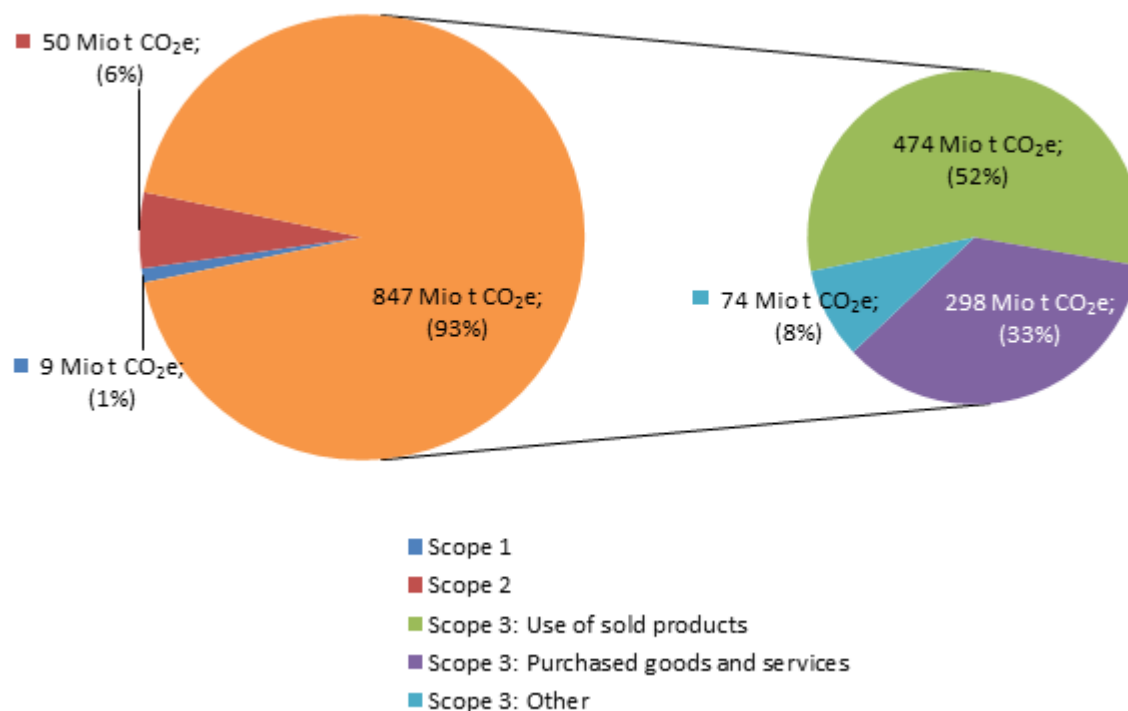
Figure 5.6. Definition of Scopes in GHG Protocol Corporate Value Chain Standard



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 5.7](#) 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 5.7. 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 tool for companies to understand and influence their overall impact on climate change in collaboration with their supply chain partners.

A number of recognised standards to comprehensively assess and disclose GHG emissions are available. The results of the assessment 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) which 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, in parallel to the Product Environmental Footprint⁸², and therefore not yet adopted.

Figure 5.6 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:

⁸² With the aim of establishing a common method for measuring life cycle environmental performance, the European Commission developed the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) methods. The use of these methods was object of a Commission Recommendation in 2013 (<http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013H0179>). The development of product- and sector-specific rules is being tested (between 2013 and 2016) by more than 280 volunteering companies and organisations grouped in 26 pilot cases (see list on http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm).

- 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 (GHG Protocol 2011, 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 can identify and address all the applicable 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. However, the specific boundaries and processes for Scope 1, 2, and 3 categories (as presented in [Figure 5.7](#) above) can differ significantly from company to company.

Once GHG emissions (scope 1,2 and 3 as much as possible) have been estimated, companies can 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 (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF₆), and nitrogen trifluoride (NF₃). As NF₃ 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 5.9](#) provides an overview of typical sources of these greenhouse gases related to EEE.

Table 5.9. Selected EEE-related sources of GHGs

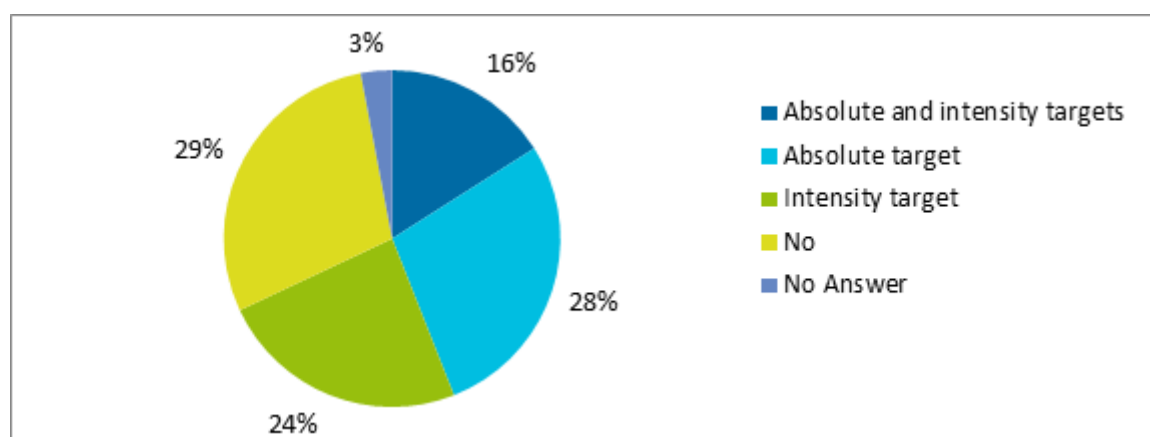
CO ₂	From burning of fossil fuels for electricity, transport and other energy, burning of solid waste; from production of cement, metals (such as iron and steel) and certain chemicals
CH ₄	From production and transport of coal, natural gas, and oil; from agricultural products; from landfills
N ₂ O	From 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 can 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. Moreover, the main sources and underlying processes of the major share of identified greenhouse gas emissions can also be described.

However, disclosure alone is not best practice and, to a certain degree, is already in fact common practice among large EEE manufacturers. It is best practice therefore to combine comprehensive disclosure with ambitious GHG reduction targets and achievements for most significant GHG emission sources (including Scope 1,2 and 3). 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 5.10.](#)). Additionally, frontrunner companies 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 5.8. 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.

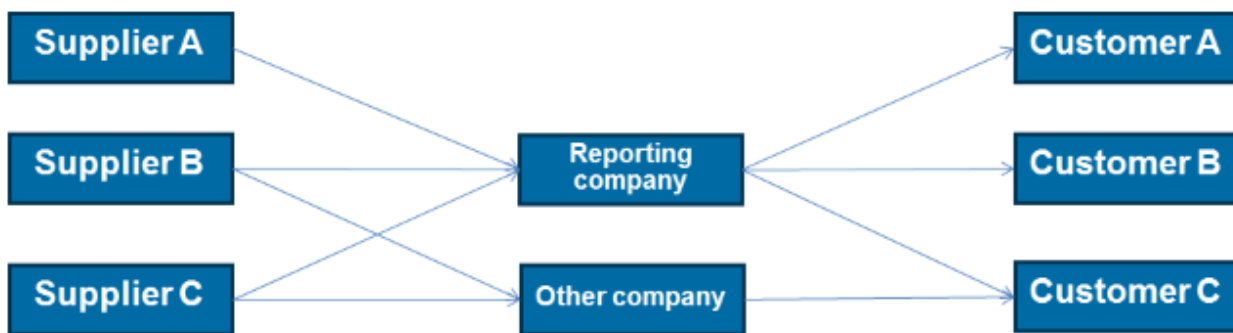
5.2.2.2 Achieved environmental benefits

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 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 ([Figure 5.9](#)).
- 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 5.9. 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:

- Suppliers would be implementing GHG reducing measures also in absence of a specific supply chain program by the company implementing the BEMP;
- 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.

5.2.2.3 Appropriate environmental performance indicators

The implementation and environmental benefit of the BEMP can be monitored by the following performance indicators:

- Periodical (e.g. annual) publication of GHG emissions calculated with a recognised standard method (Y/N);
- Categories of scope 3 emissions included in the assessment (Y/N);
- Periodical (e.g. annual) disclosure of absolute or relative GHG emission reduction targets (Y/N);
- Periodical (e.g. annual) disclosure of demonstrated actual absolute and/or relative GHG emission reductions (Y/N).

5.2.2.4 Cross-media effects

Calculation and disclosure of GHG emissions does not lead to any environmental cross-media effect. The implementation of GHG emission reductions, instead, as with many energy efficiency measures, can entail replacement of existing capital equipment with new material which production has caused additional emissions of GHG (embodied GHG). However, usually, the additional GHG emissions are counterbalanced by the GHG emissions reductions achieved.

5.2.2.5 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) use for transport and storage of sold products;
- 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 is usually the electricity use.

In general, data for value chain (upstream and downstream) GHG emissions is gained through two means:

- based on a value chain model or scenario for the purchased goods and services and for the use of sold products and the application of secondary data from databases;
- by directly engaging suppliers and customers asking them for site-/process-specific (“primary”) data.

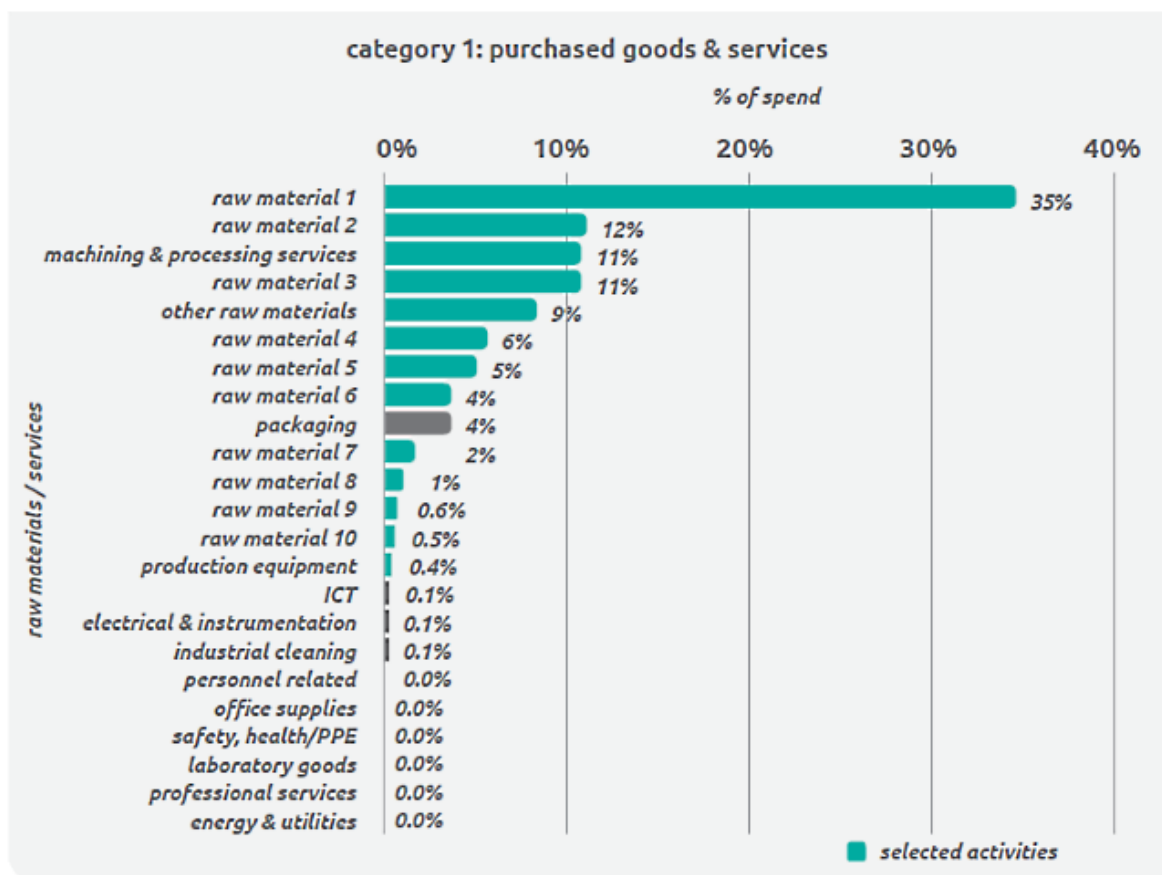
Companies should aim at increasing the share of specific data from:

- Suppliers, for the most relevant purchased goods and services;
- Customers, for the use of the most relevant products sold.

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 5.10](#) 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 5.11](#)). A company may, for example, also do a detailed analysis of activities which can influence more easily or that is deemed relevant by stakeholders.

Figure 5.10. Example of outcome of screening exercise



Source: GHG Protocol (2011), p. 67

Figure 5.11. 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 (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 5.12](#)).

Figure 5.12. Excel tools for the calculation of process specific GHG emissions (here: PFC emissions from semiconductor manufacturing)

	A	B	C	D	E	F	G
	Step #2: Enter fraction of each material that is fed into abatement tools.						
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12	V_a =	Fraction of gas _i that is fed into abatement tools					
13	a_i =	average destruction efficiency of abatement tool for gas _i					
14	A_i =	fraction of PFC _i destroyed by abatement = $a_i * V_a$					
15	A_{CF4} =	fraction of PFC _i that is converted to CF ₄ and destroyed by abatement = $a_{CF4} * V_a$					
16							
17	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 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.						
18							

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. For instance, Sharp has, over the course of several years, implemented a comprehensive Scope 3 assessment, disclosure and management plan. In 2013 Sharp reported on 10 out of 15 Scope 3 categories (see [Table 5.10](#) and [Table 5.11](#)). Scope 1 and 2 emissions together contributed 1.3 million tons CO₂e to overall GHG inventory, while Scope 3 contributed more than 31 million tons CO₂e based on Scope 3 categories assessed.

Table 5.10. 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)	381	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 5.11. 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)

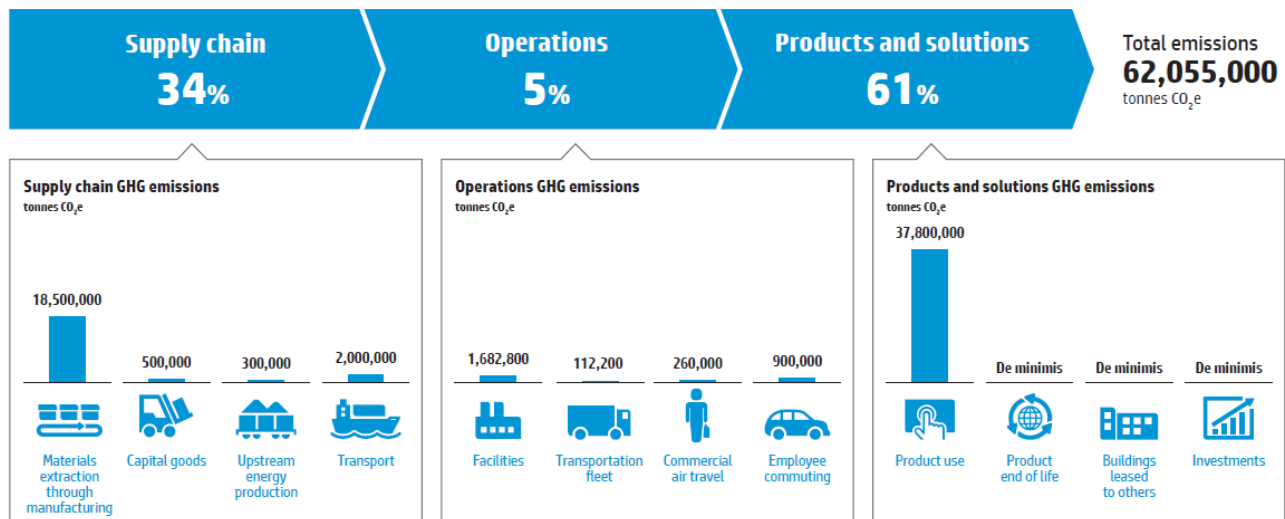
^{*9} The amount of CO₂ emissions from the use of sold products does not include avoided emissions from the use of solar cells.

^{*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 5.13](#). Again, purchased goods and services, denoted "Materials extraction through manufacturing" and product use make up major share of overall GHG emissions.

Figure 5.13. HP Fiscal Year 2013 GHG inventory

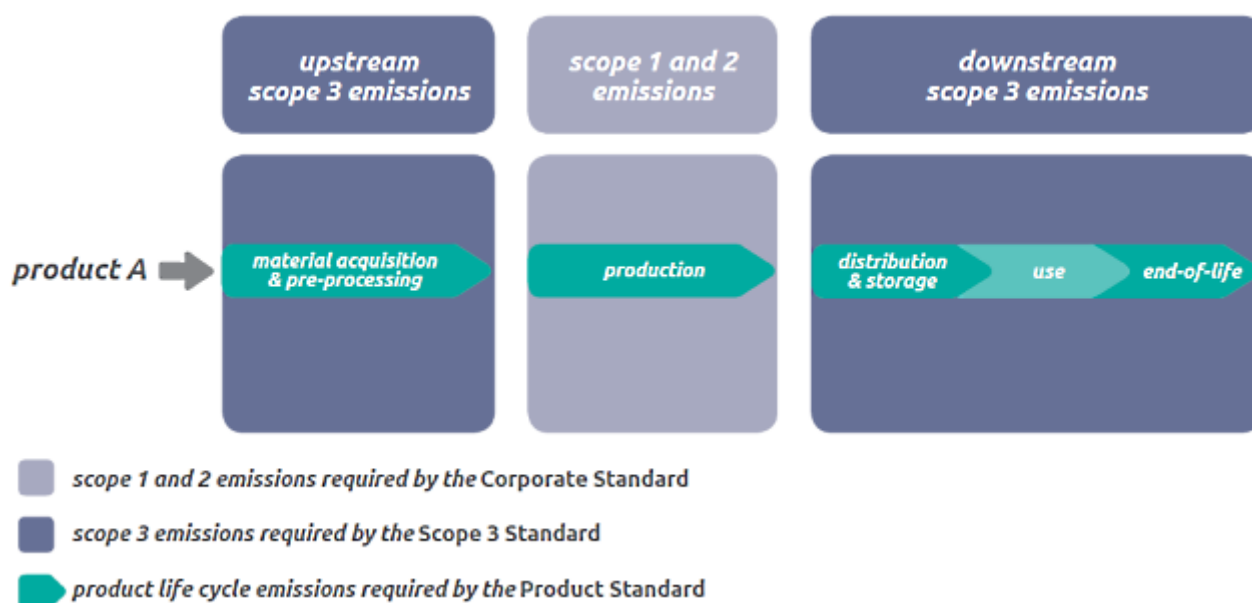


Source: HP (2014)

In order to implement this BEMP, relations to product specific carbon/ environmental footprint or LCA assessments can be established. This is possible and reasonable, particularly for the most relevant purchased and sold products. [Figure 5.14.](#) 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 5.14](#)).

Figure 5.14. Relationship between GHG Protocol Product and Value Chain Standards



Source: GHG Protocol (2011), p. 8

Figure 5.15. 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 CO₂/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 5.16](#)).

Figure 5.16. 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 ₂ e.	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 ₂ e.	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 Cisco 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. Cisco asks and encourages 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 5.12](#)). 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 5.12. 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.

5.2.2.6 Applicability

This BEMP, in principle, is applicable to all organisations; several standards and guidelines have been developed to conduct the calculation of GHG emissions and to set targets for their reduction (see 'description' and 'operational data' sections). As already mentioned in the BEMP, calculation of scope 1 and 2 emissions is relatively easy, since the responsible facilities, vehicles, processes and utilities are directly employed by the interested organisation. Instead, quantification of scope 3 emissions is much more complex, because products and manufacturing processes responsible for them are not under the control of the organisation accounting for the scope 3 emissions. Organisations wishing to account scope 3 emissions can focus first on the most relevant categories (hotspots) covered in their scope 3 emissions, involving suppliers and customers for a better assessment. While, for less relevant categories of scope 3 emissions, organisations can use data calculated from a number of GHG emission models. The BEMP 'Conducting Life Cycle Assessment (LCA) and improving lifecycle impacts' lists a number of LCA tools and inventories which could be used to estimate the GHG emissions from the value chain processes. Nevertheless, organisation accounting scope 3 emissions should work towards the inclusion of all categories of scope 3 emissions directly calculated thanks to the involvement of suppliers and customers, rather than relying on model data.

As just mentioned, synergies with other BEMPs can be established, i.e. 'Conducting Life Cycle Assessment (LCA) and improving lifecycle impacts'. Information gained from detailed value chain environmental assessment of important products can feed 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 relevant products.

Finally, 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. Therefore, the BEMPs on manufacturing of EEE can be applied by the relevant companies (e.g. manufacturers of ICs or PCBs) along the value chain of the EEE manufacturer.

5.2.2.7 Economics

Two major cost components can be clearly distinguished:

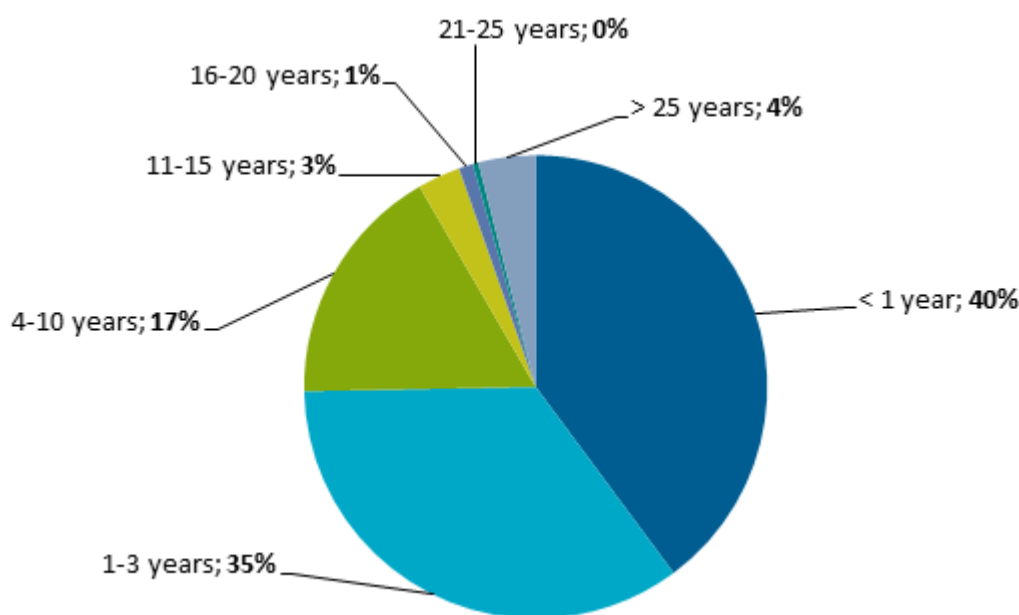
1. Costs for elaborating a Scope 3 GHG inventory, reporting, setting reduction targets;
2. Costs for specific measures for the reduction of GHG emissions.

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, pay-back the 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 75% 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 5.17](#)). 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 5.17. 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 from 1 months to 3 years.

However, this pilot study partly involved the testing of several methodologies at once by some companies.

5.2.2.8 Driving force for implementation

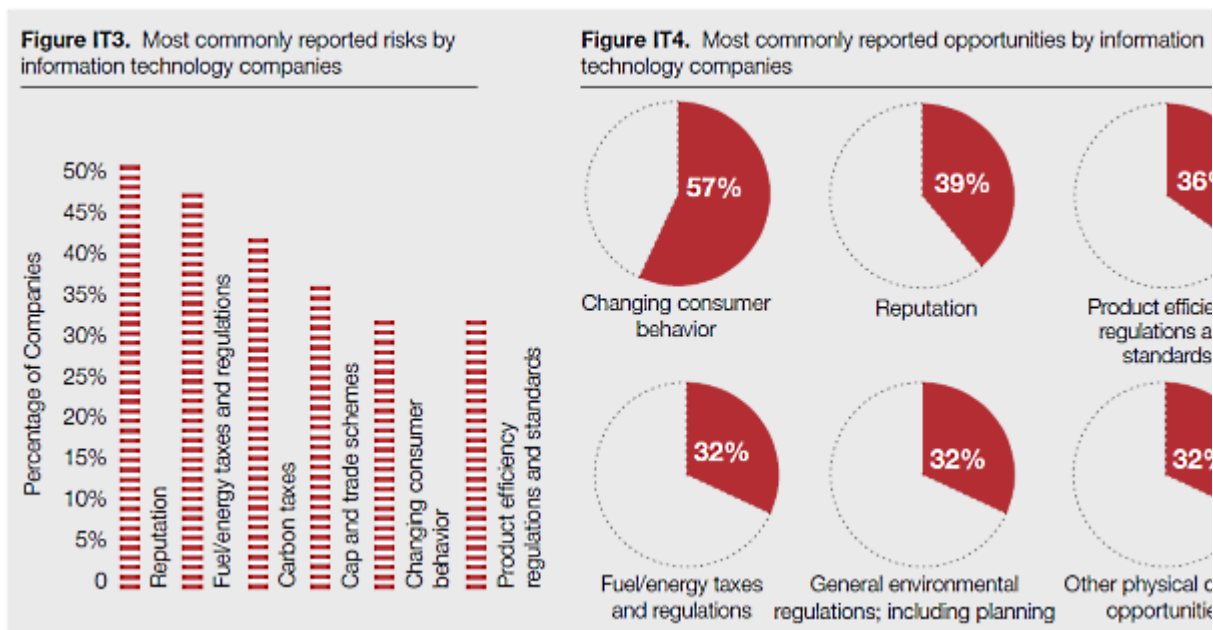
Supply chain GHG disclosure and management is attributed to a number of different driving forces: (GHG Protocol, pp. 12)

- 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 5.18](#));
- Aim to better understand risks and opportunities associated with GHG emissions;
- Demand for disclosure by customers and/or business partners (see for example [Figure 5.19](#) 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.

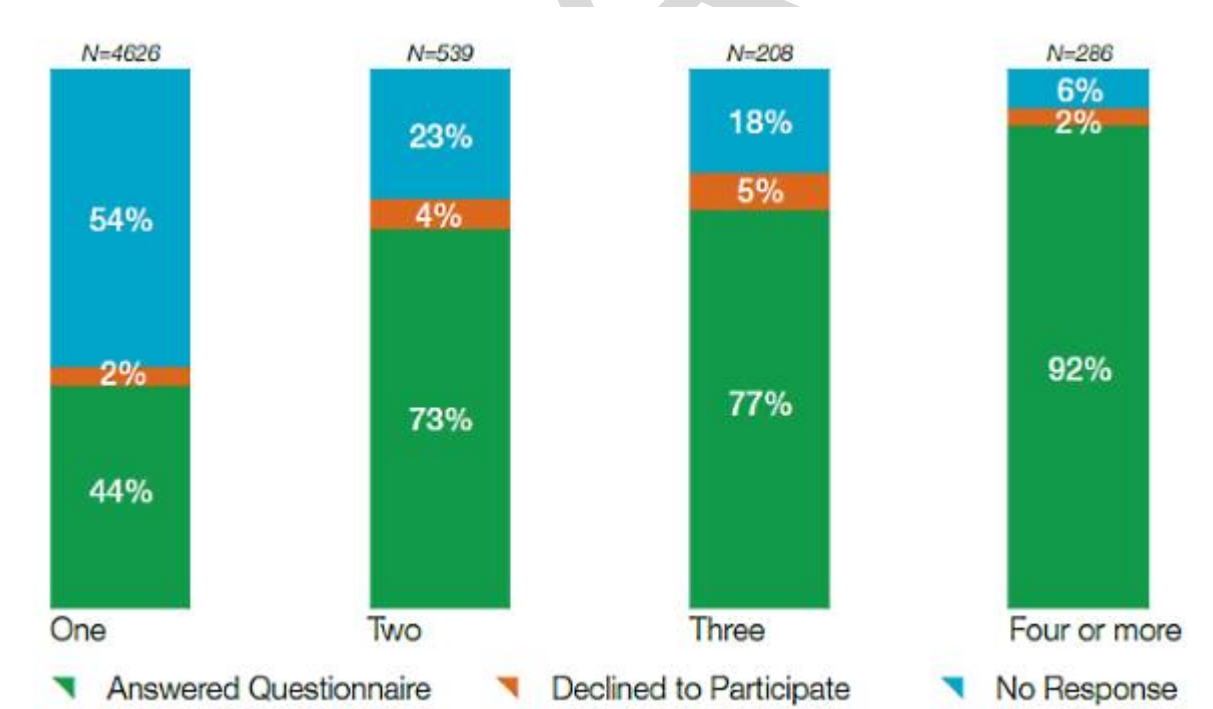
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Figure 5.18. Risks and opportunities from climate change as reported by information technology companies to the CDP Global 500



Source: CDP (2014a)

Figure 5.19. Response rate of suppliers based on number of customer requests received

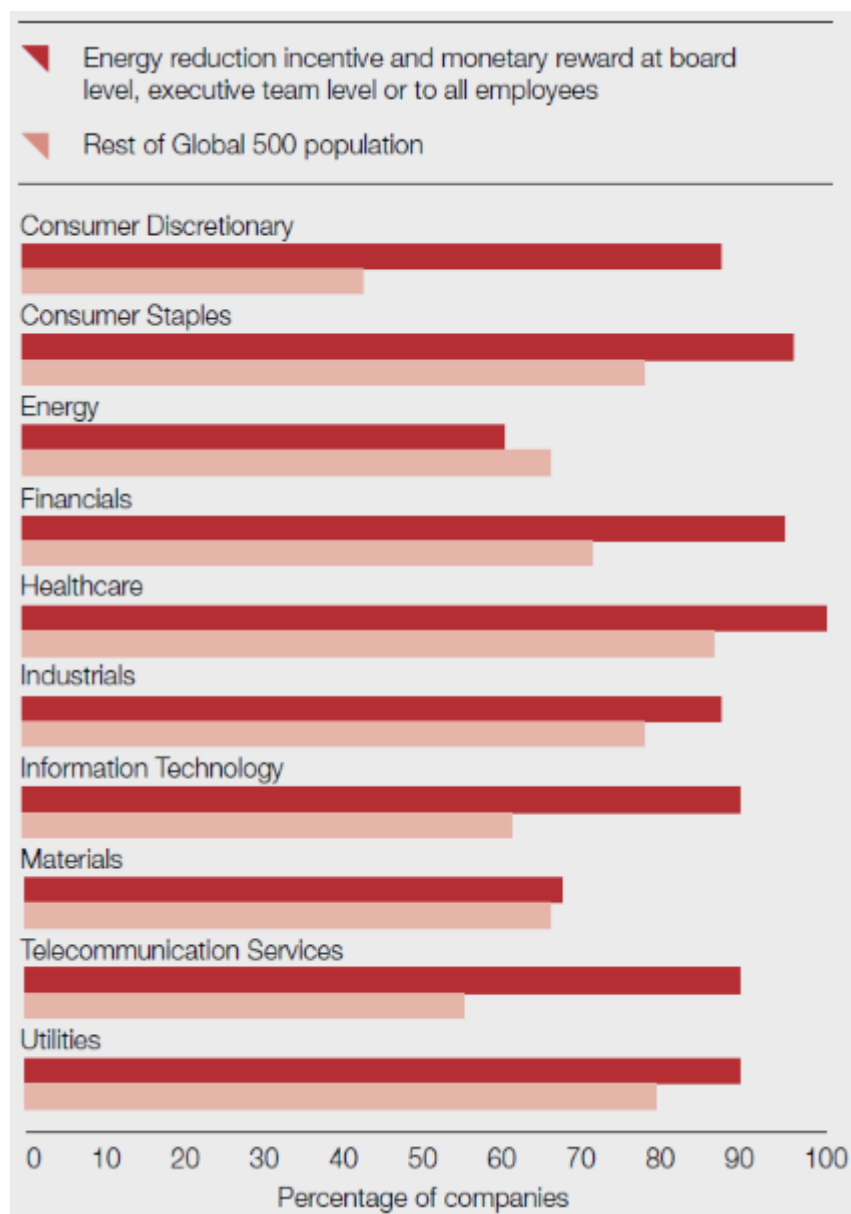


Source: CDP (2014c)

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 5.20](#)).

Figure 5.20. Share of companies with and without monetary incentives and reported absolute GHG emission reductions



Source: CDP (2013)

5.2.2.9 Reference organisations

Cisco: Discloses most Scope 3 categories to the CDP, has in place an elaborated supply chain management approach;

HP (Hewlett-Packard): Discloses most Scope 3 categories to the CDP;

Sharp: Discloses most Scope 3 categories to the CDP.

5.2.2.10 Reference literature

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5.2.3 Conducting life cycle assessment

SUMMARY OVERVIEW:						
BEMP is to make use of Life Cycle Assessments (LCA) as a decision support instrument in the context of: strategic planning (macro-level), design and planning of products, facilities, and processes (micro-level) and monitoring the environmental performance of the company (accounting). Conducting LCA on product ranges to support environmental improvements is the most relevant application area in the industry and allows setting LCA improvement targets for product ranges.						
Relevant lifecycle stages						
Manufacturing		Supply chain			End-of-life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">Inclusion of LCA according to the ISO standards 14040 and 14044 in the environmental strategy of the company and use of LCA when taking major decisions for developing new and re-designed products (Y/N)<ul style="list-style-type: none">% of product ranges for which LCA improvement targets have been met (weighted by numbers of references or by sales)						
Applicability		<p>This BEMP is broadly applicable to all EEE manufacturing companies, especially to large sized companies.</p> <p>Internal resources and complexity of LCA are potential limiting factors for the conduct of LCA for small and medium sized enterprises. However, simplified LCA screening tools and ready-made databases help mitigating the difficulties.</p>				
Benchmarks of excellence		<ul style="list-style-type: none">LCA is carried out according to the international standards ISO 14040 and ISO 14044The company carries out life cycle assessment for new and re-designed products and the results are systematically used to base product development choices				

5.2.3.1 Description

The adoption of Life Cycle Thinking (LCT), a general qualitative approach from a life cycle perspective on environmental performance, is of utmost importance to systematically analyse, evaluate, and improve the environmental performance of activities, beyond the impacts of company-owned facilities, 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 industry⁸³ (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)⁸⁴. 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. Philips⁸⁵, for instance, has been using LCA with great success for eco-design improvements of TV-sets, household appliances, lighting products, and healthcare equipment⁸⁶. 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.

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

⁸³ ICT (Information and Communication Technologies), CE (Consumer Electronics)

⁸⁴ http://ec.europa.eu/environment/eussd/smcp/dev_pef.htm

⁸⁵ <http://www.philips.com/about/sustainability/ourenvironmentalapproach/greeninnovation/circulareconomy.page>

⁸⁶ http://ec.europa.eu/enlargement/taix/dyn/create_speech.jsp?speechID=19779&key=9aa1f2c85a2d27c1bd61f68d50d3329

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; Kloeppfer 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 decisions⁸⁷.

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 environmental 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).

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 CSR⁸⁸ 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 minimisation 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 improvements⁸⁹ 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.

5.2.3.2 Achieved 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

⁸⁷ 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.

⁸⁸ Corporate Social Responsibility

⁸⁹ The continuous improvement of an organisation's environmental performance constitutes the central proposition of both environmental management schemes, EMAS and ISO14001.

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 (Andreă 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 implications 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 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.

5.2.3.3 Appropriate environmental performance indicators

At the organisational level, appropriate performance indicators could be the following:

- Inclusion of LCA according to the ISO standards 14040 and 14044 in the environmental strategy of the company and use of LCA when taking major decisions for developing new and re-designed products (Y/N)
- % of product ranges for which LCA improvement targets have been met (weighted by numbers of references or by sales)

N.B. these do not capture the metrics which a company may choose to use within the process of carrying out an LCA at product level, which may cover e.g. global warming potential (GWP), product carbon footprint etc... depending on the environmental impact categories prioritised by the organisation (see "Operational data" section below).

5.2.3.4 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.

5.2.3.5 Operational data

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 comply with 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.

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 ⁹⁰	Carbon Footprinting tool for users in various industry sectors
Ecolizer 2.0 ⁹¹	An LCA-based booklet tool for designers to estimate environmental impacts
EIOLCA ⁹²	Economic input-output LCA using macro-economic data of the EEE sector
eVerdee ⁹³	Tool developed by the EcoSMEs project (2004), Guidelines for EEE industry
LCA-to-go ⁹⁴	EEE sector-specific online tool developed by the LCA-to-go project (2014)
Life cycle analyses tool ⁹⁵	Simple generic LCA tool with an intuitive user interface
LiMaS ⁹⁶	LCA web-suite developed for companies in the sector of energy-related products (ErP) and electrical-electronic products (EEE)
OpenLCA ⁹⁷	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 ⁹⁸ proprietary full-scale LCA software provided by PE international: product and process chain analysis.
- SimaPro ⁹⁹ proprietary full-scale LCA software provided by PRé Consultants: based on a hierarchical product tree concept.

⁹⁰ <http://www.ccalc.org.uk>

⁹¹ <http://www.ecodesignlink.be/en/tools/ecolizer-1>

⁹² <http://www.eiolca.net>

⁹³ <http://www.ecosmes.net/everdee/login2?idlanguage=null>

⁹⁴ <http://www.lca2go.eu>

⁹⁵ http://design-4-sustainability.com/life_cycle_analyses

⁹⁶ <http://www.limas-eup.eu>

⁹⁷ <http://www.openlca.org> <http://greendelta.com>

⁹⁸ <http://www.gabi-software.com/index>

⁹⁹ <http://www.pre-sustainability.com/simapro>

- Umberto¹⁰⁰ 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 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 description corresponds more or less to the situation in reality (e.g. an alloy purchased from a supplier).

- European reference Life Cycle Database (ELCD)¹⁰¹: contains reviewed LCI data for a range of materials, energy carriers, transport, and waste management processes.
- Idemat database¹⁰²: 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).
- ProBas¹⁰³: 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)¹⁰⁴: 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

¹⁰⁰ <http://www.umberto.de/en>

¹⁰¹ <http://eplca.jrc.ec.europa.eu/ELCD3> (available as zip package)

¹⁰² www.ecocostvalue.com (open the link "data" and download the xls file)

¹⁰³ www.probas.umweltbundesamt.de

¹⁰⁴ <http://www.ecoinvent.ch>

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-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 photovoltaics (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 5.21).

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 website¹⁰⁵. 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 5.21. Screenshots of the LCA-to-go web-suite for the electronics sector

¹⁰⁵ <http://www.lca2go.eu/sectors/electronic.en.html>

Scenario: Manufacturing Distribution Use End-of-life KEPIs Selection

Overhead miscellaneous parts: 10.0 %

Raw materials and production

Part: Material/Component:

Quantity: Component age: years Component total lifetime: years

Part	Material/Component	Quantity	Unit	Age (y)	Total lifetime (y)
Housing & internal structural elements	aluminum	0.90	g	0.0	8.51
Printed Circuit Board Assemblies	Laptop mainboard (270 cm ²)	1.00	units	0.0	8.51
Memory	DRAM, DDR3, 40 nm, max. 1Gb/chip	1.00	GB	0.0	8.51
Processor	2 cores, application server	1.00	units	0.0	8.51
Storage	3.5" HDD	1.00	units	0.0	8.51
Power supply	Power Supply	50.00	VA output rating	0.0	8.51
Cables	cable	1000.00	g	0.0	8.51
Connectivity	WLAN	1.00	units	0.0	8.51
Connectivity	USB	2.00	units	0.0	8.51
Connectivity	HDMI	1.00	units	0.0	8.51
Connectivity	VGA, DVI	1.00	units	0.0	8.51
Optical Disc Drive	Optical Disc Drive	1.00	units	0.0	8.51

Left side: data input page

		CF	Cu	As	Ta	W	Sn	Al	Si	Fe	Pb	Cl	Br	I	Ag	Au	Co	Cd	Cr	Hg	Mn	Ni	P	S	Se	Te	Zn	Zr	Bi	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ	FA	FB	FC	FD	FE	FF	FG	FH	FI	FJ	FK	FL	FM	FN	FO	FP	FQ	FR	FS	FT	FU	FV	FW	FX	FY	FZ	GA	GB	GC	GD	GE	GF	GG	GH	GI	GJ	GK	GL	GM	GN	GO	GP	GQ	GR	GS	GT	GU	GV	GW	GX	GY	GZ	HA	HB	HC	HD	HE	HF	HG	HH	HI	HJ	HK	HL	HM	HN	HO	HP	HQ	HR	HS	HT	HU	HV	HW	HX	HY	HZ	IA	IB	IC	ID	IE	IF	IG	IH	II	IJ	IK	IL	IM	IN	IO	IP	IQ	IR	IS	IT	IU	IV	IW	IX	IY	IZ	JA	JB	JC	JD	JE	JF	JG	JH	JI	JJ	JK	JL	JM	JN	JO	JP	JQ	JR	JS	JT	JU	JV	JW	JX	JY	JZ	KA	KB	KC	KD	KE	KF	KG	KH	KI	KJ	KK	KL	KM	KN	KO	KP	KQ	KR	KS	KT	KU	KV	KW	KX	KY	KZ	LA	LB	LC	LD	LE	LF	LG	LH	LI	LJ	LK	LM	LN	LO	LP	LQ	LR	LS	LT	LU	LV	LW	LX	LY	LZ	MA	MB	MC	MD	ME	MF	MG	MH	MI	MJ	MK	ML	MM	MN	MO	MP	MQ	MR	MS	MT	MU	MV	MW	MX	MY	MZ	NA	NB	NC	ND	NE	NF	NG	NH	NI	NJ	NK	NL	NM	NN	NO	NP	NQ	NR	NS	NT	NU	NV	NW	NX	NY	NZ	OA	OB	OC	OD	OE	OF	OG	OH	OI	OJ	OK	OL	OM	ON	OO	OP	OQ	OR	OS	OT	OU	OV	OW	OX	OY	OZ	PA	PB	PC	PD	PE	PF	PG	PH	PI	PJ	PK	PL	PM	PN	PO	PP	PQ	PR	PS	PT	PU	PV	PW	PX	PY	PZ	QA	QB	QC	QD	QE	QF	QG	QH	QI	QJ	QK	QL	QM	QN	QO	QP	QQ	QR	QS	QT	QU	QV	QW	QX	QY	QZ	RA	RB	RC	RD	RE	RF	RG	RH	RI	RJ	RK	RL	RM	RN	RO	RP	RQ	RR	RS	RT	RU	RV	RW	RX	RY	RZ	SA	SB	SC	SD	SE	SF	SG	SH	SI	SJ	SK	SL	SM	SN	SO	SP	SQ	SR	SS	ST	SU	SV	SW	SX	SY	SZ	TA	TB	TC	TD	TE	TF	TG	TH	TI	TJ	TK	TL	TM	TN	TO	TP	TQ	TR	TS	TT	TU	TV	TW	TX	TY	TZ	UA	UB	UC	UD	UE	UF	UG	UH	UI	UJ	UK	UL	UM	UN	UO	UP	UQ	UR	US	UT	UU	UV	UW	UX	UY	UZ	VA	VB	VC	VD	VE	VF	VG	VH	VI	VJ	VK	VL	VM	VN	VO	VP	VQ	VR	VS	VT	VU	VV	VW	VX	VY	VZ	WA	WB	WC	WD	WE	WF	WG	WH	WI	WJ	WK	WL	WM	WN	WO	WP	WQ	WR	WS	WT	WU	WV	WW	WX	WY	WZ	XA	XB	XC	XD	XE	XF	XG	XH	XI	XJ	XK	XL	XM	XN	XO	XP	XQ	XR	XS	XT	XU	XV	XW	XX	XY	XZ	YA	YB	YC	YD	YE	YF	YG	YH	YI	YJ	YK	YL	YM	YN	YO	YP	YQ	YR	YS	YT	YU	YV	YW	YX	YZ	ZA	ZB	ZC	ZD	ZE	ZF	ZG	ZH	ZI	ZJ	ZK	ZL	ZM	ZN	ZO	ZP	ZQ	ZR	ZS	ZT	ZU	ZV	ZW	ZX	ZY	ZZ	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ	FA	FB	FC	FD	FE	FF	FG	FH	FI	FJ	FK	FL	FM	FN	FO	FP	FQ	FR	FS	FT	FU	FV	FW	FX	FY	FZ	GA	GB	GC	GD	GE	GF	GG	GH	GI	GJ	GK	GL	GM	GN	GO	GP	GQ	GR	GS	GT	GU	GV	GW	GX	GY	GZ	HA	HB	HC	HD	HE	HF	HG	HH	HI	HJ	HK	HL	HM	HN	HO	HP	HQ	HR	HS	HT	HU	HV	HW	HX	HY	HZ	IA	IB	IC	ID	IE	IF	IG	IH	II	IJ	IK	IL	IM	IN	IO	IP	IQ	IR	IS	IT	IU	IV	IW	IX	IY	IZ	JA	JB	JC	JD	JE	JF	JG	JH	JI	JJ	JK	JL	JM	JN	JO	JP	JQ	JR	JS	JT	JU	JV	JW	JX	JY	JZ	KA	KB	KC	KD	KE	KF	KG	KH	KI	KJ	KK	KL	KM	KN	KO	KP	KQ	KR	KS	KT	KU	KV	KW	KX	KY	KZ	LA	LB	LC	LD	LE	LF	LG	LH	LI	LJ	LK	LM	LN	LO	LP	LQ	LR	LS	LT	LU	LV	LW	LX	LY	LZ	MA	MB	MC	MD	ME	MF	MG	MH	MI	MJ	MK	ML	MM	MN	MO	MP	MQ	MR	MS	MT	MU	MV	MW	MX	MY	MZ	NA	NB	NC	ND	NE	NF	NG	NH	NI	NJ	NK	NL	NM	NN	NO	NP	NQ	NR	NS	NT	NU	NV	NW	NX	NY	NZ	OA	OB	OC	OD	OE	OF	OG	OH	OI	OJ	OK	OL	OM	ON	OO	OP	OQ	OR	OS	OT	OU	OV	OW	OX	OY	OZ	PA	PB	PC	PD	PE	PF	PG	PH	PI	PJ	PK	PL	PM	PN	PO	PP	PQ	PR	PS	PT	PU	PV	PW	PX	PY	PZ	QA	QB	QC	QD	QE	QF	QG	QH	QI	QJ	QK	QL	QM	QN	QO	QP	QQ	QR	QS	QT	QU	QV	QW	QX	QY	QZ	RA	RB	RC	RD	RE	RF	RG	RH	RI	RJ	RK	RL	RM	RN	RO	RP	RQ	RR	RS	RT	RU	RV	RW	RX	RY	RZ	SA	SB	SC	SD	SE	SF	SG	SH	SI	SJ	SK	SL	SM	SN	SO	SP	SQ	SR	SS	ST	SU	SV	SW	SX	SY	SZ	TA	TB	TC	TD	TE	TF	TG	TH	TI	TJ	TK	TL	TM	TN	TO	TP	TQ	TR	TS	TT	TU	TV	TW	TX	TY	TZ	UA	UB	UC	UD	UE	UF	UG	UH	UI	UJ	UK	UL	UM	UN	UO	UP	UQ	UR	US	UT	UU	UV	UW	UX	UY	UZ	VA	VB	VC	VD	VE	VF	VG	VH	VI	VJ	VK	VL	VM	VN	VO	VP	VQ	VR	VS	VT	VU	VV	VW	VX	VY	VZ	WA	WB	WC	WD	WE	WF	WG	WH	WI	WJ	WK	WL	WM	WN	WO	WP	WQ	WR	WS	WT	WU	WV	WW	WX	WY	WZ	XA	XB	XC	XD	XE	XF	XG	XH	XI	XJ	XK	XL	XM	XN	XO	XP	XQ	XR	XS	XT	XU	XV	XW	XX	XY	XZ	YA	YB	YC	YD	YE	YF	YG	YH	YI	YJ	YK	YL	YM	YN	YO	YP	YQ	YR	YS	YT	YU	YV	YW	YX	YZ	ZA	ZB	ZC	ZD	ZE	ZF	ZG	ZH	ZI	ZJ	ZK	ZL	ZM	ZN	ZO	ZP	ZQ	ZR	ZS	ZT	ZU	ZV	ZW	ZX	ZY	ZZ
TOTAL per product use year		41.96	11.18	0.00	0.00	0.02	0.00	1.39	2.69	-	0.08	0.00																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														

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.

5.2.3.6 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 footprints¹⁰⁶. 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). However, simplified LCA screening tools and ready-made databases help mitigating the difficulties of the implementation of a LCA.

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

¹⁰⁶ <http://www.hp.com/hpinfo/globalcitizenship/09gcreport/enviro/design/lifecycle.html>

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,
- 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).

5.2.3.7 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 "Operational data")
- 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.

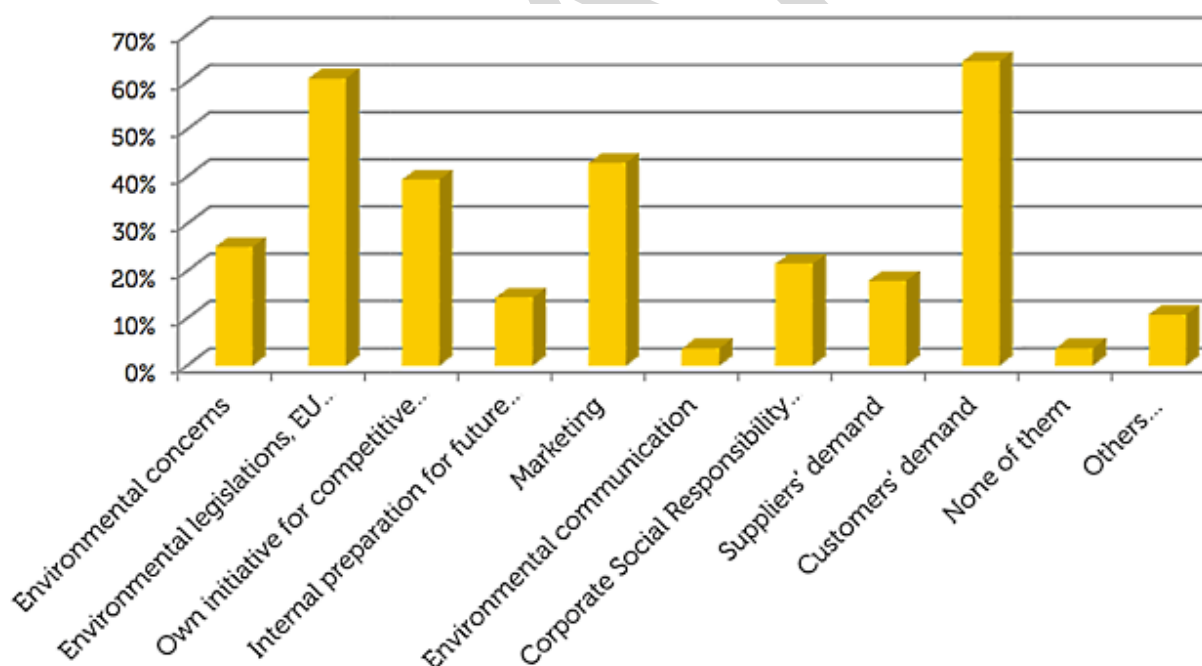
On the other hand, LCA does not necessarily have to be a costly undertaking for businesses. Free LCA tools and databases are available online (see "[Free LCA-software tools](#)" in section "Operational data"). Simplified methods, such as the LCA-to-go concept, make it possible to get started with LCA 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.

5.2.3.8 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 project¹⁰⁷. Findings suggest that environmental regulations and governmental policies are the strongest driver for firms to analyse 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 5.22. Drivers for environmental assessment (SMEs of the electronics sector)



Source: Pamminer & Schischke (2011, p.59)

5.2.3.9 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).

¹⁰⁷ www.lca2go.eu. The LCA-to-go project, 2011–2014, was financed under the European Union's Seventh Framework Programme.

ABB

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 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 PEFCE 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 LC¹⁰⁸ to expedite the implementation of life cycle assessments. EcoChain has developed a simplified LCA methodology¹⁰⁹, 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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DRAFT

5.2.4 Increasing the content of recycled plastics in EEE

SUMMARY OVERVIEW						
BEMP is to increase the use of recycled plastics in the manufacturing of EEE products, where applicable according to the required material properties. This can be achieved by closed-loop recycling of plastic production scrap, closed-loop recycling of post-consumer plastics from own products as well as purchasing recycled plastics made from post-consumer plastic waste (open-loop recycling).						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">– Share of recycled plastics used in the manufacture of a specific EEE product or product group out of the total plastics use for that product or product group (%)– Total amount of recycled plastics used in manufacturing (tonnes)– Sales of products manufactured with recycled plastics out of total sales of products (%)						
Applicability		This BEMP is suitable for many polymers that are used in EEE manufacturing. Recycled plastics can replace virgin plastics in those cases where the required material specifications can be met.				
Benchmarks of excellence		N/A				

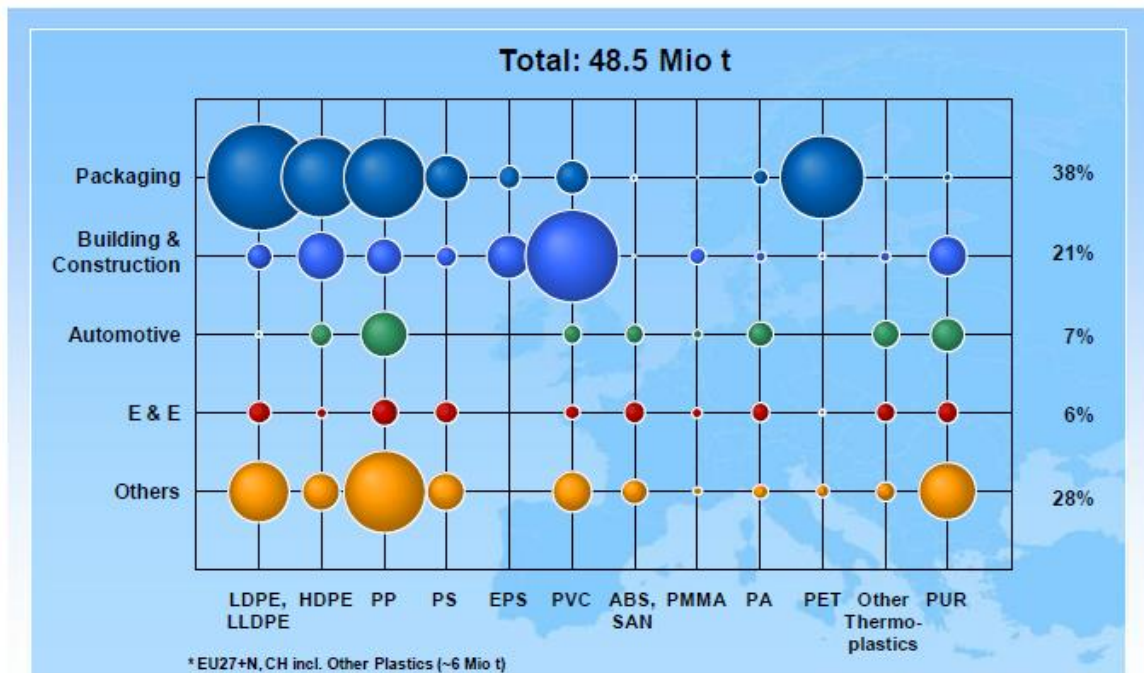
5.2.4.1 Description

Plastics play an increasingly important role among the materials used in EEE manufacturing. Since the 1980s, the mass share of plastics in electrical and electronic equipment has continuously increased (APME 2001).

According to Plastic Europe, 245 million tonnes of plastic was produced on a global basis 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 the EEE manufacturing sector only plays a significant role for certain plastic types. Important plastic types in EEE are PA; PE, PP, PS, ABS, PMMA and PCV (Mudgal et al. (2011), Sander & Wirth 2012).

Figure 5.23. Consumption of plastic according to various branches and plastic types

Europe Plastics Demand* by Segments 2008



Source: PlasticsEurope Market Research Group (PEMRG)

1

Source: Sander & Wirth (2012)

The following figure presents the polymer composition of some EEE.

Figure 5.24. Typical applications of primary polymers in EEE

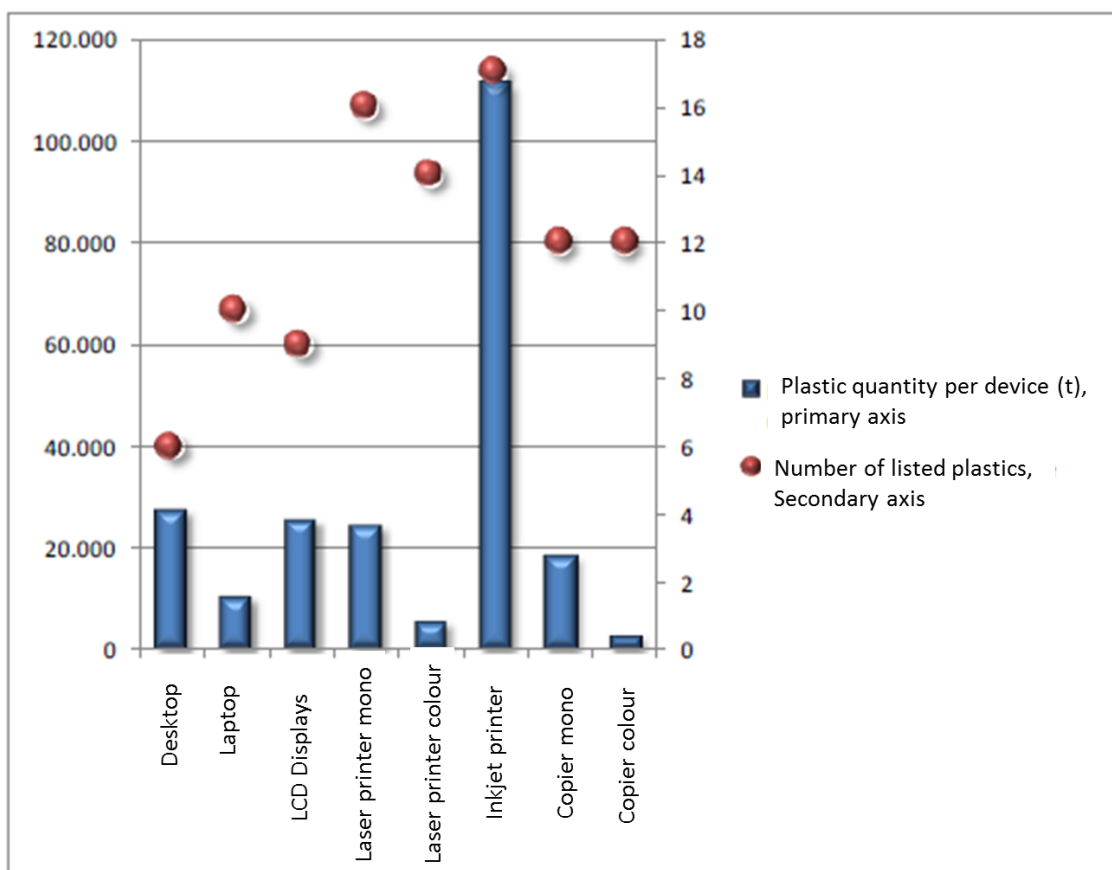
Application	Type of plastic
Components inside washing machines and dishwashers, casings of small household appliances (coffee makers, irons, etc.) Internal electronic components	PP
Components inside refrigerators (liner, shelving) Housings of small household appliances, data processing and consumer electronics	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)

There is little information available with respect to the use of recycled plastics in EEE applications. However, there is a large potential.

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) and Imaging Equipment (Lot 4). As the next figure shows, the major share of plastic waste in applications analysed by Sander & Wirth (2012) currently comes from the inkjet printers (49%). Desktop PCs, displays and monochrome laser printers each account for about 11% of the total volume of waste plastics in the selected product groups.

Figure 5.25. Potential of plastic waste in selected applications



Source: Sander & Wirth (2012)

The following figure describes the composition by polymer of the main Waste Electrical and Electronic Equipment (WEEE) items collected.

Figure 5.26. 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

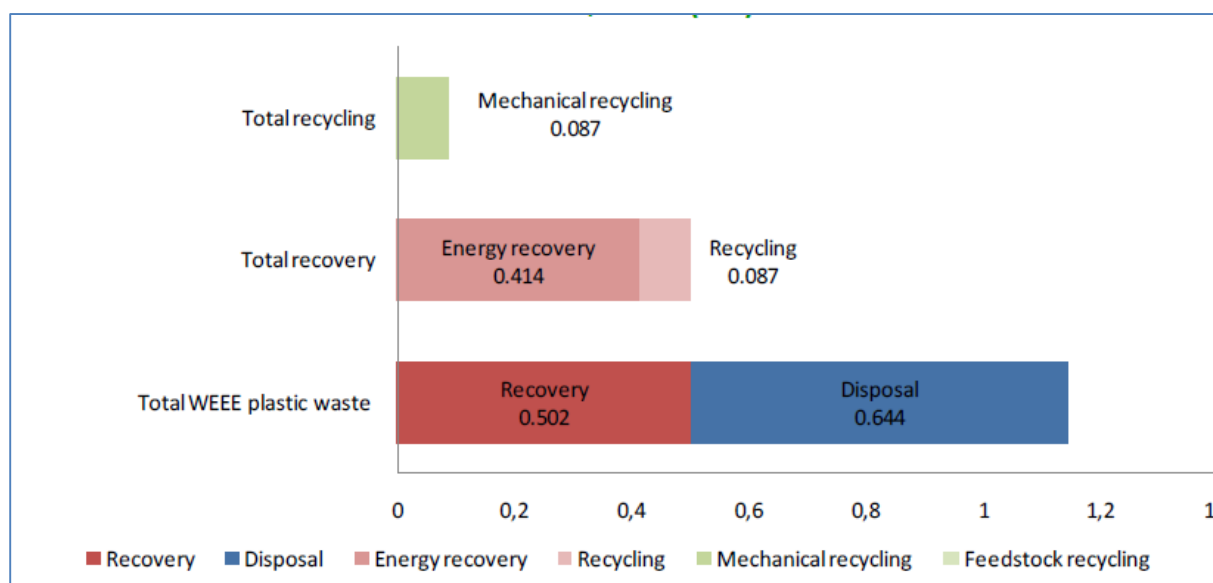
According to Mudgal et al. (2011), the complexity of WEEE items is illustrated by the fact that all items contain at least three different types of polymers. Small household appliances can contain as many as six different plastic types.

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%, was 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.

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%). Despite the low global recycling rate, some countries (e.g. Norway, Germany, and Austria) achieve recycling rates over 80% for plastic waste from EEE.

Figure 5.27. Treatment of total plastic waste from WEEE in EU-27, Norway and Switzerland, 2008 (Mt)



Source: Mudgal et al. (2011), as taken 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 (APME 2001); 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 optimise towards metal recovery, which results in waste plastic that is neither suitable for mechanical recycling nor feedstock recycling (Mudgal et al. 2011).

It is considered to be best environmental management practice for EEE manufacturers to use recycled plastics for their products wherever applicable according to the required material properties. This can be achieved by the following three approaches:

1. Closed-loop recycling of plastic production scrap;
2. Closed-loop recycling of post-consumer plastics from own products;
3. Purchasing recycled plastics made from post-consumer plastics (open-loop recycling).

As the first (and in many cases easiest option) closed-loop recycling of plastic production scrap is based on treatment and re-use of plastic scrap (e.g. rejects, trimmings, etc.) generated during the manufacturing processes of the EEE company. Since the feedstock is only based on industrial waste, this approach is also called 'post-industrial' recycling. In order to implement this approach, the EEE company can operate the recycling process

in their own premises, which would require at least the installation of shredders and re-granulating facilities, or hand over the waste material to an external service provider.

Closed-loop recycling of post-consumer plastics from own products refers to an approach where secondary plastics are obtained from the recycling of post-consumer EEE products, i.e. plastic parts of products that have reached the end of their useful service life. A key element of a closed-loop approach is the idea that recycling is performed with a feedstock based on the same product or at least products from the same company or industry (e.g. housings from computers or household appliances) that are collected in individual take-back systems.

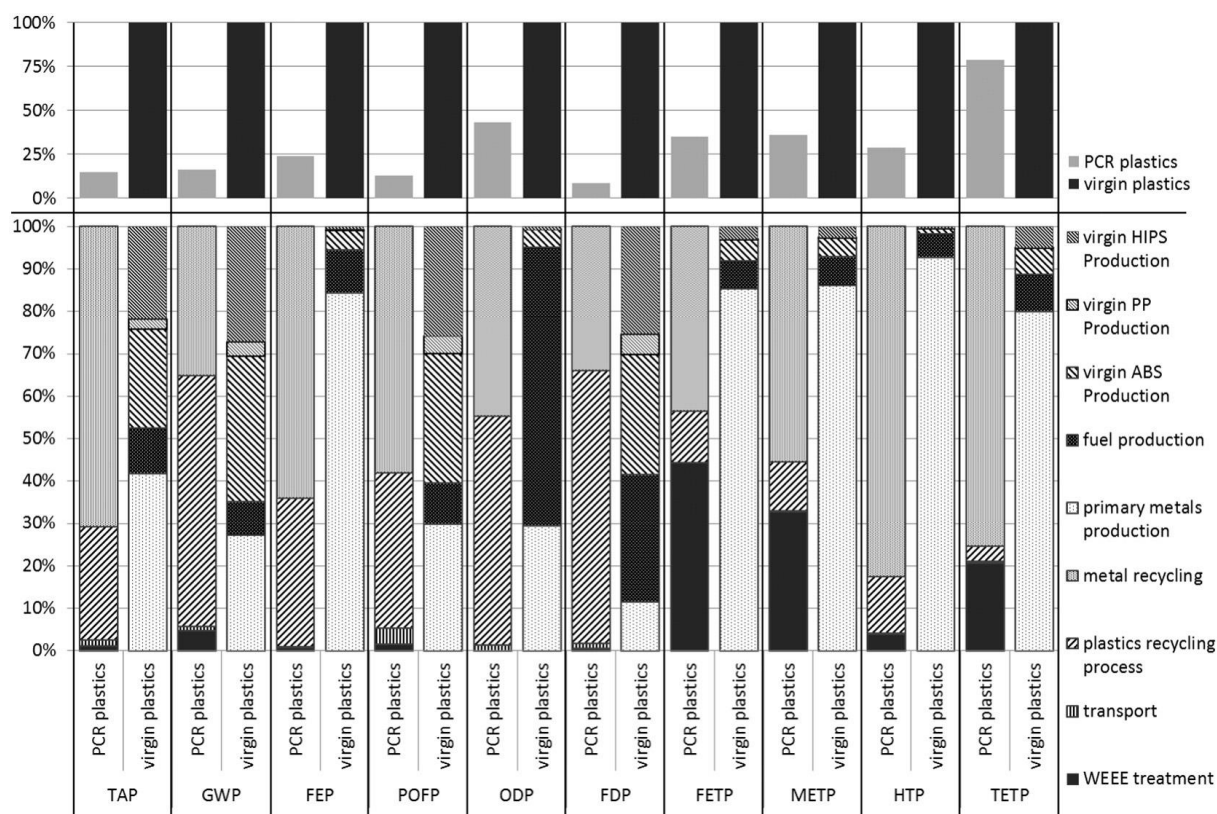
The third option to use recycled plastics for EEE manufacturing is a sourcing of secondary polymers from providers that are specialized in the recycling of post-consumer plastic waste. In this case, materials from other products than EEE can be part of the feedstock, and the materials are recycled in an open loop. Currently, the product portfolio of available secondary plastics encompasses acrylonitrile-butadiene-styrene (ABS), high impact polystyrene (HIPS), blends of polycarbonate with ABS (PC/ABS), polypropylene (PP), mineral-filled PP and high-density polyethylene (HDPE).

5.2.4.2 Achieved environmental benefits

The use of recycled plastics during the manufacture of EEE is an important contribution to resource efficiency: it decreases the demand for virgin polymers, which finally results in a reduced demand for primary resources, and namely crude oil.

Furthermore, the recycling of plastics has significant environmental benefits compared to the virgin production of plastics in terms of environmental issues, such as climate change, acidification, eutrophication, human toxicity and eco-toxicity. In a recent study, Wäger & Hirsch (2015) exhaustively investigated the life cycle environmental impacts associated with the production of post-consumer recycling (PCR) plastics from the mixed, plastics-rich WEEE in an operational, state-of-the-art plastics recycling plant (sections "Operational data" and "Reference organisations" below). The environmental impacts were determined by means of a life cycle assessment (LCA) approach and ReCiPe, the most recent LCA impact assessment method. The study comes to the conclusion that the use of recycled plastics results in global warming potential and a fossil depletion potential that is five to six times lower than that of the virgin plastics production. Also the other LCA impact categories (like acidification, eutrophication, human toxicity and eco-toxicity, etc.) are significantly lower (see following figure):

Figure 5.28. Environmental impacts associated with the production of 1 tonne of plastics from post-consumer recycling (PCR plastics) and primary production (virgin plastics)



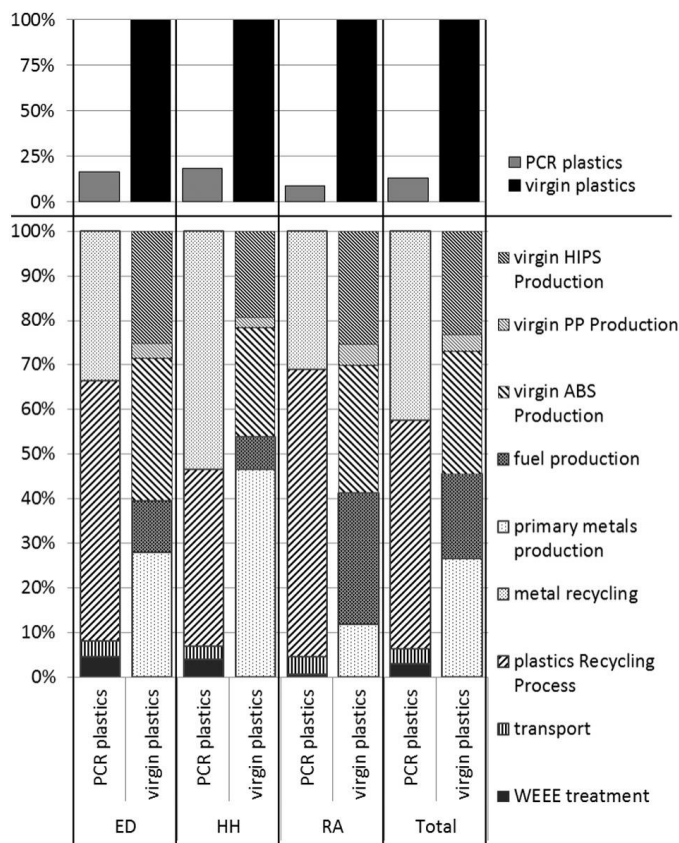
Note: The upper part refers to total values, relative to the option with the higher impacts; the lower part shows split into the individual process steps for each option. Shown are the ReCiPe mid-point indicators terrestrial acidification potential (TAP), global warming potential (GWP), freshwater eutrophication potential (FEP), photochemical oxidant formation potential (POFP), ozone depletion potential (ODP), fossil depletion potential (FDP), freshwater ecotoxicity potential (FETP), marine ecotoxicity potential (METP), human toxicity potential (HTP), and terrestrial ecotoxicity potential (TETP).

Source: Wäger & Hirschier 2015

Concerning the contributions to the overall results, Wäger & Hirschier (2015) show that the process steps of the actual recycling activity (i.e. WEEE treatment, transport and the subsequent plastics recycling process) are responsible for about 70% of the total impact of the PCR plastics system. Within the virgin plastics production system, the production of the primary plastics accounts for 50–60% of the total impact. The remaining part is in both cases largely dominated by the respective metal treatment process step.

In addition to the results for the mid-point impact categories shown above, it is interesting to note that results for the endpoint impact categories like "Ecosystem Diversity" (ED) go in the same direction (see following figure). Concerning those endpoint impact categories, virgin plastics production has an impact exceeding that of the PCR plastics production by a factor of six to ten.

Figure 5.29. Environmental impacts associated with the production of 1 tonne of plastics from post-consumer recycling (PCR plastics) and primary production (virgin plastics)



Source: Wäger & Hirschier 2015

Note: The upper part refers to total values, relative to the option with the higher impacts; the lower part shows the split into the individual process steps for each option. Shown are the ReCiPe endpoint results for the damage categories "Ecosystem Diversity" (ED), "Human Health" (HH), and "Resource Availability" (RA), as well as the total impact.

These results are confirmed by other studies on plastics recycling, which, however, mainly focus on other mostly pure plastics fractions (Lazarevic et al., 2010; Rajendran et al., 2012, WRAP 2010), and provide the necessary evidence for the environmental benefits that are associated with use of recycled plastics, not only within EEE manufacturing.

These results are in line with the data from MBA Polymer, a front-running producer of PCR plastics (see section "Reference organisations"), which considers that its products save 80-90% of energy and 1-3 tonnes of CO₂ per tonne (MBA Polymers 2012).

However, in some cases, the properties (e.g. mechanical properties) of the PCR plastics do not exactly match those for virgin plastics. Therefore, for certain applications, PCR plastics cannot provide exactly the same functionalities (see section "Applicability"). Moreover, further limitations may be posed by the presence of hazardous substances in the post-consumer recycled polymers.

5.2.4.3 Appropriate environmental performance indicators

An appropriate metric for assessing progress in the implementation of this BEMP is the share of recycled plastic used in the manufacture of EEE out of the total amount of plastics. As most EEE manufacturing companies have a wide range of different products, it is most meaningful to apply this indicator at the product / product group level (e.g. desktop computers).

In order to get an impression of the absolute relevance of plastics for the manufacturing operations of the company, the total amount of recycled plastics used (absolute figure) can be used as a complementary indicator.

Metrics	Description
%	Share of recycled plastic used in the manufacture of a specific EEE product or product group out of the total plastics use for that product or product group
kg or tonnes	Total amount of recycled plastics used in manufacturing

For the monitoring the overall relevance of the approach of using recycled plastic throughout the product portfolio, the following indicator can be useful:

Metrics	Description
%	Sales of products manufactured with recycled plastics out of total sales of products

When using this indicator, a company should also specify what is the minimum threshold of the share of recycled plastics considered for inclusion of a product in the indicator. In other words, they should clarify whether they report the share of products with a large share of recycled plastics (e.g. at least 35% or 50%) or whether products with only a minor share of recycled plastics (e.g. at least 1%) are also taken into account.

5.2.4.4 Cross-media effects

The production processes for recycled polymer plastics require the utilisation of various resources for the collection and processing of recycled content (water, energy, etc.) and are responsible for generating various emissions (greenhouse gases, gases contributing to acidification, eutrophication and photochemical oxidants, etc.). However, the LCA-based comparison of the manufacture of recycled materials with the alternative use of virgin materials has clearly shown that, from an environmental perspective, the use of recycled plastics is beneficial. This depends however, on various factors such as the logistics of collection and processing of polymer waste (see section "Achieved environmental benefits").

Another cross media effect lays in the potential presence of hazardous substances in the recycled plastics. Several studies have shown that substances of concern may be found in plastics from WEEE at levels that exceed maximum concentration values for new products defined in the European RoHS Directive. This includes substances that have deliberately been introduced into the plastics matrix (e.g. flame retardants and plasticizers) during primary production as well as substances accidentally introduced through cross-contamination during pre-treatment of WEEE. Cadmium used in pigments (Schlummer et al. 2007) or commercial polybrominated diphenyl ethers (PBDE) like c-pentaBDE, c-octaBDE or c-DecaBDE used as flame retardants (Morf and Taverna 2004; Morf et al. 2005; Peeters et al. 2014; Schlummer et al. 2007; Vyzinkarova and Brunner 2013; Wäger et al. 2012) are examples of deliberately introduced substances. Lead from printed circuit boards (Schlummer et al. 2007; Wäger et al. 2012) is an example of an accidentally introduced substance. Therefore, the production of post-consumer plastics from WEEE requires a separation of these substances and/or of the plastics containing these substances to a level that is compliant with legal requirements (Wäger et al., 2012).

Finally, in order to bring the properties of the recycled material to the level of performance of virgin plastics, additives may be necessary in the compounding of various plastic polymers (such as recycled PP and PET resins). The possible hazardous properties of such additives need to be carefully considered when determining the choice of substances to be used, to avoid negative cross-media effects in terms of toxicity.

5.2.4.5 Operational data

This section provides further details and operational data on the three approaches to increase the content of recycled plastics in EEE products introduced in the 'Description' section.

Closed loop recycling of plastic production scrap

Closed-loop recycling of production plastic scrap (e.g. rejects, trimmings, etc.) generated during the manufacturing processes of the EEE company represents the first and in many cases the easiest option for recycling plastics, because the waste material is often of single origin and has defined parameters. Since the feedstock is only covering industrial waste, this approach is also called 'post-industrial' recycling.

This can be implemented by EEE manufacturers either operating the recycling process in their own premises, which would require at least the installation of shredders and re-granulating facilities, or providing the waste material to an external company specialized in the procurement of a large variety of different industrial plastic scrap (covering many standard polymers like PE, PET, PMMA, PP, PVC, etc.) for recycling and re-purposing that industrial plastic back through the manufacturing supply chain. In-house recycling is only feasible in the case of large amounts of waste material of one or a limited number of different polymers. Regardless of the chosen approach, it is of key importance to avoid contamination or mixing different plastics.

Due to its limited complexity, closed-loop recycling of production waste has already been implemented in several companies. One example is Kärcher, a German producer of high-pressure cleaners, where the process started in 2013. After having tested the approach for two years, in 2015, 78 tonnes of standard polypropylene production waste were recycled and used as granulate in the company's own manufacturing processes (Kärcher 2016).

Closed-loop recycling of post-consumer plastics from own products

Closed-loop recycling of post-consumer plastics refers to an approach where secondary plastics are obtained from the recycling of post-consumer EEE products. A key element of a closed-loop approach is the idea that recycling is performed with a feedstock based on the same product or at least products from the same company or industry (e.g. casings from computers or household appliances) that are collected in individual take-back systems.

A current example of this approach is the OptiPlex™ desktop by Dell. Previously, the company used recycled-content plastics derived from water bottles and other plastic sources, and has recently shifted to a closed-loop system based on plastics from computers. The recently launched OptiPlex 3030 All-in-One™ is made with third party-certified¹¹⁰ closed-loop recycled plastics. The customers can return their old systems via a company-specific collection system. After separating out plastics, they are sorted into types and shipped to manufacturing partners in China. Within the same procedure, other materials from the computers are separated as well and subsequently sold on the commodities market. At the partner companies in China, the polymers are shredded, melted and blended (currently 35% recycled content), and then moulded into new parts (back plate of the computer/monitor) and finally assembled into the computer. As recycling and take-back efforts increase, Dell plans to extend the approach on other materials such as metals (Dell 2016).

Another example of closed-loop recycling of plastic was established by Sharp and Kansai Recycling Systems Co. Ltd. The two companies jointly developed a 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 2001. By combining a high-efficiency metal removal line, high-purity PP (polypropylene) separation and recovery technology, and other property

¹¹⁰ The product is certified by UL Environment to their closed-loop standard.

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 (Sharp 2012).

Furthermore, well-established closed-loop recycling of post-consumer plastics can be observed in the manufacture of inkjet printing and laser cartridges. Even though cartridge recycling is not the best option according to the waste hierarchy (they can be refilled and re-used rather than sent for recycling¹¹¹), it can serve as an illustrative example how closed-loop recycling can be implemented.

Printer cartridges are manufactured from different polymers. 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 2014b).¹¹² Both Lexmark and Canon manufacture laser toner cartridges, among others with high-impact polystyrene (HIPS) (Lexmark 2014a; Canon 2014a).

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. The recycling of both PET and PP have enabled HP to manufacture more than 75% of new inkjet cartridges and 24% of laser jet toner cartridges with recycled plastic content. At the end of January 2014, HP had used more than 62,000 tonnes of recycled content material in the manufacturing of over 2 billion new ink and toner cartridges (HP 2014c).

Lexmark also 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. It reports an average content of 18% of post-consumer plastics in cartridges in 2016, aspiring to increase it to 25% by 2018 (Lexmark 2016).

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" (Canon 2014a).

HP is using plastic bottles and clothing hangers (respectively) to supplement the supply of PET and PP for their cartridges; 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.

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. The programs practiced by Canon, HP and Lexmark demonstrate how a manufacturer can successfully blend two different incoming streams of used plastic to ensure a steady supply: a close-loop source and an external stream such as upcycled bottles and hangers. This stops leakage and cascaded recycling that Circular Economy seeks to minimise. Increasing the amounts of recycled content are

¹¹¹ 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 allows cartridges to be re-used.

¹¹² HP uses both materials across a variety of cartridge types, and 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)

considered to be of key importance in order to foster the shift away from virgin materials.

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 cartridges is important for raising the efficiency of such schemes. To allow for easier recycling of plastics, different plastics need to be separable from each other as well as from other materials such as metals. To this end, some manufacturers have changed product design. Canon, for example 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).

Purchasing recycled plastics made from post-consumer plastics (open-loop recycling)

The third option to use recycled plastics for EEE manufacturing is a sourcing of secondary polymers from companies recycling post-consumer plastics of different origins.

For example, Electrolux has selected MBA Polymers as supplier for their AEG-Electrolux "UltraActive Green" vacuum cleaner in 2009. The purchased post-consumer ABS allowed Electrolux to increase the use of recycled materials to 55% for the body of this product at that time (MBA Polymers 2009). In its current products, a recycled plastic share of up to 70% has been reached (Electrolux 2015).

Their provider, MBA Polymers (see also section "Reference organisations"), operates a plant for treating post-consumer material from all over Europe. The process allows the mechanical separation of the polymeric material from the other materials, and the obtained recyclates are sold for re-use in specific applications, including consumer electronics (MBA Polymers 2016a).

This plant produces post-consumer plastics from automotive shredder residues, consumer electronic devices, appliances and other end-of-life durable goods. In detail, the processes begin with a size reduction of the material input, include the removal of non-plastics (metal, rubber, wood, glass, fluff, foam, textiles, dirt etc.), washing and preparation (clean plastics and remove non-target plastics), polyolefin purification (cleaning-sorting of PP and PE), styrenics purification (cleaning-sorting of ABS and HIPS) and end with formulation, blending and compounding (MBA Polymers 2012).

The product portfolio encompasses acrylonitrile-butadiene-styrene (ABS), high impact polystyrene (HIPS), blends of polycarbonate with ABS (PC/ABS), polypropylene (PP), mineral filled PP and high density polyethylene (HDPE) products. The company stresses that the sourcing is from 100% post-consumer feedstock, which is consequently diverted from landfilling or incineration. Typical target products for the recycled ABS polymers include housings for vacuum cleaners, while HIPS (High-Impact PolyStyrene) can be used for printer casings.

MBA Polymers also offers a premium grade product (EvoSource™) for applications that demand UL-HB recognition (referring to special flammability tests) and provides support to comply with external labels, such as the German 'Blue Angel' and EPEAT (Electronic Product Environmental Assessment Tool) by the NGO 'Green Electronics Council' (MBA Polymers 2012). EEE applications using MBA Polymers EvoSource™ plastics encompass coffee machines, copiers, printers and vacuum cleaners (MBA Polymers 2016b).

5.2.4.6 Applicability

This BEMP is suitable for many polymers that are used in EEE manufacturing. However, the technical properties of recycled plastics in some cases do not exactly correspond to those of the equivalent virgin plastics. Accordingly, the recycled plastics only can replace virgin plastics in those cases where they comply with the specifications of the customer or where they can be modified with standard additives (such as impact modifiers) to meet the desired specifications.

In a study of the Waste & Resources Action Programme (WRAP 2010) it could be demonstrated that using recycled WEEE-derived plastics in high-performance electrical products is a viable technical and economic option. WRAP worked together with two global electronic companies, Bowers & Wilkins and Meridian, to trial recycled plastics in place of the virgin plastics used at the time for the components:

- 800 series hi-fi loudspeakers by Bowers & Wilkins (B&W);
- 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;
- 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 needed further modification to match colour and gloss level. The use of PC-ABS, however, proved more problematic, highlighting the need for mould designs to be considered to accommodate recycled material 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.

Another 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).

Concerning the specific process of closed-loop recycling, two interesting lessons can be learned from the experience of HP to improve the applicability of such approach (Ord 2014b):

- the use of alternative post-consumer plastic streams is important to ensure a steady supply of recycled plastics;
- creating long-term relationships with recyclers (i.e. suppliers) enables the recycling of plastics with a technically demanding mechanism, while also having a positive impact on the quality, quantity and costs of recycled plastics.

5.2.4.7 Economics

The costs for the recycling of plastics include costs of the collection mechanism, costs for sorting, disassembly and handling of collected items as well as costs for re-granulating and compounding recycled material that can be used in production.

According to Ord (2014c), the factors that need to be considered to determine the economic feasibility of switching from virgin to recycled plastics include:

- Collection costs;
- Recycling costs (cost of capital, inputs, and labour);
- Recovery rate of recycling process;
- Recycled material content in the target product as well as
- Commodity prices.

Depending on the complexity of the recycled product and the process itself, the recovered plastic can cost more or less compared to virgin resin (the price of which also varies over time due to demand and the price of feedstock). In the case of recycled PET and PP, for instance, their price is competitive with the price of virgin material. Recycled material 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's experience with the recycling of printer cartridges, with the exception of collection costs, the recycling processing costs of printer cartridges can largely be offset through the recovery and re-use of the plastics and precious metals resulting from the process. Other factors of influence include increasing virgin plastic prices, continuous improvement of recycling process efficiencies and continued progress on product design for recycling (Ord 2014d).

For other polymers, different constraints concerning the economic feasibility for their recycling have been reported. Peeters et al. (2014) estimate the total processing cost for recycled blends of PC and ABS, under a scenario with manual disassembly, to be around 60% of the price of virgin material. For a scenario with automated sorting and density separation, the processing cost can drop to approx. 25% of the virgin price.

Moreover, in the case of waste arising at the EEE manufacturer, it needs to be considered that costs of 100–160 EUR/tonne for transporting and incinerating plastics with energy recovery can be avoided by recycling those plastics (Salhofer et al. 2011).

5.2.4.8 Driving force for implementation

Economic aspects (section 5.2.4.7) are among the major driving force for the implementation of this BEMP.

Another important rationale is the WEEE Directive which in particular aims at reducing the disposal of waste and at contributing to the efficient use of resources by re-use, recycling and other forms of recovery. With the recycling targets that have increased after the recast of the Directive (2012/19/EU entered into force on 13 August 2012 and became effective on 14 February 2014), the waste fraction of plastics is considered to be of key importance in terms of reaching the defined recycling and recovery targets.

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 are also interested in increasing the use of recycled plastics.

Another driving force for some companies is the requirements in terms of content of recycled plastics set by some eco-labels. These levels vary considerably between the different type I eco-labels such as the Blue Angel, Nordic Swan, EcoMark, EPEAT and the TCO Label "TCO Certified Edge Displays". As an example, the following figure shows the EPEAT criteria for the material selection of imaging equipment.

Figure 5.30. EPEAT criteria for the use of post-consumer plastic (R=Required; O=Optional)

4.2 Materials selection	
R	4.2.1.1 Declaration of postconsumer recycled plastic content
R	4.2.1.2 Minimum content of postconsumer recycled plastic
O	4.2.1.3 Minimum 5% to 10% content of postconsumer recycled plastic
O	4.2.1.4 Minimum 25% content of postconsumer recycled plastic
R	4.2.2.1 Declaration of biobased plastic materials content
O	4.2.2.2 Minimum content of biobased plastic material
R	4.2.3.1 Declaration of product weight

Source: EPEAT (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).

Finally, another driving force for the use of recycled polymers, reported e.g. by HP, has been the general shift towards design for the environment and design for recycling (Kaminski 2014). For instance, prototypes of new inkjet cartridges are sent to the cartridge recycler to check recycling efficiencies and identify aspects that can be changed in design before mass production (PDR 2014).

5.2.4.9 Reference organisations

The following examples of organisations that have successfully implemented this BEMP:

- **Canon:** The company practices closed-loop recycling for laser toner cartridges with high-impact polystyrene (HIPS) (Canon 2014a).
- **Electrolux:** The producer of household appliances has chosen MBA Polymers (see below) as ABS supplier for its brand 'AEG'. Currently, a recycled plastic share of up to 70% has been reached in selected products (MBA Polymers 2016b; Electrolux 2015).
- **HP:** HP 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 2014b).
- **Lexmark:** Lexmark implemented a closed-loop toner cartridge recycling practice with HIPS and 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 2018 (Lexmark 2016).
- **Kärcher:** The German producer of high-pressure cleaners introduced a process for the closed-loop recycling of polymer-based production waste to be reused in the company's own manufacturing processes (Kärcher 2016).
- **MBA Polymers:** The company operates plants for WEEE treatment in Austria, the UK and China with an annual processing capacity of 175,000 tons. Whereas the plants in

Austria and China focus on recycling of WEEE, a facility specialized on plastics recycling was opened at Worksop (UK) in 2010 (MBA Polymers 2012).

- **Sharp:** Since 2001, Sharp introduced closed-loop plastic material recycling technology to recover plastic from used consumer electronics and reuse it in parts of new consumer electronics for the Japanese market. The company uses 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 refrigerators (Sharp 2012).

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- | | |
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5.2.5 Protecting and enhancing biodiversity along the EEE supply chain

SUMMARY OVERVIEW						
BEMP is to develop and implement a program for managing biodiversity impacts related to supply chain products and supply chain activities.						
Based on a mapping of products and materials provided by the supply chain and of their relevant impacts on biodiversity, procurement guidelines and requirements can be formulated, targeting changes in relation to products and components with a larger potential to impact biodiversity.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">• Implementation of a periodic assessment of biodiversity impacts of products and materials provided by the supply chain (y/n)• Formulation of procurement guidelines and requirements for the most relevant products and materials identified in the biodiversity assessment (y/n)• For each of the groups of products (e.g. wood and paper products) for which procurement requirements have been developed by the company:<ul style="list-style-type: none">◦ Share of products qualifying as priority procurement (%)◦ Share of products qualifying as acceptable procurement (%)◦ Share of products qualifying as procurement to be avoided (%)• The share (by purchase volume) of suppliers that have provided initial reporting as to their potential impacts on biodiversity (%)• The share (by purchase volume) of suppliers that have developed a biodiversity management plan (%)• The share (by purchase volume) of suppliers that are implementing their biodiversity management plan (i.e. making progress towards achieving set targets) (%)						
Applicability		Applicable to all EEE manufacturing companies.				
Benchmarks of excellence		<ul style="list-style-type: none">• The company implements a programme for a periodic assessment of biodiversity impacts of products and materials provided by the supply chain and the results of the assessment are used to formulate procurement guidelines and requirements on the most relevant products and materials.				

5.2.5.1 Description

With the exception of businesses in the primary sector, the main negative effects on biodiversity caused by most businesses are usually associated with their supply chains. Almost all raw materials and (intermediate) products obtained by the purchasing department of a business are in some way associated with biodiversity-related environmental effects. These may take various forms, such as impacts on ecosystems

caused by mining and extraction of raw minerals, by the planting of monoculture forests for producing paper, etc. (KNU & LCF 2015)

The BEMP on "Protecting and enhancing biodiversity" (section 4.2.8), deals with measures implemented by EEE manufacturers at their own manufacturing facilities to contribute to the well-being of eco-systems on a local basis. However, through applying measures for promoting the protection and enhancement of biodiversity in the supply chain, EEE manufacturers can extend the range of their contribution. Through the implementation of suitable procurement guidelines and requirements, EEE manufacturers can influence biodiversity both directly, through the purchase of products which may impact the ecosystem at the place where they are used (e.g. cleaning products or lubricants used by EEE manufacturers), and indirectly, by influencing the production and manufacture of resources and components provided by the supply chain, which have biodiversity effects during their production.

As already explained in the section 5.2, electronics supply chains are very complex networks with many different actors performing different functions. Therefore, the production of materials and resources relevant to the EEE sector must be examined closely to identify those activities that impact biodiversity more significantly. Such activities can be influenced by working with the supply chain to enhance biodiversity protection and to manage activities that impact biodiversity. It is thus considered best environmental management practice for EEE manufacturers to develop and implement a program for managing biodiversity impacts related to supply chain products and supply chain activities.

Managing impacts related to supply chain products refers to specific products that have a biodiversity impact (e.g. when the EEE manufacturer uses them). Action is through introducing certain criteria to procurement specifications/guidelines that address the specific product. This gives preference to a product with certain qualities in procurement. Though this could also influence supplier activities, it is expected that the impact is in relation to a specific product or product group.

Managing impacts related to supply chain activities, instead, refers to changing the activities of the supplier not just in relation to one product but in a more comprehensive way. Action is introduced by requiring the supplier to adjust its activities across all or most of its operations. This may or may not impact directly the product being procured, but will address the general biodiversity impact of the supplier.

A program for managing supply chain biodiversity impacts must first identify supply chain products and activities with the largest potential to impact biodiversity. This should be done through a mapping exercise of products and materials provided by the supply chain and of their relevant impacts on biodiversity. Impacts depend on the nature of the material or component (e.g. having a potential for impacts of ecosystems during use), or it may depend on the way that components or materials are produced and where this takes place (e.g. in case damaging emissions can enter the environment and have adverse effects on the eco-systems of the production place).

Subsequently, procurement guidelines and requirements can be formulated, targeting changes in relation to those products and components with a larger potential impact on biodiversity. Progress towards their implementation can be periodically monitored to assess improvements.

Measures can be developed according to two different approaches or combining both:

- The first approach is more appropriate to short term suppliers or in fields where there is already a range of suppliers providing products/materials/services with a lower impact on biodiversity. It entails giving preference to procurement of products and materials that have a lower impact on biodiversity.
- The second approach is more relevant for long term suppliers as it principally entails working together with suppliers on the development of their own biodiversity management practice. This approach gives preference to suppliers that are

developing and implementing measures to reduce and remediate biodiversity impacts linked to their activities.

The first approach is to be implemented by formulating requirements in procurement guidelines as to certain properties of procured goods or as to how they are to be produced. For example procurement criteria should be formulated to create a preference for purchasing FSC¹¹³ paper for product packaging or for purchasing biodegradable cleaning materials. Similarly criteria could be developed for non-toxic solvents for use in the EEE manufacturing production process. When located in areas with water scarcity, suppliers of components the production of which requires significant amounts of water can be required to apply and document measures for managing and reducing water consumption. Suppliers of mineral resources can be required to document the origin of resources and the proximity of biodiversity hot-spots as well as measures implemented to reduce impacts on such eco-systems or to remediate possible impacts.

The second approach is to be implemented by requiring suppliers to develop their own programmes for managing biodiversity impacts, including the setting and fulfilment of targets for reducing the biodiversity impacts of their activities. Such activities can be supported by providing suppliers with, for instance, guidance documents or informative seminars, on the one side and by auditing implementation on the other side, in particular with long term suppliers. Suppliers that adopt such a program and, overtime, present documented results of its implementation are given preference in procurement.

5.2.5.2 Achieved environmental benefits

Conditions and criteria developed by EEE manufacturers that suppliers are required to fulfil in relation to their operations can result in environmental benefits and as such, where they are initiated or promoted by procurers (such as EEE manufacturers), their benefit, or a portion thereof, can indirectly be associated with the activities of the procurer.

Additionally, when an EEE manufacturer purchases cleaning products or solvents that are more environmentally friendly, this reduces its impacts on biodiversity at the place of their application. This can also be the case where the supply chain provides certain components or substances that may be associated with a risk of emissions to the environment (such as leakage of refrigerant agents, lubricants etc.). In such cases, procurement that gives preference to available alternatives with reduced negative impacts on adjacent eco-systems creates benefits for biodiversity.

The extraction of resources can also have potential impacts on the ecosystem. For example metallic raw materials such as gold and tantalum used in the production of electronic equipment are primarily mined in countries that have an extensive biodiversity (KNU & LCF 2016). Tin mining creates various impacts on ecosystems, both if mined on land or on the sea bed. The former can cause pollution of water sources, loss of soil fertility and change of landscape. In the latter, silt and sludge can harm corals, sea grass, mangroves and water fauna such as turtles, fish and clams (FOE, 2012). Procurement requirements that give preference to metals sourced from mines that apply measures to prevent negative impacts on adjacent eco-systems or to remediate impacts that cannot be prevented, result in benefits for biodiversity, as such impacts are reduced.

In a report of 4EEIA (2013) on biodiversity conservation case studies, it is specified that procurement of raw materials, for the manufacture of EEE and its components, can result in various impacts on biodiversity. For each impact, an action aimed at reducing or preventing such impacts is recommended:

- Identifying, reducing and eliminating the use of minerals sourced from mines with an impact on biodiversity (e.g. located in biodiversity hotspots and where care is not

¹¹³ The Forest Stewardship Council (FSC) certification ensures that products come from well managed forests that provide environmental, social and economic benefits. For more information see <https://ic.fsc.org/en/certification>

taken to prevent or remediate impacts on ecosystems) can prevent the destruction of the ecosystem due to development of mineral resources and rare metal mining.

- The assessment of efforts made by suppliers to consider ecosystem management, based on Green Procurement Guidelines, can promote the reduction or remediation of environmental impacts due to light, noise and vibrations of factories as well as emissions to water, air and soil of chemical compounds.
- Encouraging suppliers towards the reduction of wastes, of CO₂ emissions and of the use of chemical compounds can assist in reducing atmospheric changes related to greenhouse gas emissions.
- Procurement of materials that consider biodiversity, for example FSC products (i.e. certified to be sourced from sustainably managed forests) can reduce impacts related to the use of biological materials such as and wood and wood pulp resources.

5.2.5.3 Appropriate environmental performance indicators

The indicators for quantifying the degree of implementation of biodiversity management in the supply chain and the related benefits to the environment need to be tailored to the specific approach implemented.

Through the monitoring of the shift of procured products from ones associated with negative impacts on the ecosystem to others considered to be more sustainable, a range of benefits achieved through procurement of products used by the EEE manufacturers can be estimated. EEE manufacturers focusing on requirements for products need to develop indicators in relation to the specific areas of activity addressed through the procurement requirements. Progress should be measured in relation to actual procurement, allowing a para-quantification of the benefits of the applied procurement measures. For example, in relation to procured wood and paper products (e.g. used for packaging), procurement guidelines can define designations for products manufactured from different wood sources according to their sustainability. Where targets have been set for shifting from the procurement of products considered less sustainable to those considered as more sustainable, the share of procurement of products of a certain designation can be monitored to establish the degree of implementation of such targets. For example, at first stages, a target can be set that a certain share, such as 50% of all procured products must be of the two highest designations. More progressive targets should be set for the following years to allow a gradual improvement and/or a target year for achieving 100% procurement of products of the highest designation. The following table provides an example of a designation for wood and paper products and a method for their monitoring.

Metrics	Description
%	Share of wood and paper products qualifying as priority procurement: Products from timber certified by a third party that the supplier does not harm forests with high environmental conservation values and that the supplier conducts sustainable forest management; or products of recycled origin.
%	Share of wood and paper products qualifying as acceptable procurement: Products from timber confirmed as legally logged.
%	Share of wood and paper products qualifying as procurement to be avoided: Products from timber not confirmed as legally logged.

Similar targets and indicators should be developed for each of the groups of products (e.g. biodegradable products used for cleaning) for which procurement requirements have been developed by the company.

These indicators can be summed up as:

For each of the groups of products (e.g. wood and paper products) for which procurement requirements have been developed by the company:

- Share of products qualifying as priority procurement (%)
- Share of products qualifying as acceptable procurement (%)
- Share of products qualifying as procurement to be avoided (%)

Where EEE manufacturers attempt to encourage their suppliers to start monitoring and reducing their impacts on biodiversity, the indicators allow to monitor progress throughout the supply chain, but any quantification of the environmental benefits achieved is challenging, both in terms of collecting sufficient data and in terms of how to allocate certain benefits back to the EEE manufacturer.

Manufacturers that have developed such practices often monitor the amount of suppliers who have implemented a scheme to monitor and yield biodiversity benefits as well as the stage of implementation of the scheme (where targets have been set and the degree to which they have been achieved). Progress can be monitored as follows:

Metrics	Description
%	The share (by purchase volume) of suppliers that have provided initial reporting as to their potential impacts on biodiversity;
%	The share (by purchase volume) of suppliers that have developed a biodiversity management plan;
%	The share (by purchase volume) of suppliers that are implementing their biodiversity management plan (i.e. making progress towards achieving set targets).

Additionally, the biodiversity impacts of products and materials provided by the supply chain along with the formulation of procurement guidelines and requirements for the most relevant products and materials should be addressed by the following two qualitative indicators:

- Implementation of a periodic assessment of biodiversity impacts of products and materials provided by the supply chain (Y/N)
- Formulation of procurement guidelines and requirements for the most relevant products and materials identified in the biodiversity assessment (Y/N)

5.2.5.4 Cross-media effects

Implementing actions with the aim of reducing a certain environmental impact can also lead to negative environmental impacts, when decisions are taken on a partial knowledge basis and without considering possible effects that an activity may have on other environmental media.

For instance, although products manufactured from timber of tree plantations can substitute the sourcing of wood from natural forests, plantations may negatively impact the environment when they are managed as monocultures and thus reduce local biodiversity. Agricultural practices of such plantations may also be less sustainable where pesticides or fertilizers are applied to increase yields. Although such cultivation activities are an alternative to deforestation and illegal logging in forest areas with a high level of

biodiversity, it needs to be ensured that they do not result in their own negative impacts on biodiversity. Thus, when addressing such products in procurement requirements, care must be taken to differentiate between forestry practices that are truly sustainable and beneficial to the environment and those that are not.

A further aspect worth noting is related to shifting supply to biodiversity aware suppliers, where they exist, to reduce the biodiversity impacts in the short term. In the longer term, this approach is only sustainable if the efforts of a supplier, which has developed a plan to reduce its biodiversity impact but may be still in initial implementation stages, are sustained. Through accompanying the procurement with a requirement to fulfil certain targets within a given time, an EEE manufacturer can support biodiversity benefits in the long term while also ensuring a better supply of goods with lower impacts on biodiversity in the future. Thus care should be given to diversify when setting targets for the share of procurement of certain goods to allow a short term improvement through a certain share of goods but also to promote a long term process through other shares of procurement.

5.2.5.5 Operational data

The EEE supply chain is very complex. Associating certain materials or components with possible risks to biodiversity can be a challenging task and understanding where impacts may be relevant along the supply chain adds to the challenge. OEMs which would like to develop a biodiversity management practice in relation to their supply chain activities need to start by **mapping the various components and materials procured** and understanding the potential that these may have to impact biodiversity.

Although EEE manufacturers are recommended to map their own supply chain in this respect, a number of EEE associations have also made an effort of identifying areas that may be of relevance. As a response to the "Aichi Biodiversity Targets", adopted at the 10th meeting of the Conference of the Parties to the Convention on Biological Diversity held in Nagoya Japan, four Electrical and Electronic Industry Associations (4EEIA)¹¹⁴ have identified eight of the targets as relevant to the electrical and electronic industries, and have created action guidelines for each of them, so as to support their members in promoting biodiversity in the EEE sector. These guidelines for action of the EEE industries were published in a first edition in March 2016 (4EEIA 2016). The action guidelines for Target 4 specifically address the supply chain, recommending member companies to conduct the following activities in their production activities and supply chains at each life-cycle stage wherever possible, in order to achieve sustainable consumption and production:

- Continuous efforts to reduce CO₂ emissions in the production process;
- The provision of products and services that contribute to achieving a low-carbon society;
- Reducing the volume of waste to be landfilled;
- The 3R activities (Reduce, Reuse and Recycle);
- The procurement of biodiversity-friendly materials.

In relation to this target, examples of possible actions are given, which are relevant for implementation both by EEE manufacturers and by manufacturers in their supply chain, in order to reduce the amounts of resources used (and, subsequently, the impacts of their sourcing on the environment), to promote procurement of biodiversity friendly materials and to promote environmentally conscious designs, etc. (4EEIA 2016)

Action guidelines for Target 8 deal with the reduction of pollution and are also relevant for the supply chain, clarifying the focus of some members on the use of chemicals in

¹¹⁴ The associations are The Japan Electrical Manufacturers' Association (JEMA), Japan Electronics and Information Technology Industries Association (JEITA), Communications and Information network Association of Japan (CIAJ) and Japan Business Machine and Information System Industries Association (JBMIA).

products and materials (see Fuji Electric example below). It is explained that the pollution of water, air, soil, etc., by chemical substances and excess nutrients causes biodiversity loss and degradation of ecosystem functions and must be managed to reduce such effects. This is relevant for chemical substances used in the manufacture of products and components (including those produced by the supply chain), for substances present in agrochemicals and fertilizers applied to green spaces within business premises (provided by suppliers) and for substances that may have been used in the production of agricultural products (provided by suppliers) used in cafeterias of the company (4EEIA 2016).

A Japanese EEE manufacturer, the Brother Group (2016a), established a biodiversity conservation policy in 2012, thereafter expanding the scope to cover activities in all business operations, which also include EU manufacturing facilities in the UK and in Slovakia. Among others, it is stated that the Brother Group identifies the impact of all its operations (including procurement of raw materials) on biodiversity, applying measures to gradually reduce the impact.

As part of this mapping exercise, consideration should be given to products or materials that show a large potential for impact of biodiversity and thus also a potential for promoting suppliers which have developed their production in a way that reduces or prevents such impacts. Such components or materials should be in the focus of the first measures to be developed in relation to procurement guidelines.

After products and materials supplied by the supply chain have been mapped, it is necessary to consider and formulate criteria and requirements for procurement guidelines that address the various aspects and promote products and materials which have a lower impact on biodiversity.

As explained in the 'Description' section, two different approaches can be developed and used separately or combined:

1. developing requirements for products and materials relating to their properties or how they are to be produced;
2. requiring suppliers to take action and promoting their own development of biodiversity practices.

For the first approach, EEE manufacturers need to identify materials or components where a property or certain aspects of the production can be addressed through the formulation of procurement requirements that need to be fulfilled by the product or whose fulfilment awards the supplier with additional points to be considered in the commissioning of the contract. For example, consideration can be given to acquiring minerals extracted from areas not in the vicinity of biodiversity hotspots, or requirements pertaining to the rehabilitation of the environment of mined areas can be included in supplier requirements (KNU & LCF 2015).

The requirements set must correspond to levels of environmental performance available on the market, or no supplier would be available to achieve them. Thus, requirements need to be applied gradually and the evolution of the requirements need to be communicated in advance so that suppliers are motivated to develop their practices. In this respect, differentiation can be made between core criteria that are obligatory and additional criteria that results in additional points for a certain offer.

The following examples demonstrate aspects that can be addressed through the first approach:

- The Mitsubishi Electric Group Biodiversity Action Guidelines state that the company shall preserve biodiversity through green procurement activities. This is based among others on the recognition that the corporation procures natural resources such as minerals, fuels and plants, which can have an impact on the level of biodiversity (4EEIA 2013, pg. 14).

- The Panasonic Corporation introduced Green Procurement Guidelines for wood in consultation with the Japanese World Wide Fund for Nature (WWF). The guidelines define three categories for classifying timber and wood materials offered by suppliers, distinguishing between such resources in relation to certification schemes, sustainable forest management, legal logging activities, etc. To monitor the progress of implementation of this measure, the Panasonic Corporation set a target for fiscal year 2013 to eliminate the procurement of timber and wood materials of category 3, i.e. wood which is not confirmed to be legally logged. In 2012 only 0.6% of total procurement of such goods was still from this category, while almost 75% was already in the highest category which includes resources certified by 3rd parties not to harm forests with high conservation values, to be sourced from forests with sustainable management or to be of a recycled source (4EEIA 2013, page 33).
- The Brother Group began implementing green procurement activities from February 2001, prioritizing the procurement of environmentally friendly parts and materials for all products that the group sells. Among others, the green procurement policy activities require buying goods (parts, materials, sub-materials, and products) that do not contain hazardous chemical substances specified by the Brother Group¹¹⁵ (Brother 2016b). In relation to Aichi target 8, pollution reduction, Brother also promotes green procurement to ensure biodiversity-conscious procurement of raw materials. This is done by avoiding chemical substances that affect the environment when procuring raw materials for products, using FSC certified paper, etc. (Brother 2016a)
- In terms of procurement, SMF, a manufacturing facility of SHARP located in France, has switched to using biologically degradable paints and cleaning materials where alternatives provide comparable performance (in some cases despite additional costs) and where this is technically possible. Additional areas where SMF procures products with lower biodiversity impact, include paper products used for packaging, which are certified by FSC (Forest Stewardship Council) (SMF 2014).
- As part of its 18th Environmental Action Plan (2014-2017), Ricoh has developed activities with relevance to the supply chain, planned to be implemented in the facilities of the group. These include, for example, the use of wood-based products in consideration of biodiversity (Ricoch 2014a).

Additional requirements could be developed to address components and materials relevant to EEE manufacturing. For example, procurement criteria could be developed to give preference to non-toxic solvents for use in the production process. In cases where the EEE manufacturer procures certain components or materials from suppliers located in areas with water scarcity, suppliers can be required to apply and document measures for managing and reducing water consumption in cases where production consumes large amounts of water. Suppliers of mineral resources should be required to document the origin of resources and the proximity of biodiversity hot-spots as well as measures implemented to reduce impacts on such eco-systems or to remediate possible impacts.

As for the second approach, at first stage, EEE manufacturers need to collect information from suppliers as to their current activities and impacts on biodiversity. After this initial stage, they need to consider how to promote suppliers to develop their own biodiversity management plan. A level of commitment between the EEE manufacturer and the supplier is likely to increase the level of engagement of the supplier and thus such approaches are more suitable for long-term suppliers. These can be supported with guidance and trainings so that they can learn from examples provided by the EEE manufacturer as to actions that they can implement in their operations. Once a management plan has been developed, the EEE manufacturer can also require reporting of accomplishments, on the one hand to ensure progress but on the other hand also providing a means for quantifying environmental benefits related to the program. Various examples show that companies are also active in relation to this second approach:

¹¹⁵ See details in the Brother Group Green Procurement Standards (Ver. 8.0) under http://download.brother.com/pub/com/en/eco/pdf/gpse_ver8_0.pdf

- The green procurement activities of the Brother Group require buying products from suppliers who promote environmental conservation activities (Brother 2016b). The Brother Group Green Procurement Standards also require suppliers to establish an environmental management system, including restriction and management of hazardous chemicals, the monitoring and reducing of greenhouse gas emissions in the suppliers' business activities and its supply chain and the preservation of biodiversity (Brother 2016c).
- Within procurement, Fujitsu Ltd. relates supplier activities to three indicator levels, and requests that initiatives related to sustainable use of resources and preventing damage to biodiversity be developed and implemented. To assist suppliers in development in this direction, meetings and seminars are held by the corporation for suppliers, and guidelines presenting case studies, detailed explanations for reference activities and checklists for confirming the link between activities and biodiversity are provided to suppliers (4EEIA 2013, pg. 35).

Fuji Electric, a member of the 4EEIA Biodiversity Working Group, applies both approaches. Fuji Electric formulated the Fuji Electric Biodiversity Action Guidelines in March 2010 with the aim of minimizing the impact of its operations on biodiversity (Fuji Electric, 2016a). Its activities over the last years address biodiversity in the supply chain on two levels.

- The first level regards **procurement** of materials with reduced environmental footprint from suppliers actively engaged in environmental protection. To ensure appropriate control across the supply chain, suppliers are required to comply with the Fuji Electric Green Procurement Guideline on prohibited substances as well as to put in place chemical substance management systems, particularly with respect to the chemicals contained in materials and parts (Fuji Electric, 2016b).
- A second level regards the collection of information as to activities that suppliers undertake in relation to environmental preservation and its evaluation as part of award criteria in procurement. This is done through a few routes.
 - Suppliers are requested to compile information as to their activities in various areas. The list, including, among others, environmental aspects, is presented to suppliers and their cooperation is requested to fulfil certain activities (Fuji Electric, 2016b). Items related to protecting the environment can be expected to have at least an indirect impact on the environment and address the following aspects (Fuji Electric, 2016c):
 - Development and implementation of an environmental management system and disclosure of information as to achievement of its environmental practices;
 - Management of the chemical substances used in products and in manufacture;
 - Compliance with legislation and respective reduction of the company's environmental impacts (drainage, sewage, emissions, GHG emissions, waste, etc.), as well as initiation of voluntary standards for further improvements;
 - Development of targets and continuous efforts to save resources (energy, raw materials)
 - Fuji Electric also requests its suppliers to complete a survey (Fuji Electric, 2016d) as to their environmental activities. The survey seeks to understand whether suppliers have taken various actions (developed environmental management schemes; set targets for environmental preservation; are active towards managing, monitoring and improving pollution control, energy consumption, resources use and emission reduction; etc.). Information collected is on a yes/no basis and as such can only give a first understanding as to the areas of activity of a certain supplier towards various environmental goals. However, such initiatives can raise awareness in the supply chain towards various areas of environmental action, as well as implying where more stringent supplier requirements may be introduced in the future.

- The Procurement Guidelines (Fuji Electric, 2016e) further state that besides quality, price and delivery date, the three following environmental aspects are taken into consideration in the overall decision on selection of suppliers:
 - Measures for environmental preservation, including active engagement in environmental preservation activities;
 - Implementation of a control system for chemical substances contained in products;
 - Measures for content of chemical substances for supplied materials.

5.2.5.6 Applicability

As discussed in other BEMPs in Chapter 5 (“BEMPs for supply chain management”), many EEE manufacturers have developed requirements related to the use of various substances by their suppliers.

Additionally, various EEE manufacturers mention biodiversity in their sustainability reports, often referring for example to responsible sourcing of paper and materials used for packaging (e.g. Apple 2016).

In this sense, it appears that a large number of EEE manufacturers can already associate some of their procurement measures with positive impacts on biodiversity.

However, it seems that only in a small number of cases, such measures have been developed with the direct aim of reducing the impacts on biodiversity and as part of a comprehensive management plan addressing biodiversity impacts in the supply chain.

From information available in the public realm, it seems that there are only a few EEE manufacturers who have systematically audited the possible influences that their activities and the activities of their supply chain have on biodiversity and that have set up more comprehensive schemes for reducing effects on biodiversity of supply chain activities. Such manufacturers have started with a first review of the possible impacts of all activities, producing an overview of the potential for risks to biodiversity from various activities. This then allows the gradual introduction of changes to procurement criteria and to procurement requirements such as the development of similar schemes by suppliers. As the EEE supply chain is relatively complex, it is not practical to expect the implementation of measures to derive benefits within a few years, but rather a more long term approach needs to be developed, starting with the implementation of measures that are easier to apply, but that help in creating awareness and change in the supply chain, thus facilitating the implementation of more advanced measures in the future.

5.2.5.7 Economics

Quantifying actual costs and benefits of measures developed to protect and enhance biodiversity along the EEE supply chain is difficult.

In terms of costs, some of the procured products and services may become more expensive if they fulfil certain requirements. This price premium needs to be carefully considered when establishing the requirements. In addition, there are staff costs and, if relevant, cost of external consultants. For instance:

- Costs of employees involved in the first stages of “auditing” the possible impacts of the materials and services provided by the supply chain;
- Costs of consulting services that may assist in the initial auditing and development of criteria and requirements related to biodiversity and procurement;
- The costs of employees involved in the development of procurement criteria and in the assessment of compliance with such criteria in tendering.

It is difficult to discuss economic benefits as these are in some case intangible and in many cases also indirect. However, according to KNU (2015), quite often, measures to

promote biodiversity result in considerable cost savings and enhance a business' public image and its reputation among its clients.

In terms of costs and benefits for the suppliers, these vary depending on the supplier and its range of activities to be undertaken. For example, where suppliers are manufacturers of components, costs and benefits shall be similar to those mentioned in the "Economics" section of the BEMP 4.2.8 of this document (4.2.8.7). Upon moving through the supply chain, the closer a supplier is to the sourcing of materials, the more the range of costs would be different as would be different the range of activities implemented, with a more direct impact on biodiversity.

5.2.5.8 Driving force for implementation

KNU (2015, pg. 10, table 1) lists various examples of direct and commercial risks resulting from a loss of biodiversity and the reduced functionality of ecosystems. Though not all of these can be understood to be directly relevant to the EEE sector, a few are detailed here, as such risks may constitute a driving force for manufacturers to include various measures for protecting biodiversity in their management plans, including measures related to the supply chain:

- Risks of loss of reputation - Damage to the image of industries or individual business due to the negative effects of economic activities on biodiversity;
- Market-related risks - Changes in buying behaviour (end consumer, business to business), with a stronger emphasis on biodiversity criteria;
- Regulation- and law-related risks - Restricted access to species-rich (conservation) areas, such as a prohibition on mining in conservation areas;
- Legal / liability risks - Lawsuits against industries or businesses for causing the loss of biodiversity, for example under the EU Environmental Liability Directive;
- Financial market risks - Consideration of biodiversity criteria when financial institutions grant credit and make investments; biodiversity as an assessment criterion in sustainability ratings.

From a report of 4EEIA (2013), it can be understood that procurement of raw materials from sources with lower impacts on the ecosystem can support the long-term security of materials while also strengthening the supply chain. This can lead to a reduction of procurement costs (for example where depleted resources are recycled by suppliers or where urban mining is a source of raw materials) as well as increasing the image of the brand.

5.2.5.9 Reference organisations

- Brother - has developed green procurement measures both towards specific products and in order to promote the development of biodiversity awareness and measures within the supply chain;
- Ricoh - in relation to procurement of specific products with a reduced impact on biodiversity during their consumption (pesticides, wood and paper);
- Sharp - in relation to procurement of specific products with a reduced impact on biodiversity during their consumption (wood and paper, cleaning materials, paints);
- Fuji Electric - has developed green procurement measures both towards specific products and in order to promote the development of biodiversity awareness and measures within the supply chain;
- Fujitsu Ltd. - requests its suppliers to develop initiatives for promoting sustainability and biodiversity.

- Sony Corporation - addresses the consideration of biodiversity in the supply chain through "procurement that leads to biodiversity" and "switching to paper, which considers biodiversity" (4EEIA 2013, pg. 9);
- The Mitsubishi Electric Group – green procurement requirements aim to preserve biodiversity;
- The Panasonic Corporation, for example in relation to procurement of wood and timber products.

5.2.5.10 Reference literature

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DRAFT

6 BEMPs fostering circular economy

6.1 Techniques portfolio

This section deals with management and strategic practices that electrical and electronic equipment manufacturers can implement to foster circular economy, such as changing design practices, remanufacturing products, or developing more sustainable business models

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). Processes for recycling WEEE are instead considered to be out of scope.

In specific, the BEMP on *strategic guidance on designing products for the circular economy* (section 6.2.1) describes approaches and processes implemented by EEE manufacturers during the design phases to ensure that their products are easy to repair, refurbish, reuse and recycle. 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 resource efficiency at the end-of-life of EEE equipment.

The following two BEMPs on *Integrated Product Service Offerings (IPSO)* and *Remanufacturing or high quality refurbishment* (sections 6.2.2 and 6.2.3 respectively) describe practices helping to prevent waste by refurbishing. While the BEMP on *Integrated Product Service Offerings* describes a business model that offers economic advantages when providing services instead of products, the BEMP on *Remanufacturing or high quality refurbishment* 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.



Table 6.1 summarises the developed BEMPs for circular economy chapter and provides an overview of the addressed environmental pressures.

Table 6.1. Overview of the environmental pressures addressed by each developed BEMP for circular economy chapter

	BEMP	Resource efficiency	Water	Waste	Energy & climate change	Hazardous substances
6.2.1	Strategic guidance on designing products for the circular economy	X		X	X	X
6.2.2	Integrated Product Service Offerings	X		X	X	
6.2.3	Remanufacturing or high quality refurbishment of used products	X		X	X	

6.2 Description of best environmental management practice

6.2.1 Strategic guidance on designing products for the circular economy

SUMMARY OVERVIEW						
<p>BEMP is to have an approach in place that ensures that consideration for all the different environmental aspects, and specifically a move towards the circular economy, is systematically integrated into the design process of products. Such an approach is based on:</p> <ul style="list-style-type: none">• setting environmental goals for the improvement of the environmental performance of the products, either at the company level (general goals for all products) or at the level of a specific product; objectives need to be clear, well defined and communicated at the company level so that there is an awareness of employees at all levels;• integrating into the design process inputs and feedback from the different units tied to the product manufacture, use and end-of-life, as well as, in some cases, from external stakeholders;• creating a feeling of a collective effort throughout the company towards the development of the various design specifications for the new products. <p>This is implemented by one or both of the following approaches:</p> <ul style="list-style-type: none">• setting an internal environmental standard for the design of new products at the company level, with defined general goals and compulsory requirements, which are continuously enhanced based on feedback from different units within the organisation; when starting the design of each specific products, these are then converted into design specifications for the specific product;• establishing an interdisciplinary design committee or steering group for the design of each product, involving representatives from all different relevant units tied to the various product stages directly in the actual design process.						
Relevant life cycle stages						
Manufacturing		 Supply chain		End of life		
Main environmental benefits						
Resource efficiency	 Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">• Setting of circular economy objectives for new products (y/n)• Number of different units across the company having contributed to design processes• Share of products or components (by number or revenue) for which design cycles or redesign cycles have been embarked upon that explicitly address the different approaches of circular economy (%)• Environmental benefits achieved by the products designed or redesigned with circular economy objectives sold during the year over their lifecycle (carbon emissions, resource efficiency...)						

Applicability	Applicable to all EEE manufacturing companies.
Benchmarks of excellence	<ul style="list-style-type: none"> – Design cycles or redesign cycles that explicitly address the different approaches of circular economy have been embarked upon for at least 50% of products and components – The company has in place circular economy objectives for new products and an effective product design process to ensure these are achieved

6.2.1.1 Description

The transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, requires a profound transformation of the way our entire economy works, and, more specifically, a thorough rethinking of the way products are made and used as well as what happens to them once they reach the end of their use life. These aspects, and, therefore, how 'circular' a product is, depend very heavily on the choices made at the design phase.

Some EEE manufacturers have prominently integrated aspects of circular economy into their business model by defining objectives for the design and redesign of their products, in order to facilitate durability, repair, refurbishment, reuse as well as better dismantling and recycling.

However, the solutions implemented by each manufacturer for each of its own products, both in terms of business model and actual properties of the products, are specific to the products to which these were applied. What is more replicable and can be of inspiration for other EEE manufacturers are the approaches, on a management and strategic level, to ensure that the design of products considers all environmental aspects, including the fate of the product at the end of its (first) use life and how to make the product more 'circular'.

These approaches fit in the innovation cycle of the company, where new products and their design are often based on the evaluation and lessons learned from previous products.

The following figure illustrates the Delft Model of the innovation process, showing how various stages of a products life cycle can be evaluated so that valuable feedback for the design process can be integrated into further design (or redesign) stages.

Figure 6.1. The Delft model of the innovation process

proposals to operationalise the stated goals, together with the evaluation of previous/other products, into the design phase(s) of new products.

- in some cases, the involvement of external stakeholders (e.g. recyclers).

For example, where repair is in focus, it is important to identify limitations in the design of a product for reparability (for example difficulties in accessing components that have a higher tendency to malfunction), but also to understand how the manufacture and supply of spare parts for repair can be managed. An objective of higher recyclability, instead, requires not just a redesign to allow the use of materials that are easier to recycle, but could also benefit from inputs from recyclers and difficulties they may have with dismantling or with the use of various resins and sealants.

In practice, the actions currently implemented by EEE manufacturers to implement the aims listed above can be grouped in two approaches, which can be applied separately or also in conjunction:

- setting an internal environmental standard for the design of new products at the company level, with defined general goals and compulsory requirements, which are continuously enhanced based on feedback from different units within the organisation; when starting the design of each specific products, these are then converted into design specifications for the specific product;
- establishing an interdisciplinary design committee or steering group for the design of each product, involving representatives from all different relevant units tied to the various product stages directly in the actual design process.

6.2.1.2 Achieved environmental benefits

Through meeting circular economy objectives at the early stages of product design, benefits can be achieved in relation to a net reduction of resources used, either directly, where the process results for example in a higher recycling rate, or indirectly where product service life is extended through easier reparability, reuse and refurbishment. In some cases, where the use of hazardous chemicals is avoided to facilitate recycling at end-of-life (EoL), benefits also derive in relation to reduced use of such substances and their subsequent reduced appearance in the waste stream.

6.2.1.3 Appropriate environmental performance indicators

The implementation of this BEMP can be monitored at three different levels:

- at a management level, looking at the presence of set circular economy objectives for new products and at the degree of involvement of the various units in the design process;
- at the design function level, observing the number of products or components for which new design cycles (or redesign cycles) that explicitly address circular economy objectives have been embarked upon;
- at the products level, monitoring the actual environmental benefits achieved by the products designed or redesigned with circular economy objectives and aggregating those results over time and number of products.

These can be operationalised into the following indicators:

Metrics	Description
y/n	Circular economy objectives are set for new products
number	Number of different units across the company having contributed to design processes
%	Share of products or components (by number or revenue) for which design cycles or redesign cycles have been embarked upon that explicitly address the different approaches of circular economy

various units	Environmental benefits achieved by the products designed or redesigned with circular economy objectives sold during the year over their lifecycle (carbon emissions, resource efficiency...)
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The first indicator only looks at whether the EEE manufacturer has set circular economy objectives for new products. It is useful for companies to report that they are committed to take action in the area of designing more 'circular' products. They can also state whether those objectives are company-wide, and applicable to all products or all products in a certain product group, or specifically for some products / ranges / product groups.

The second indicator aims to demonstrate whether feedback from various levels of the product stages is incorporated into the design stage (manufacture, marketing and logistics, processing at EoL). For this purpose it is recommended to start by mapping out the various units or activities of relevance for contributing (or providing feedback) for developing design specifications and requirements to be fulfilled in relation to the design of new products or redesign of existing ones. From a management perspective, it is useful to monitor contributions from the various units mapped in order to ensure their gradual involvement in the development of specifications, which take the circular economy objectives into consideration.

As the implementation of the practice is developing, monitoring of its impact can begin by observing the number of products or components for which new design cycles (or redesign cycles) have been embarked upon (% of product portfolio or % of revenue related to coverage of portfolio).

Finally, indicators to monitor progress in benefits associated to the implementation of these processes can be developed to allow quantifying environmental impacts. In this respect, monitoring improvements related to the objectives in redesigned products over time is useful to monitor achievements. Although this is much more difficult, because it requires looking at different environmental aspects (e.g. through LCA) and comparing a new products with a previous product it is considered to substitute, it is also the more meaningful evaluation of the benefits of this practice. For products addressed in the redesign processes, benefits should be considered over their whole life time and in all lifecycle phases, with an understanding that in products with longer design cycles, benefits can be expected to appear at later stages.

6.2.1.4 Cross-media effects

Most circular economy objectives are about extending the service life of products. While this is definitely beneficial from a resource efficiency perspective, certain trade-off may exist in comparison to new products, in relation to energy consumption. For many products, the development of new designs has had a focus on reducing the energy consumption during use, which is, in most cases, a very relevant environmental aspect. Thus, if product service life is extended, the resource savings come at the cost of not materialising energy savings related to consumption in the use phase, which, for some products, may be very significant. For different products, the optimum point after which the benefits of extended service life do not off-set the negative impacts because of the higher energy consumption would be different and needs to be considered carefully during the design phase. LCA is the tool which is often use to consider these trade-offs and ensure that the new products have overall environmental benefits.

Some practices that are related to the circular economy, such as refurbishment and reuse may also mean that components that were manufactured in the past and still use certain hazardous materials, phased-out in new designs, benefit from an extended service life. Subsequently, the hazardous substances that may have already been phased-out from new similar products on the market are still in circulation and will reach the waste stream at a later point, where they will have to be disposed of properly. An example of evidence of this aspect can be found in exemption 31a of Annex IV of the

Directive 2011/65/EU (RoHS 2)¹¹⁶ which was requested to allow the further circulation of such products despite their possible use of RoHS regulated substances.

6.2.1.5 Operational data

The sustainable life-cycle of a product begins at the design stage and can be influenced through the development of specifications for the design process. To ensure an impact, the consideration of such requirements in new design needs to be mandatory, requiring implementation or, at least, a gradual integration of requirements over a certain period of time. Requirements can be addressed at system design in relation to various environmental impacts throughout the entire lifecycle and can incorporate requirements targeted at achieving a transition towards a circular economy.

In many cases, circular economy aspects are translated into requirements for products in terms of changing what happens when the product reaches its end-of-life or by extending the service life to delay the end-of-life. To be effective, this requires a feedback mechanism from the different business units tied to the various stages of the product life into the design stages, in order to facilitate a continuous evaluation and integration of the aspects identified as areas for potential improvement.

For example, EEE manufacturer Siemens Healthcare has established an internal environmental standard on "Specifications on environmentally compatible product and system design". This contains compulsory requirements that are defined and continuously enhanced involving the various units that have interfaces with the product throughout its life-cycle and can help identifying where improvements can be implemented. The internal environmental standard was developed to close the information loop between the end of life of one product and the development phase of a new one for product designers (Siemens 2012).

For example, a critical material assessment methodology has been developed by Siemens to help product designers to evaluate potential critical materials (ecological / toxicological effects / possible future scarcity) and support decisions for avoiding or reducing the use of particular substances (Siemens 2015, pg. 25-26). Since Siemens views closing material loops as important, it has been included in the environmental standard for product development (Siemens 2012).

Another example from Siemens is that a product qualifies for the SIEMENS Environmental Portfolio if it is at least 20% more energy efficient compared to a predecessor or competitor product (this means either 20% less energy consumption, or 20% more output at the same energy consumption) (Russinger 2016). This model can be adjusted to integrate design requirements related to circular economy (Russinger 2016).

The formulation and use of internal environmental product design specifications in Siemens Healthcare was used to achieve various circular economy objectives. The design process of a new product begins with the formulation of design specifications. At this stage, a "requirement engineer" reviews the overall environmental design specifications to clarify which are relevant for the design process of the specific product. On this basis, the requirements for the specific product design are formulated and integrated in the design process, similarly to how environmental regulation and safety regulations are fed into the specifications (Plumeyer & Russinger, 2016a).

Examples of the units contributing to the definition of the specifications at Siemens Healthcare are (Plumeyer & Russinger, 2016a):

- the logistics unit;

¹¹⁶ See Commission Delegated Directive (EU) 2016/585 of 12 February 2016 amending, for the purposes of adapting to technical progress, Annex IV to Directive 2011/65/EU of the European Parliament and of the Council as regards an exemption for lead, cadmium, hexavalent chromium, and polybrominated diphenyl ethers (PBDE) in spare parts recovered from and used for the repair or refurbishment of medical devices or electron microscopes (Text with EEA relevance), available under: <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016L0585>

- the marketing unit, also pertaining to how the take back of a product can be ensured through communication with consumers;
- the customer service unit, which can formulate specifications where customers report a certain shortcoming or a function that would improve the performance of a certain product;
- representatives who collect aspects related to the recycling of products/components at end-of-life;
- the refurbishment unit, which can formulate specifications that will allow easier dismantling or that will increase the likelihood of certain parts being reused or refurbished.

A practice in place at Siemens Healthcare has also allowed improving products in relation to easier dismantling and easier recycling. One requirement that has been integrated in the specification is related to the marking of parts produced from thermoplastics. Parts above a threshold mass (defined by the sector unit) are required to be marked with the plastic type according to ISO 11469 so that at end-of-life they can be dismantled and identified more easily for recycling. When the requirements engineer reviews such a requirement, he will only take it on board if the product to be developed is to contain plastic parts above the specified weight (Plumeyer & Russinger, 2016a).

Siemens Healthcare has also been refurbishing some of its devices for many years. Incorporating feedback from representatives involved in the refurbishment process, components requiring a higher durability or needing to be easy to dismantle can be improved appropriately (Plumeyer & Russinger, 2016a). Feedback is also important to identify areas where the interface between hardware and software need to allow updating the programming of refurbished products, or the use of components from older devices in new products to allow their reuse. It is also important to create a method for feedback from consumers, e.g. in terms of needs for refurbished articles.

In some cases, the early involvement of certain suppliers in the design of a product can also be beneficial. For instance, this is done at smartphone manufacturer Fairphone.

The first step in the design of the Fairphone 2 was to define the product in broad terms, including functionality, form factors and more constraining aspects such as price points, volumes and target audiences. In its general objectives, Fairphone included product longevity and easy reparability. Based on these objectives, the design team included engineering, design and manufacturing partners and these were embarked upon at early stages of the process. For example, certain key elements of the product can constrain how it can be developed. In the case of mobile phones the platform is a good example as it determines a large share of the elements of the design and needs to be supported by the original design manufacturer (ODM). Fairphone looked into possible platform vendors (and the pros and cons of the platform in relation to the requirements and objectives) and brought the ODM on board at early stages. A technology consultancy specialized in tackling difficult integration challenges in the creation of consumer electronics (including mobile phones) was also brought on board as was a design and innovation consultancy experienced in sustainable, environmentally conscious design. This multifaceted design team allowed focusing not only on the phone as it is sold but also considered the user experience when opening up the product for maintenance, upgrade and repair. For instance, the design team also looked at how to give instructions to users on phone maintenance and repair (Fairphone 2015b).

In some cases, it may be relevant not only to involve input from various units or from external suppliers and consultancies, but also to research what factors influence the product in focus and would allow its design to be more in line with circular economy aspects. For example, in the case of Fairphone, where longevity was an important objective, the key drivers that push people to replace their devices on a regular basis and the fundamental features of conventional smartphone architectures that trigger those drivers were investigated. Results of this investigation were then considered in the

redesign of the new model. After compiling a range of improvement possibilities (for Fairphone 2 compared to the first Fairphone), a subset of items was selected that could be addressed through engineering in a reasonable time frame, and the trade-offs that were inherent with those various options were explored. For example, the protection case was integrated into the phone, eliminating the redundancy of protector and back panel and also including a rubber rim feature that wraps around the edge of the glass, protecting the display from the most common causes of screen damage. In other cases, the objectives required compromise. For example, keeping water and dust ingress (a common cause of failures) to a minimum could be improved through a “sealed” design of the product housing, but this type of architecture conflicted with the ambitions, to allow the opening and repair of the device. Employing seals and gaskets in the Fairphone 2 construction was a compromise for establishing a sufficient level of protection from ingress without a severe impact on the reparability objective. The decision to create a modular design, facilitating repair, also impacted the level of the mechanical construction and the electrical interfaces. For this purpose for example the thickness constraint of the phone was relaxed to give more flexibility in the architecture (Fairphone 2016b).

6.2.1.6 Applicability

This BEMP is applicable to all EEE manufacturers that wish to introduce circular economy aspects in their products. It is easier to implement in organisations where similar practices have already been developed to promote innovation in other fields in the design of new products, as the existing system could be adapted, possibly only differing in the range of units to be involved and the aspects to be addressed in relation to the specific circular economy objectives. This BEMP is also easier to implement in companies whose core business is based on environmental objectives, or where design practices are not well established already and can follow the models presented in this BEMP from the beginning.

6.2.1.7 Economics

It is difficult to speak about the possible costs of implementing this BEMP in tangible terms. Organisations can expect to have certain costs, particularly at first stages of implementation when employees involved need to invest more time in order to integrate new procedures and to change possible mind-sets. When the practice becomes more established or where similar practices already exist in relation to innovative design, costs can be expected to decrease.

In terms of benefits, a primary source of economic benefits may yield from some of the environmental benefits related to resource use. In certain cases this would also translate into a decrease in energy consumption, where, for example, certain components can be re-used and do not require the manufacturing of new ones, or where a larger availability of recycled, secondary materials decreases costs of production of primary ones.

A second source of economic benefits is that, in certain cases, developing products or components so that they can be repaired, reused or refurbished can also create room for new business, such as maintenance or refurbishment services or the provision of parts.

6.2.1.8 Driving force for implementation

The initial driving force for implementing this BEMP is the general strive towards a more circular economy, which for manufacturers also translates into a conservation of resources.

As the possibilities to reuse, repair and refurbish components or products have an influence on consumer behaviour and is communicated to consumers to allow the development of such practices, a further driving force is the public image that is associated to such practices. For example, the communication of the design process and integration of reparability aspects have played a significant part in the development of Fairphone. Other companies that have been developing the reparability of EEE products

have also received positive publicity in the last year. For example, PuzzlePhone¹¹⁷ was rewarded the “Catalysing Disruptive Innovation Award” for a modular mobile-phone design that expands the lifespan of phones by the Green Electronics Council (GEC) in September 2016 at the Electronics Goes Green Conference in Berlin, Germany. At this event, circular economy issues were addressed in various sessions and were also the focus of three of the “Key note speakers”¹¹⁸.

6.2.1.9 Reference organisations

The following examples of organisations that have successfully implemented this BEMP:

- AT&S – in relation to refurbishment and reuse and their participation in the Horizon-2020 research project “SustainablySMART” (AT&S 2016)
- Fairphone – in relation to reparability aimed at extending product longevity;
- PuzzlePhone – in relation to modular design aimed at extending product longevity (still in conceptual stage).
- Siemens, Siemens Healthcare – in relation to refurbishment and reuse, improving dismantling and recyclability and other environmental aspects.

6.2.1.10 Reference literature

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¹¹⁷ For more information see: <http://www.puzzlephone.com/> the product is still in conceptual stages.

¹¹⁸ Including: Circular Economy: Focus on Critical, Conflict and Precious Metals, presented by Fabrice Mathieux from JRC; Circular Economy Pushing Innovative WEEE Recycling and Business Models, presented by Norbert Zonneveld of the European Electronics Recyclers Association; and How is Circular Economy Influencing Product Design and Business Models? Resented by Conny Bakker from TU Delft. For further details see: <http://electronicsgoesgreen.org/keynotes/>

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DRAFT

6.2.2 Integrated Product Service Offerings

SUMMARY OVERVIEW						
BEMP is for EEE manufacturers to provide Integrated Product Service Offerings (IPSO) both in business to businesses and business to consumers, shifting from designing and selling physical products to providing a product-service system that leads to an improved functional and environmental performance. For instance, IPSO create incentives for manufacturers to ensure their products are durable or offer the opportunity to take-back products to redeploy them or refurbish them for further use.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
<ul style="list-style-type: none">Implementation of the IPSO model ensuring that it delivers environmental benefits (Y/N)Take-back rates of products installed at customer premises within the IPSO per product category (%)Share of reused devices out of the total number of devices installed within the IPSO (%)						
Applicability		<p>The IPSO model is especially applicable to electrical and electronic equipment with large capital cost and long use life.</p> <p>The applicability in the field of electrical household appliances with limited purchasing costs, low bill of materials or large size/weight is limited (e.g. take-back is not feasible if the economical/technical value is too low compared to transportation costs)</p>				
Benchmarks of excellence		<ul style="list-style-type: none">The company adopts IPSO in its business ensuring that it leads to a continuous improvement of the environmental performance of the product-service offered100% take-back rate for post-consumer devices from leasing contracts and 30% refurbishment rate				

6.2.2.1 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 brings 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 → washing clothes, 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. In light of this, it is clear that the IPSO model aligns economic interests of customers and product manufacturers: in fact, customers do not need to afford the purchase and ownership costs (and the burdens related to insurance and regular safety checks) of products while product manufacturers can increase the generation of revenues by improving the durability and reparability of the devices produced.

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). Another example is Hewlett Packard Enterprise (HPE) which offers flexible IT capacity services to companies which would like to use public cloud (avoiding the purchase of IT equipment) but also wish to control the hardware and software on their premises. The business model of HPE Flexible Capacity consist of providing the client company with a hybrid infrastructure service that delivers a public cloud experience with the benefits of on-site premise IT. HPE supports clients to choose the hardware and software at the customer’s premises, but the client does not pay for the purchase of the equipment (which is owned by HPE) but for the use, based on metered usage. Additionally, an on-site buffer allows customer to quickly scale up IT capacity when needed, and this avoids spending on unused capacity (HPE, 2016).

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 efficiency¹¹⁹.

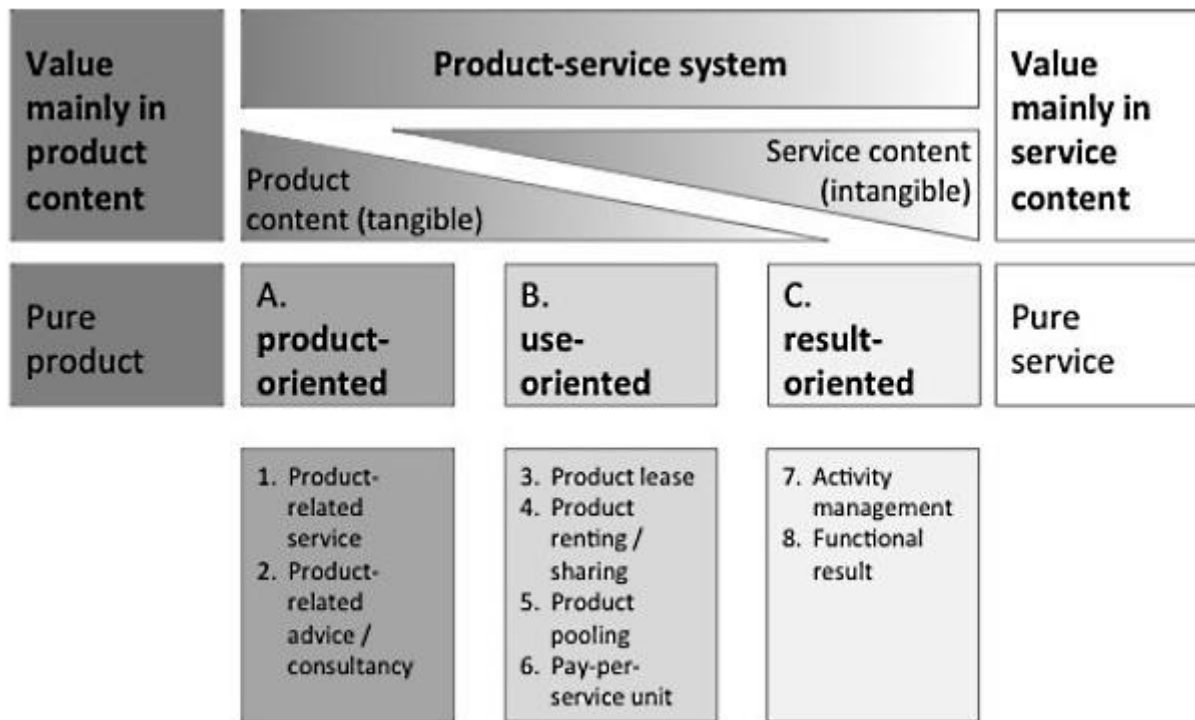
Establishing product/service-based business models is an innovation process that requires product manufacturers to extend their perspective beyond the point of sale. Becoming a service provider necessitates much closer communication with consumers and public clients. Typically, this yields better insights 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 environmental improvements can be achieved only if they are a separate part of a company's environmental policy and innovation strategy. Therefore, this BEMP explicitly covers IPSO models that:

- Lead to durable and easy to refurbish products;
- Offer the opportunity to take-back products in order to redeploy them;
- Ensure the collection, repair and recycling of EEE.

Figure 6. 2. The product-service system and its subcategories

¹¹⁹ 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.



Source: Fischer et al. (2012), cited after Tukker et al. (2006)

For the sake of clarity, as explained above, this BEMP is about shifting the business focus of an EEE manufacturer from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands and lead to an improved environmental performance. While, the next BEMP presented in this document (remanufacturing or high quality refurbishment of used products) focuses on collecting used devices (which were produced by the company), refurbish and bring them onto the market for reuse. Therefore, such BEMP is about refurbishing activities, carried out by EEE manufacturers, which achieve the same product quality levels of the device when it was first placed on the market.

6.2.2.2 Achieved 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 and reparability (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 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 manufactured. 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 IPSO models, it is therefore recommended to conduct an LCA analysis on individual IPSO models. Some general indications can come from 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. Within the IPSO scheme, Xerox runs also a product take-back scheme as integral part of the leasing service, in order to improve the reuse and recycling of the printers. This is possible thanks to an improved design of the products, which ensure a higher dismantling and recovery of materials. 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 cleaning¹²⁰ in private households. The offering encompassed the function of textile cleaning in form of a 'pay-per-wash' contract. Instead of selling washing machines, the equipment was leased to households (Fischer et al. 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, guarantees on machine performance, and equipment take-back for recycling.

6.2.2.3 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. The main environmental benefit can be achieved thanks to the increased life-time of equipment and the improved refurbishing, repair and recycling, however, due to the large system boundary of servicing contracts, a 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:

- implementation of the IPSO model ensuring that it delivers environmental benefits (Y/N);
- share of the reused devices out of the total number of devices installed within the IPSO (%);
- take-back rates of products installed at customer premises within the IPSO per product category (%).

6.2.2.4 Cross-media effects

As illustrated in section "Achieved environmental benefits" the implementation of an IPSO model can lead to improve the environmental performance (lifetime, reparability, recycling) of electrical and electronic equipment. However, prolonged use-phases also

¹²⁰ <http://www.ellenmacarthurfoundation.org/business/toolkit/in-depth-washing-machines#fn11>

mean that devices stay in use and consequently they might have lower energy efficiency than 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).

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 6.2.3.5).

6.2.2.5 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 (Figure 6.3) 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 6.3. The plan-do-check-act cycle according to EMAS



Source: European Commission (2014)

The rest of this section suggests best practice approaches to implement the IPSO model through the application of the plan-do-check-act cycle for an improved environmental performance of the services offered. This work may be undertaken in the framework of an EMAS registered corporate environmental management system (Worthington, 2012).

Regarding 1 (Introduction of a service-oriented culture in a company):

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.

Regarding 2 (Revision of a new pricing model for products and service offerings):

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 (Interlinking support offerings with customer relations and new product design processes):

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 lifetime, repair, refurbishment and recycling as important aspects in the design brief of new products. This may require closer inter-linkage 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 (Capacity building for customer support, maintenance services, and delivery/take-back logistics):

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 (Set-up or contracting of repair/refurbishing centres):

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 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 (Establishing a monitoring system for economic and environmental improvements):

The process of implementing IPSO business cases generates a lot of new experiences in companies. A systematic monitoring is essential 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 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 5.2.3 (BEMP on Conducting Life Cycle Assessment) provides more details on best practices in LCA implementation.

Regarding 7 (Review of lessons learned from IPSO implementation and decision making towards next steps to be taken):

Continuous improvement 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 can be evaluated based on key-figures such as the ones presented in Section 6.2.2.3. The assessment may indicate improvement potentials towards better utilisation or design of devices. This recognition would lead to revision of design briefs for new product generations (e.g. aiming at longer life-time). That leads directly to the next plan-do-check-act cycle.

6.2.2.6 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.

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), low bill of materials or large size/weight appliances (if the economical/technical value is too low compared to take-back transportation costs). Instead, applicability is higher in the fields of electronic equipment and capital intensive devices (e.g. IT-equipment, washing machines).

6.2.2.7 Economics

In the B2B segment, integrated product/service offerings are widely established, suggesting that significant economic benefits are achieved by such business models. The B2C model is less well established but rapidly growing, suggesting that economic benefits are relevant also in this market segment. 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.
- 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).
- 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.
- Improved social responsibility: The environmental benefits from IPSO (see section "Achieved environmental benefits") can form an integral part of a company's social responsibility and CSR communication.

On a more general level, Beuren et al. (2013) summarise the benefits of product/service systems for various stakeholder groups as follows:

- Consumer: 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.
- Provider: 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.
- Environment: 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.
- Society: Public pressure on environmental issues grows, Increase the supply of services; new jobs.

6.2.2.8 Driving force for implementation

A major driving force for integrated product service offerings are the economic benefits and the potential further business opportunities offered by the IPSO scheme described in section "Economics". 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.

6.2.2.9 Reference organisations

- Xerox: Pay-per-copy
- Philips Lighting: Pay-per-lux
- Electrolux: Selling cleaning function "pay-per-wash"
- Ricoh: Comet Circle™

6.2.2.10 Reference literature

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6.2.3 Remanufacturing or high quality refurbishment of used products¹²¹

SUMMARY OVERVIEW						
BEMP is to prevent waste by remanufacturing or refurbishing used EEE products and bringing them into the market for reuse. The remanufactured or refurbished products achieve at least the same quality levels they had when they were first placed on the market and are sold with appropriate warranty.						
Relevant life cycle stages						
Manufacturing		Supply chain			End of life	
Main environmental benefits						
Resource efficiency	Water	Waste	Emissions to air	Energy and climate change	Biodiversity	Hazardous substances
Environmental performance indicators						
• Use of LCA to demonstrate that the remanufacturing or refurbishment activities have environmental net benefits, also in light of energy efficiency gains of new product models (Y/N)						
Applicability		This practice is particularly suitable for mid- or high-capital intensive equipment.				
Benchmarks excellence	of	• LCA was used to demonstrate that the remanufacturing or refurbishment activities have environmental net benefits, also in light of energy efficiency gains of new product models.				

6.2.3.1 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 (German Environment Agency, 2015). Such used devices can be remanufactured or refurbished and brought onto the market for reuse and this is an effective measure to prevent waste generation. Remanufacturing of EEE equipment already represents a relevant economic activity; in fact in 2012, the ICT remanufacturing (including printer cartridges) had a turnover of about €6 billion in the EU (Bitkom, 2015).

This BEMP describes remanufacturing or refurbishing activities that achieve product quality levels (both cosmetically and functionally) identical with those of the device when it was first placed on the market. Remanufactured or high quality refurbished equipment is backed by at least the same warranty, maintenance and support options as the equivalent new product. Moreover, this BEMP addresses remanufacturing and refurbishing that generates second-hand equipment that complies with all applicable standards related to safety and reliability that are in place at the time of remanufacture/refurbishment, in fact, sometimes, there could be some legislative

¹²¹ 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 'operational data' section 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.

obstacles to remanufacturing/refurbishment of equipment¹²². Thus, the BEMP describes one specific segment out of a range of activities that support the reuse of used electrical and electronic equipment (UEEE).

Please note that the terms "high quality refurbishment" and "remanufacturing" are not uniformly defined and either one or the other is used to refer to the same activities in different subsectors of the EEE manufacturing sector. "High quality refurbishment" and "remanufacturing" include all the actions (i.e. dismantling, restoring, replacing components and testing) carried out to allow the product to meet its original design specifications (ERN, 2015; Zero Waste Scotland, 2015). The performance of the product after 'high quality refurbishing' or 'remanufacturing' is expected to be at least the same as the original performance specification ('like new') or better, and the remanufactured or refurbished product comes with a warranty that is equivalent or better than that of the newly manufactured product. It should therefore be noted that in the context of this BEMP 'high quality refurbishment' and 'remanufacturing' are considered synonyms. In the EEE sector, the term 'high quality refurbishment' has been used widely for medical devices, while for the IT equipment it is more common to employ the term 'remanufacturing' (Hieronymi, 2016).

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. Moreover, OEMs also have sales specialists and specialised distribution channels to sell the refurbished products.

Generally, high quality refurbishment activities involve a series of actions ranging from the selection of used devices to service and maintenance activities. These steps are further described in [Table 6.2](#).

¹²² Changes to legislation that affect product design can create obstacles for remanufacturing/refurbishment, if new requirements apply retroactively to products first placed on the market before such requirements came into force. An example of exception 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 industry 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."

Table 6.2. Activities for remanufacturing or high quality refurbishing of used products

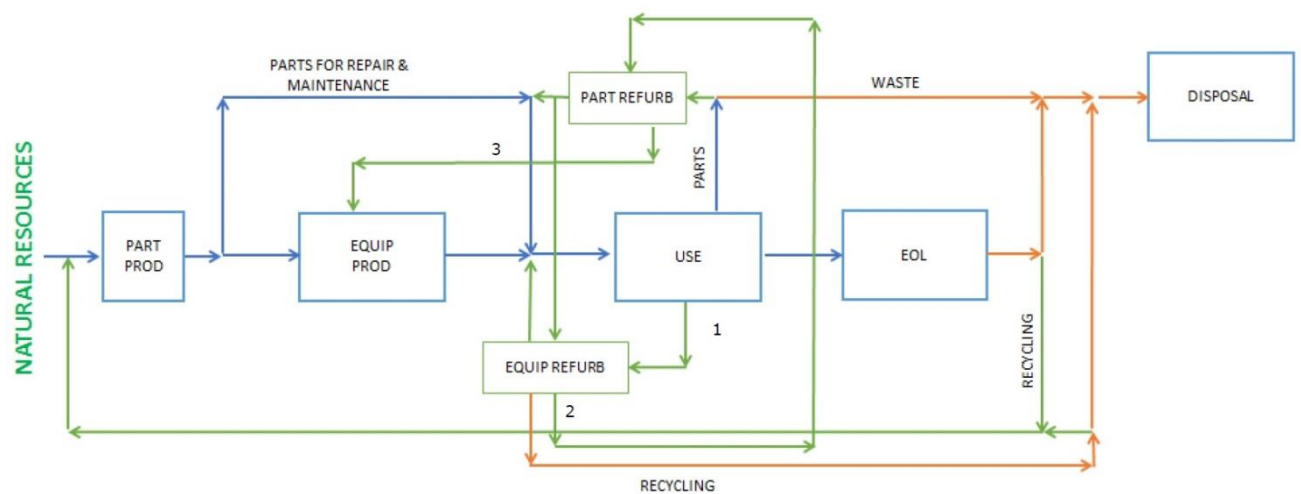
Step No.	Name	Description
1	Selection	<p>During this step, decisions regarding the type and condition of devices for refurbishing are taken. Typically, the selection process is based on criteria related to the types of models, age and condition of devices, and possibly also service history and performance.</p> <p>These criteria are used to enable a targeted sourcing and to avoid the purchase of devices, which will prove unsuitable for high quality refurbishing.</p>
2	Sourcing	<p>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.</p> <p>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.</p> <p>Sourcing is the most critical element of the IT refurbishment process: if there is not enough input the remanufacturing operations will face economic challenges.</p>
3	Technical Refurbishing	<p>The technical refurbishing encompasses all steps necessary to bring a device back to the original level of functionality, including 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.</p>
4	Sale/Delivery	<p>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.</p>
5	Warranty	<p>Remanufacturing also requires technical support, including repair and maintenance within the warranty conditions and periods.</p>

Source: Moeller M. et al., 2015

High quality refurbishment can require the substitution of parts and components of the used equipment (3- technical refurbishment - [Table 6.2.](#)) and these parts can be replaced with new or refurbished ones. The substituted parts are not wasted but, if possible, also refurbished. The same approach can be adopted during maintenance and repair of equipment: all the substituted parts can be checked and then sent to refurbishment (if suitable). Often, EEE manufacturers source from different suppliers some parts of the devices they produce, therefore, if these parts need to be refurbished, their actual manufacturers can be involved in the process by agreeing with them and sending the components to be refurbished.

Refurbished used parts can be reused to remanufacture used equipment or in the production of new devices (COCIR 2016). This approach has already been developed for medical devices ([Figure 6.4](#)), but it can be applicable also to other EEE equipment, provided that there are some limitations to the applicability of this BEMP presented later in the 'Applicability' section. Refurbished used parts can also be sold to third parties for repair and refurbishment of devices. This option, which can stimulate the market of remanufacturing of used EEE, can also be a relevant business for OEMs.

Figure 6.4. Circular economy approach for high quality refurbishment of medical devices



1 - Reuse of medical devices: medical devices are refurbished and then sold

2 – Reuse of parts generated during refurbishment, repair or maintenance: such parts are refurbished and used for refurbishment, repair and maintenance

3 – Reuse of parts in manufacturing: refurbished parts are used to manufacture new equipment

Source: COCIR (2016)

6.2.3.2 Achieved environmental benefits

The environmental benefits of this BEMP result from waste prevention and savings by reduced production of new devices: less natural resources and energy are used and less waste needs to be treated and disposed. For instance, between 2003 and 2009, reduction of CO₂ emissions thanks to reuse of remanufactured products (across ICT sectors) increased 10 fold (Bitkom, 2015).

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.

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 impacts¹²³. This is particularly 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.

¹²³ 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.

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 $\sim > 10$ 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)¹²⁴.

With regard to equipment such as medical equipment, the environmental net benefit due to lifetime extension has to be calculated individually, also taking into account energy efficiency gains of new devices.

6.2.3.3 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, life cycle thinking can be used to demonstrate that refurbishing activities have environmental net benefits, also in light of energy efficiency gains of new product models. In light of this, a suitable formulation for an environmental performance indicator is:

- Use of LCA to demonstrate that the remanufacturing or refurbishing activities have environmental net benefits, also in light of energy efficiency gains of new product models (Y/N)

While refurbishing activities targeting consumer products can refer to existing literature and studies (see section "Achieved environmental benefits"), refurbishing of other devices should ideally conduct own LCA-based assessments to make sure that the activities have environmental net benefits

6.2.3.4 Cross-media effects

Although the extension of product lifetime has mostly significant environmental net benefits (see section "Achieved environmental benefits"), 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 where the devices are used.

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;
- will most likely experience only limited energy-efficiency improvements in the near future.

6.2.3.5 Operational data

As presented in [Table 6.2](#), 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

¹²⁴ 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.

history of devices, which will not be possible for all types of electrical and electronic equipment¹²⁵.

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. 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 refurbishing¹²⁶. 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 carried out 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 allow a smooth and undamaged transport of used devices from the customers' location to the refurbishing facility. While some smaller equipment can be transported by courier service (e.g. packed 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 categorised as waste (WEEE) and will therefore require to be handled by companies authorized to deal with waste. In case of trans-boundary transport, the notification according to the procedures of the Basel Convention¹²⁷ is required.

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 6.5](#), the technical refurbishing encompasses:

- Visual inspection;
- Safety test;
- Function test;
- Data eradication;
- Software removal/uploading;
- Disassembly;
- Substitution of worn out parts with new or refurbished parts;
- 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

¹²⁵ 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.

¹²⁶ 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.

¹²⁷ Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal.

appearances of devices. This might require varnishing of surfaces or the exchange of certain parts such as control units.

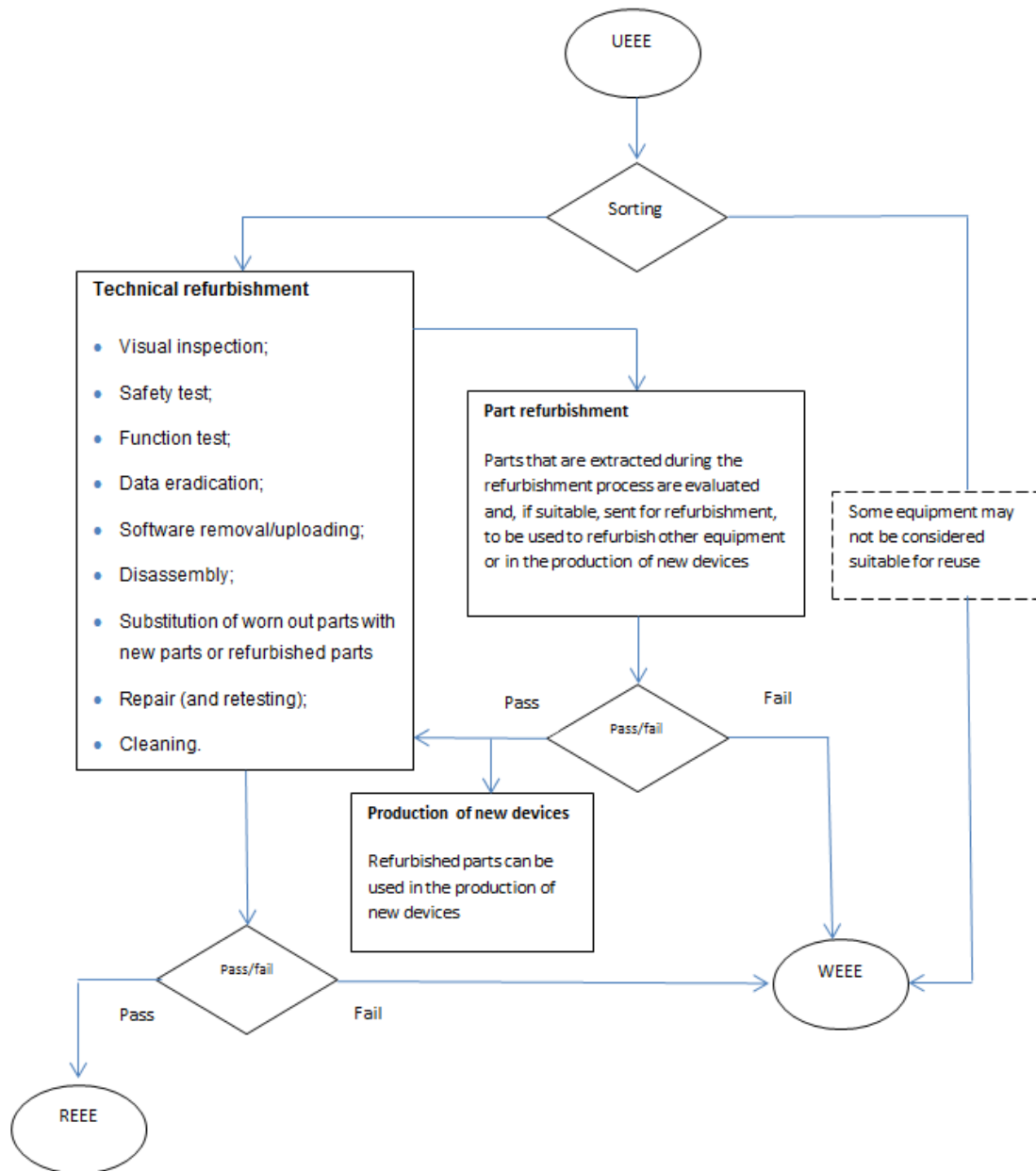
| As illustrated in [Figure 6.5](#), during refurbishment, parts are extracted and they can be checked, sent for refurbishment (if suitable) and reused to refurbish/repair/service other equipment or manufacturing new devices. Additionally, as described in section "Description" parts which are removed during maintenance and repair of devices, if possible, can also be refurbished and later reused to refurbish other devices or manufacturing new equipment. Parts which were not manufactured directly by the EEE manufacturer can be sent for refurbishment, after reaching an agreement, to the supplier of the EEE manufacturer (i.e. the actual manufacturer of the part).

Further guidelines for technical refurbishing are laid out in COCIR (2009), COCIR (2016) and MITA 2015-1standard¹²⁸ on refurbishment of 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. For high quality refurbishment, as described in section "Description", 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 and a number of standards have been developed to check reliability of products after refurbishment, i.e.:

- ISO/IEC 24700:2004: product that contains reused components;
- IEC IEC 62309:2004: reliability and functionality of reused parts and their usage within new products.

¹²⁸ Available for download at: <https://www.nema.org/Standards/Pages/Good-Refurbishment-Practices-for-Medical-Imaging-Equipment.aspx>

Figure 6.5. Overview of activities for refurbishing activities



Note: EEE = electrical and electronic equipment; REEE = reuse EEE; UEEE = used EEE; WEEE = waste EEE

Source: adapted from BSI (2011)

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 use. For this reason, OEMs have developed specific marketing solutions (e.g. 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).

6.2.3.6 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 for new equipment is not strongly developed (Plumeyer et al. 2014). It is key for the success of the BEMP that the company ensures that the refurbished products meet the technical specifications of the original products.

Generally, high quality refurbishment of used devices 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 to be refurbished, the remaining service life should be taken into account. This is because warranty packages with technical support, repair and maintenance can be best guaranteed within the timespan of a product which is serviced by the OEM.

6.2.3.7 Economics

High quality refurbishment of capital-intensive products is reported to be economically profitable. The costs of all elements of the remanufacturing process can be minimised ensuring not to jeopardize quality. To this aim, strategies include the use of remanufactured spare parts and concentrating repairs in European specialised and automated repair and remanufacturing centres.

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.

6.2.3.8 Driving force for implementation

Remanufacturing or high quality refurbishment are typically conducted for the following reasons:

- To respond to customer demand for cost-efficient but high-quality alternatives to new models;
- To supply of high quality “older” products that enable the customers to transition to new technology in a timeframe that suits them;
- To demonstrate environmental responsibility within the core hardware business.

In addition, Green Public Procurement can also be considered a relevant driving force since public administrations can be seen as relevant market actors for buying high quality used equipment.

6.2.3.9 Reference organisations

- Siemens Healthcare;
- Other OEMs in the medical sector, including Philips and General Electrics;
- FEI (manufacturer of electron microscopes);
- HP - HP Renew program for HP Servers, Storage and Networking Solutions as well as Notebooks and Desktop PCs
- Apple in co-operation with Dataserv GmbH;

- Deckel Maho Gildenmeister (manufacturer of machines).
- Cisco – Cisco Refresh program for routers, switches, optical, wireless, network modules, port adapters, voice, etc.
- IBM - IBM Certified Pre-Owned Equipment for IBM Servers, Storage, PC and Intel-based servers, Printers and Networking
- Ricoh – Ricoh GreenLine for printers
- Canon and Lexmark – remanufacturing of printers and multifunction devices

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7 Conclusions

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 optimisation process. Most of these metrics are on qualitative level and expressed in physical units (e.g. electricity use in kWh/m²). However, especially concerning the less process-oriented BEMPs and especially for the field of supply chain management, qualitative metrics had to be developed. Table 7.1 presents all the key indicators and the benchmarks of excellence for each identified BEMP.

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Table 7.1. Key environmental performance indicators and benchmarks of excellence (where available) for each identified BEMP

BEMPs	Applicability	Benchmarks of excellence	Key environmental performance indicators
BEMPs for Manufacturing activities			
Energy efficient cleanroom technology (Section 4.2.1)	<p>Broadly applicable to all electrical and electronic equipment manufacturers that operate cleanrooms.</p> <p>For new built cleanroom facilities, ACR can be lower than recommended ACR range according to its classification, but requires efforts to ensure and adjust the quality requirements of the cleanroom. For existing cleanroom facilities, particle count-based control and continuous monitoring can be applied to reduce ACR values.</p>	N/A	<p>Energy use for printed circuit board manufacturing (kWh/m² of processed printed circuit board)</p> <p>Energy use for semiconductors and integrated circuits manufacturing (kWh/cm² of silicon wafers)</p> <p>Air Change Rate (number/hour)</p> <p>COP (Coefficient of Performance) of the cooling equipment installed (kWh cooling energy produced / kWh energy used)</p> <p>Water conductivity (µS/cm)</p>
Energy efficient cooling technology (Section 4.2.2)	<p>Measures to improve the energy efficiency of cooling are broadly applicable to electrical and electronic equipment manufacturing companies.</p> <p>To be able to implement free cooling, the temperature level of the return flow of the cooling system must be above the outdoor temperature and enough space must be available on the outdoor area of the production site.</p> <p>Absorption cooling is applicable where a source of waste heat or renewable heat is continuously available at the production site or in its surroundings.</p> <p>The economic feasibility of the proposed measures depends substantially on the existence of a year-round cooling load.</p>	N/A	<p>Coefficient of Performance (COP) for individual cooling equipment (kW provided cooling power / kW power used)</p> <p>Coefficient of System Performance including the energy required to run the supplementary equipment of the cooling system e.g. pumps (kW provided cooling power / kW power used)</p> <p>Use of cooling cascades (Y/N)</p> <p>Use of free cooling (Y/N)</p> <p>Use of heat recovery ventilators (Y/N)</p> <p>Use of absorption chillers (Y/N)</p> <p>Energy use of the cooling system per unit of turnover (kWh/€)</p>
Energy efficient reflow soldering (Section 4.2.3)	This BEMP is applicable to electrical and electronic equipment manufacturers with reflow soldering operations, and especially relevant for the production of Printed Circuit Boards (PCB).	N/A	<p>Total energy demand per unit of surface of the processed printed circuit board (kWh of electricity / m² of PCB)</p> <p>Nitrogen consumption per unit of surface of the processed printed circuit board (kg of nitrogen / m² of PCB)</p>

BEMPs	Applicability	Benchmarks of excellence	Key environmental performance indicators
	The measures for new soldering equipment are applicable when the overall decision to install a new reflow soldering line is taken. The return of investment depends considerably on increased yield, performance, maintenance requirements rather than energy savings		
On-site copper recycling in process chemicals (Section 4.2.4)	The BEMP is applicable to printed circuit board production facilities. However, the economic feasibility depends considerably on the production levels, and thus on the amount of high quality copper that can be recovered (e.g. over 60 t of copper per year). A further limitation is the space needed for the on-site recycling system, which ranges between 50 and 80 m ² depending on the arrangement of the installation and the volume of the buffer tanks. However, this does not necessarily need to be right next to the etching process.	N/A	On-site copper recycling system in place (Y/N) Amount of copper recycled from etching process agents (t/year)
Cascade rinsing systems and water use optimisation (Section 4.2.5)	<p>The BEMP is broadly applicable to printed circuit boards manufacturing companies. The optimisation measures and the installation of multiple cascade rinsing systems with at least four stages are applicable both in existing facilities and in new-build. In the case of cascade rinsing systems with four or more stages, the available space may pose some limitations.</p> <p>Five-stage cascade rinsing system specifically is mostly applicable for systems with high machine throughput or highly concentrated electrolytes and the following additional limiting factors need to be considered:</p> <ul style="list-style-type: none"> Highly concentrated rinse water leads to a greater use of chemicals and longer time needed for sedimentation in 	At least 50% of the rinsing facilities are equipped with a cascade rinsing system with four or more stages	<p>Total water consumption in the fabrication plant (l/m² of PCB manufactured)</p> <p>Share of cascade rinsing systems with four or five stages out of the total number of rinsing facilities (%)</p> <p>Water consumption in cascade rinsing systems with four or five stages compared with the water consumption in three-stage cascade rinsing systems (%)</p> <p>Five-stage cascade rinsing system in place (Y/N)</p>

BEMPs	Applicability	Benchmarks of excellence	Key environmental performance indicators
	<p>deionisation for waste water treatment.</p> <ul style="list-style-type: none"> – Heating of the rinsing bath water due to increased numbers of pumps, which increases pressure by germ contamination. – Germ contamination needs to be mitigated by implementing proper water disinfection techniques. 		
<p>Minimising perfluorocompound emissions</p> <p>(Section 4.2.6)</p>	<p>The BEMP is broadly applicable to semiconductor fabrication facilities using PFC gases. The specific measures that can be implemented in a facility need to be assessed on a case by case basis.</p> <p>Process optimisation is broadly applicable and can be effective measure both in existing facilities and in new-build CVD chambers. It is the only measure which also saves costs, since it can allow lower gas consumption and better throughput.</p> <p>Substitution of PFC gases is often technically unfeasible, especially for plasma etching.</p> <p>Remote plasma cleaning technology using NF_3 and point-of-use plasma etching abatement are broadly applicable. They are especially relevant for new semiconductor fabrication facilities or in facilities where equipment is being renewed on a larger scale. However, these are associated with high investment costs.</p> <p>Burner/scrubber systems are broadly applicable although space, existing infrastructure and investment costs may be limiting factors</p>	<p>The Normalised Emission Rate for PFC emissions is lower than $0.22 \text{ kgCO}_2\text{eq/cm}^2$</p>	<p>Normalised Emission Rate for perfluorocompounds emissions ($\text{kg CO}_2\text{eq/cm}^2$)</p> <p>Minimisation of the PFC emissions by applying one of the following techniques:</p> <ul style="list-style-type: none"> – applying process optimisation focused on CVD chamber cleaning (Y/N) – substituting of PFC gases with lower global warming potential (Y/N) – installing remote plasma cleaning technology (Y/N) – using POU abatement techniques (Y/N)
Rational and efficient	The measures described in this BEMP are	The electricity use of the	Electricity use of the compressed air system per unit of volume at

BEMPs	Applicability	Benchmarks of excellence	Key environmental performance indicators
use of compressed air (Section 4.2.7)	broadly applicable to all EEE companies that use compressed air. Regarding the recovery of waste heat, a continuous demand for process heat is necessary in order to realise the corresponding energy and cost savings	compressed air system is lower than 0.11 kWh/m ³ of delivered compressed air, for large installations working at 6.5 bar effective, with volume flow normalised on 1013 mbar and 20°C, and pressure deviations not exceeding 0.2 bar effective. After all air consumers are switched off, the network pressure remains stable and the compressors (in stand-by) do not switch to load condition.	the point of end use (kWh/m ³) Air leakage index (NI/min)
Protecting and enhancing biodiversity (Section 4.2.8)	The BEMP is broadly applicable to all electrical and electronic equipment manufacturers.	A biodiversity action plan is implemented in all production facilities to protect and enhance the state of biodiversity (flora and fauna) at the specific site	Land use – area of land within the production site and its assessed natural value (e.g. brown fields, areas adjacent to protected areas, areas of high biodiversity value) (m ²) Area of protected or restored natural habitats within the production site, or outside but managed or protected by the manufacturer (m ²) Implementation of a site biodiversity action plan in all production facilities (Y/N)
Use of renewable energy (Section 4.2.9)	This BEMP is broadly applicable to all companies of the sector. Use of renewable electricity (own generated or purchased) is generally possible in all cases. Integration of heat from renewable sources in EEE manufacturing processes, instead, is more difficult due to their complexity, the need of high temperatures, and, in some cases, incompatibility between heat demand and seasonality of renewable heat offer.	N/A	Share of electricity from renewable sources (own generated or purchased with verified additionality) out of the total electricity use (%) Share of heat from renewable sources out of the total use of heat (%)
Optimised waste management within manufacturing facilities	This BEMP is broadly applicable to all EEE manufacturing companies. Limiting factors for the effective	Sites with a waste management strategy in place: 100%	Development and implementation of an effective waste management strategy (Y/N) Share of sites with a waste management strategy (%)

BEMPs	Applicability	Benchmarks of excellence	Key environmental performance indicators
(Section 4.2.10)	implementation of industrial symbiosis are the need for communication and coordination among different companies, i.e. lack of knowledge and insight in other companies' activities and thus potential valorisation routes for waste and by-products		Landfill diversion rate (%) For a specific product or product range, waste generation per metric ton of product or other suitable functional unit (kg/t)
BEMPs for Supply chain management			
Assessment for cost-effective and environmentally sound substitution of hazardous substances (Section 5.2.1)	This BEMP is in principle applicable to all companies of the sector. However, Small and Medium Enterprises might lack the leverage to demand Full Material Declarations from many suppliers, in which case they can request Supplier Declarations of Conformity complemented by laboratory testing.	Mandatory requirements for all major suppliers (in terms of % of supply chain expenditure) to provide a Full Material Declaration are in place.	Share of suppliers that provide a full material declaration (% of supply chain expenditure) Share of suppliers that issue a Supplier Declaration of Conformity for a company specific list of restrictions, complemented by a certification (preferably third-party) based on laboratory testing (% of supply chain expenditure) Disclosure (e.g. on website and annual sustainability reports) of the two previous indicators (y/n)
Disclose and set targets for supply chain GHG emissions (Section 5.2.2)	This BEMP is applicable to all companies of the sector. However, there are some limitations in the calculation of scope 3 emissions, due to the complexity of the value chains of electrical and electronic equipment	GHG emissions (including scope 1, 2 and the most relevant scope 3) are calculated with a recognised standard method and periodically published Absolute or relative GHG emission reduction targets are disclosed publicly Absolute and/or relative actual GHG emission reductions are demonstrated and periodically published	Periodical publication of GHG emissions calculated with a recognised standard method (Y/N) Categories of scope 3 emissions included in the assessment (Y/N) Periodical disclosure of absolute or relative GHG emission reduction targets (Y/N) Periodical disclosure of demonstrated actual absolute and/or relative GHG emission reductions (Y/N)
Conducting Life Cycle Assessment (Section 5.2.3)	This BEMP is broadly applicable to all electrical and electronic equipment manufacturing companies, especially to large sized companies. Internal resources and complexity of LCA are potential limiting factors for the conduct of LCA for small and medium sized	LCA is carried out according to the international standards ISO 14040 and ISO 14044 The company carries out life cycle assessment for new and re-designed products and the results are systematically	Inclusion of LCA according to the ISO standards 14040 and 14044 in the environmental strategy of the company and use of LCA when taking major decisions for developing new and re-designed products (Y/N) Percentage of product ranges for which LCA improvement targets have been met (weighted by numbers of references or by sales)

BEMPs	Applicability	Benchmarks of excellence	Key environmental performance indicators
	enterprises. However, simplified LCA screening tools and ready-made databases help mitigating the difficulties	used to base product development choices	
Increasing the content of recycled plastics in EEE (Section 5.2.4)	This BEMP is suitable for many polymers that are used in electrical and electronic equipment manufacturing. Recycled plastics can replace virgin plastics in those cases where the required material specifications can be met.		Share of recycled plastics used in the manufacture of a specific EEE product or product group out of the total plastics use for that product or product group (%) (Total amount of recycled plastics used in manufacturing (tonnes)) Sales of products manufactured with recycled plastics out of total sales of products (%)
Protecting and enhancing biodiversity along the EEE supply chain (Section 5.2.5)	The BEMP is applicable to all electrical and electronic equipment manufacturing companies.	The company implements a program for a periodic assessment of biodiversity impacts of products and materials provided by the supply chain and the results of the assessment are used to formulate procurement guidelines and requirements on the most relevant products and materials	Implementation of a periodic assessment of biodiversity impacts of products and materials provided by the supply chain (Y/N) Formulation of procurement guidelines and requirements for the most relevant products and materials identified in the biodiversity assessment (Y/N) For each of the groups of products (e.g. wood and paper products) for which procurement requirements have been developed by the company: <ul style="list-style-type: none"> – Share of products qualifying as priority procurement (%) – Share of products qualifying as acceptable procurement (%) – Share of products qualifying as procurement to be avoided (%) The share (by purchase volume) of suppliers that have provided initial reporting as to their potential impacts on biodiversity (%) The share (by purchase volume) of suppliers that have developed a biodiversity management plan (%) The share (by purchase volume) of suppliers that are implementing their biodiversity management plan (i.e. making progress towards achieving set targets) (%)
BEMPs fostering Circular Economy			
Strategic guidance on designing products for	The BEMP is applicable to all electrical and electronic equipment manufacturing	Share of products or components for which design	Setting of circular economy objectives for new products (Y/N)

BEMPs	Applicability	Benchmarks of excellence	Key environmental performance indicators
Circular Economy (repair, refurbishment, reuse and recycling) (Section 6.2.1)	companies	cycles or redesign cycles have been embarked upon that explicitly address the different approaches of circular economy: 50% The company has put in place circular economy objectives for new products and an effective product design process to ensure these are achieved	Number of different units across the company having contributed to design processes (no.) Share of products or components (by number or revenue) for which design cycles or redesign cycles have been embarked upon that explicitly address the different approaches of circular economy (%) Environmental benefits achieved by the products designed or redesigned with circular economy objectives sold during the year over their lifecycle (carbon emissions, resource efficiency etc.) (Y/N)
Integrated product service offering (IPSO) (Section 6.2.2)	The IPSO model is especially applicable to electrical and electronic equipment with large capital cost and long use life. The applicability in the field of electrical household appliances with limited purchasing costs, low bill of materials or large size/weight is limited (e.g. take-back is not feasible if the economical/technical value is too low compared to transportation costs).	The company adopts IPSO in its business ensuring that it leads to a continuous improvement of the environmental performance of the product-service offered 100% take-back rate for post-consumer devices from leasing contracts and 30% refurbishment rate	Implementation of the IPSO model ensuring that it delivers environmental benefits (Y/N) Take-back rates of products installed at customer premises within the IPSO per product category (%) Share of reused devices out of the total number of devices installed within the IPSO (%)
Remanufacturing or high quality refurbishment of used products (Section 6.2.3)	This practice is particularly suitable for mid- or high-capital intensive equipment	LCA was used to demonstrate that the remanufacturing or refurbishment activities have environmental net benefits, also in light of energy efficiency gains of new product models.	Use of LCA to demonstrate that the remanufacturing or refurbishment activities have environmental net benefits, also in light of energy efficiency gains of new product models (Y/N)

List of abbreviations and definitions

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
C2F6	Hexafluoroethane
C3F8	Octofluoropropane
c-C4F8	Octofluorocyclobutane
CD	Compact Disc
CDP	Carbon Disclosure Project
CF4	Tetrafluoromethane
CH4	Methane
CHF3	Trifluoromethane
CHP	Combined Heat and Power
CLP	Classification, Labelling and Packaging (CLP Regulation)
CMOS	Complementary Metal–Oxide–Semiconductor
CMR	Carcinogenic, Mutagenic and Reprotoxic
CO2	Carbon dioxide
CO2e	CO2 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 ₂ O	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
MWth	Megawatt (thermal)
NF3	Nitrogen Trifluoride
NiMH	Nickel Metal Hydride
NWWT	North Wales Wildlife Trust
n.y.	no year
O2	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
SF6	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

List of figures

Figure A.1: The present best practice report in the overall development of the Sectoral Reference Document.....	10
Figure 2.8. Value of EEE production between 2007-2012, EU 27 (in billion €).....	21
Figure 2.9. Contribution of EEE production value to GDP, EU27 (%).....	21
Figure 2.10. Contribution of EEE Production Value to GDP for Germany, Italy, France, and the UK (in billion €)	22
Figure 2.11. Contribution of EEE Production Value to GDP for Germany, Italy, France, and the UK (%).....	22
Figure 2.12. Value of EEE Production Between 2007 and 2012, for Spain, Austria, Hungary, and Poland (in billion €).....	23
Figure 2.13. Contribution of EEE Production Value to GDP for Spain, Austria, Hungary, and Poland (%)	23
Figure 2.14. EU Country Shares of EEE Production Value Between 2007 and 2012 (%) .	24
Figure 2.1. Absolute GWP values and percentage proportions of life cycle phases	30
Figure 2.2: Contribution analysis for the impact categories GWP and RIP	31
Figure 2.3: Metals in a mobile phone	31
Figure 2.4. Breakdown of component-specific greenhouse gas emissions (CO ₂ e) from the production phase of a Dell notebook	32
Figure 2.5. Front-end Processes and Back-end Processes of IC Manufacturing	33
Figure 2.6. Percentage Contributions to Overall GWP Outcome of Memory IC fabrication	33
Figure 2.7. Contribution of categories to environmental impacts of WEEE total (Eco Indicator '99 H/A).....	34
Figure 2.15. Overview of Input and Output Flows of Sector Activities (Manufacturers' Perspective).....	35
Figure 4.1. Cleanroom energy use	50
Figure 4.2. Free dry cooling	63
Figure 4.3. Free wet cooling.....	64
Figure 4.4. Overview of a 'balanced' unit; heat recovery ventilator	65
Figure 4.5. Scheme of absorption cooling technology	65
Figure 4.6. Energy-efficient reflow soldering equipment.....	76
Figure 4.7. Advantages of on-site copper recycling from the PCB etching solution.....	79
Figure 4.8. Model of the alkaline etchant and copper recycling installation next to the etching line.....	81
Figure 4.9. Copper cash settlement in US Dollar per tonne	81
Figure 4.10. Comparison of water consumption in cascade rinsing systems comprising 3, 4 and 5 rinsing tanks	86
Figure 4.11. Submicron patterns of integrated circuits.....	91
Figure 4.12. CVD chamber.....	91
Figure 4.13. Schematic figure of an exhaust air purification facility (burner / scrubber system).....	95

Figure 4.14. Ultrasonic testing device with rod and parabolic microphone	103
Figure 4.15. System design according to annual load duration curve.....	104
Figure 4.16. Potentials for waste heat recovery	105
Figure 4.17. Sharp's multi-faceted approach for protecting biodiversity	111
Figure 4.18. Natural development of the pond at SMF, France.....	115
Figure 4.19. Collectors for process heat applications at different temperature levels ...	125
Figure 4.20. Technical potential for the use of solar process heat of the eleven selected sectors divided in temperature ranges.....	126
Figure 4.21. Heat prices as a function of mean collector fluid temperature.....	128
Figure 4.22. Sales Quantity of Green Electricity in Germany.....	128
Figure 4.23. Mapping of hazardous waste generation in EU-28 member countries, IS, NO and TR	133
Figure 4.24. Hierarchy of waste management options according to Directive 2008/98/EC	134
Figure 4.25. Typical charge (gate fee and landfill tax) for legal landfilling of non-hazardous municipal waste in EU Member States and regions	138
Figure 5.1. Schematic overview of the scope of the supply chain BEMPs	141
Figure 5.2. Definition of Scopes in GHG Protocol Corporate Value Chain Standard.....	163
Figure 5.3. Aggregate reported Scope 3 emissions to the CDP by ICT companies and comparison to Scope 1 and 2 emissions	163
Figure 5.4. Type of emission reduction targets among 320 global ICT companies reporting to the CDP	166
Figure 5.5. Suppliers being part of multiple supply chains.....	167
Figure 5.6. Example of outcome of screening exercise.....	169
Figure 5.7. Possible criteria for identifying relevant Scope 3 activities	169
Figure 5.8. Excel tools for the calculation of process specific GHG emissions (here: PFC emissions from semiconductor manufacturing)	170
Figure 5.9. HP Fiscal Year 2013 GHG inventory	173
Figure 5.10. Relationship between GHG Protocol Product and Value Chain Standards ..	174
Figure 5.11. Sharp: Calculation method for materials procurement as established in its environmental policy.....	174
Figure 5.12. Cisco GHG emission reduction KPIs and results achieved	175
Figure 5.13. Proportion of emission reduction investments by payback time among ICT companies reporting to the CDP	179
Figure 5.14. Risks and opportunities from climate change as reported by information technology companies to the CDP Global 500	181
Figure 5.15. Response rate of suppliers based on number of customer requests received	181
Figure 5.16. Share of companies with and without monetary incentives and reported absolute GHG emission reductions	182
Figure 5.17. Screenshots of the LCA-to-go web-suite for the electronics sector	192
Figure 5.18. Drivers for environmental assessment (SMEs of the electronics sector) ...	196
Figure 5.19. Consumption of plastic according to various branches and plastic types...	201

Figure 5.20. Typical applications of primary polymers in EEE.....	202
Figure 5.21. Potential of plastic waste in selected applications.....	203
Figure 5.22. Main polymers used in the manufacture of the most common WEEE items collected.....	204
Figure 5.23. Treatment of total plastic waste from WEEE in EU-27, Norway and Switzerland, 2008 (Mt).....	205
Figure 5.24. Environmental impacts associated with the production of 1 tonne of plastics from post-consumer recycling (PCR plastics) and primary production (virgin plastics) .	206
Figure 5.25. Environmental impacts associated with the production of 1 tonne of plastics from post-consumer recycling (PCR plastics) and primary production (virgin plastics) .	207
Figure 5.26. EPEAT criteria for the use of post-consumer plastic (R=Required; O=Optional)	215
Figure 6.2. The Delft model of the innovation process	235
Figure 6. 3. The product-service system and its subcategories	246
Figure 6.4. The plan-do-check-act cycle according to EMAS	249
Figure 6.5. Circular economy approach for high quality refurbishment of medical devices	258
Figure 6.6. Overview of activities for refurbishing activities.....	262

List of tables

Table 2.1. Eurostat Data for 2011, Concerning the Number of Enterprises in the EEE Sector and its Sub-sectors in the Various EU Countries	25
Table 2.2. 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 <i>units</i> for individual countries, but in <i>hundreds</i> for European aggregates)...	27
Table 2.3. Environmental Aspects and Associated Environmental Pressures (Manufacturers' Perspective).....	35
Table 2.4. Collection Rates for various WEEE Categories and Sub-categories.....	38
Table 4.1. Overview of the Developed BEMPs for EEE Manufacturing and the Addressed Environmental Pressures	48
Table 4.2. Cleanroom classifications.....	50
Table 4.3. Conductivity and resistivity of the de-ionized water	53
Table 4.4. Achieved savings of the renovation of the Western Digital cleanroom facility.	56
Table 4.5. Annual number of hours of temperatures up to and including 18°C in selected European cities.....	63
Table 4.6. Cost data and payback times for selected measures.....	67
Table 4.7. Considerations for using nitrogen vs. oxygen	74
Table 4.8. Ore production of copper in million t/a in 1985, 1995 and 2005	82
Table 4.9. Water saving measures in cascade rinsing systems and their pay-back periods in a specific company	88
Table 4.10. Global warming potential (GWP) of relevant PFC gases; values are based on the IPPC 5 th Assessment Report.....	93
Table 4.11. Air and power losses, with related costs, caused by air leaks.....	102
Table 4.12. Payback times for selected measures	106
Table 4.13. Greenhouse Gas Emissions of Different Sources to Generate Green Electricity Compared to the National Emission factors	121
Table 4.14. Hazardous Materials Used in Photovoltaic-cell Manufacturing.....	123
Table 4.15. Additional Charges for the Three Green versions (GV) Relative to 'Grey' Electricity	127
Table 5.1. Overview of the Developed BEMPs for EEE Supply Chain Management and the Addressed Environmental Pressures.....	142
Table 5.2. Parts production and assembly locations for smartphones.....	143
Table 5.3. Selected EEE-related sources of GHGs.....	165
Table 5.4. Reported overall Scope 1, 2, 3 emissions for Fiscal Year 2013	172
Table 5.5. Detailed reported Scope 3 emissions for Fiscal Year 2013.....	172
Table 5.6. Cisco sustainability scorecard results for "key" suppliers.....	177
Table 6.1. Overview of the environmental pressures addressed by each developed BEMP for circular economy chapter.....	233
Table 6.2. Activities for remanufacturing or high quality refurbishing of used products	257
Table 7.1. Key environmental performance indicators and benchmarks of excellence (where available) for each identified BEMP.....	267

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Publications Office

doi:xx.xxxx/xxxx

ISBN xxx-xx-xx-xxxxx-x